# MULTIDIMENSIONAL INVESTIGATION OF TENNESSEE'S URBAN FOREST

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Degree
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## DEDICATION

This dissertation is dedicated to my dearest family members: to my mom, Wendy, who modeled hard work and perseverance, inspired my love of learning, and selflessly cared for my babies while I focused my attention, energy, and time on work and school; to my boys, Chris, Joshua Dale, and Brett, who motivated me to fully immerse myself in academia and do my best work so they might be inspired as I was by my mom; and my loving husband, Thomas. Your support, encouragement, and patience have been a light in my life. You love me so good.

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## ABSTRACT

Preserving existing trees in urban areas and properly cultivating urban forest conservation and management opportunities is valuable to the ever-growing urban environment and necessary for creating optimal experiences and educational tools to meet the needs of increasing urban populations. This dissertation contains studies investigating several facets of the urban forest, including environmental effects of deforestation and urbanization, tree equity, and urban forest facility management and accessibility. Community education and outreach at arboreta about the importance of the tree canopy can help promote environmental stewardship. A digital questionnaire was electronically distributed to representatives of arboreta certified through the Tennessee Division of Forestry (TDF) and the nonprofit organization Tennessee Urban Forestry Council (TUFC) to explore the current needs and interests of arboreta management. Results showed that arboretum representatives mostly feel the arboretum certification program has been beneficial to their arboretum, need fundraising support, are willing to participate in educational offerings, and are interested in becoming part of a tree pest and disease reporting network.

TDF and TUFC have a vision of having a TUFC certified arboretum within a 30-minute drive of every Tennessee community; spatial analysis showed that more than one third of Tennessee communities currently lack TUFC arboretum accessibility. Urban Heat Island Effects (UHIE) include increased temperatures and decreased evapotranspiration in cities during hot seasons, which can disproportionately impact humans in low socioeconomic status. Spatial analysis showed UHIE evidence in Tennessee, most notably in Memphis, Nashville, Knoxville, the Tri-Cities areas, and Chattanooga. A model was created to predict

evapotranspiration using land cover and socioeconomic variables. This culmination of research projects provides program recommendations, extends existing geospatial information systems models, and identifies urban heat islands and communities vulnerable to their impact.

Keywords: Urban Forest Management, Spatial Analysis, Prediction Model, Urban Heat Island, Arboretum, Tree Equity

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# CHAPTER ONE
# INTRODUCTION

## 1.1 Background

### 1.1.a Urban Forest

For many humans, the urban forest is merely a backdrop to their everyday life. The urban forest is defined as "*the sum of all woody and associated vegetation in and around dense human settlements*" (Miller et al., 2015, p. 4). The urban forest is the multidimensional unsung hero that is slowly gaining recognition of its monumental role in environmental balance. Urban forests provide many ecosystem service benefits, which can be categorized as "provisioning (e.g. food, fuel); regulating (e.g. climate regulation, water purification); supporting (e.g. nutrient cycling, primary production); and cultural (e.g. aesthetic, spiritual)" (Nowak, 2019, p. 156). Ecosystem services are defined as the benefits human populations derive, either directly or indirectly, from ecosystem functions (Costanza et al., 2014). Municipalities around the world are publicly recognizing the value of the urban forest, for example, the urban forester for the city of Cambridge, MA requested the public's assistance in watering local trees to protect them and the ecosystem services they provide from potential drought conditions (City of Boston, 2022; City of Cambridge, 2022; Walker, 2022).

While some communities are highlighting the necessity and benefits of trees, others are destroying the urban forest (Nowak and Greenfield, 2018). Unfortunately, land and tree valuation are subjective, leaving valuable heritage trees (trees greater than 100" in circumference) vulnerable to destruction by those who value profit of land development over ecosystem services provided by healthy, established trees (Council of the District of Columbia, 2016). Land developers are willing to pay fines that are meager in comparison to the tangible value of the land without the inconveniently located heritage trees (Council of the

District of Columbia, 2016; Fenston[1], 2022; Fenston[2], 2022). Ecosystem service benefit estimators like i-Tree (https://www.itreetools.org/) and ESII Tool (https://www.esiitool.com/) can calculate the value of a living, mature tree versus the young replacement trees, if any are planted to replace the former heritage trees.

1.1.b Urbanization across America

Urbanization is environmental transition with increasing human population density, from natural growing, unmanaged forest and grassland to landscapes with more impervious surfaces like concrete and asphalt. Dense settlements of humans in highly populated areas causes gray infrastructure to increase while green infrastructure decreases. During colonial settlement of North America, water was integral to transportation. Initially, natural ports and navigable waterways became home to towns and subsequent cities. Historical port cities New York City, Los Angeles, Houston and Philadelphia remain the most highly populated areas in the United States. Current estimates show that almost 83% of the United States' population is considered urban, and the urban population is projected to increase to 89% by 2050 (Center for Sustainable Systems, 2021).

The greatest rate of urbanization in the United States was seen from 1880-1929, during the Industrial Revolution (Rees, 2016). In 1850, less than 20% of America's population was considered urban, but by 1920, for the first time, half of the United States population was living in cities (Miller, et al., 2015). The Federal-Aid Highway Act of 1956 caused an increase of suburban living surrounding city centers. The ebb and flow of humans into and out of cities for various reasons continues to the present. While traditional big cities (i.e. New York City, Chicago, San Francisco) experienced a mass exodus of residents from

2020 to 2021, historically rural Tennessee ranked as the top state for migration growth in 2020 (Lockridge and Reyes, 2021). Reasons for the mass urban exodus included the COVID-19 pandemic and cities' strict regulations, polarized political tensions, and greater acceptance of telecommute working from home, which all contributed to New York City having a net loss of residents that tripled from 2019 to 2020 (Stringer, 2021). Reasons for residents' relocation included, having more personal space, lower cost of living, and more entrepreneurial opportunities are factors driving Americans to move to rural areas (Gavin, 2023). This migration of residents from urban to rural areas has caused urban sprawl in their new destination (Wang and Wang, 2022). As the population of rural residents increases, suburban areas emerge, in the absence of proper land-use planning to protect, conserve or restrict subdividing land. Land use is the function (e.g., agricultural, residential, industrial, mining, and recreational uses) of areas (U.S. EPA, 2022). Land cover is the physical land type such as forest, water, or developed structures (U.S. NOAA, 2022). Land cover in the United States from before colonialization to 2020 changed greatly as a result of human intervention (Figure 1.1). Loss of grassland and forested areas to cropland and urban areas across the Great Plains and Eastern United States is most notable, after the red urban splotches that emerged after the 1900s are considered.

The change in land cover use emerged during the time of the Industrial Revolution and drastically increased during the Reconstruction era from 1865 to 1877 that followed the United States' Civil War (Figure 1.2). During this time, there is relatively low percentage of land being used for urban areas until pasture and cropland are included.

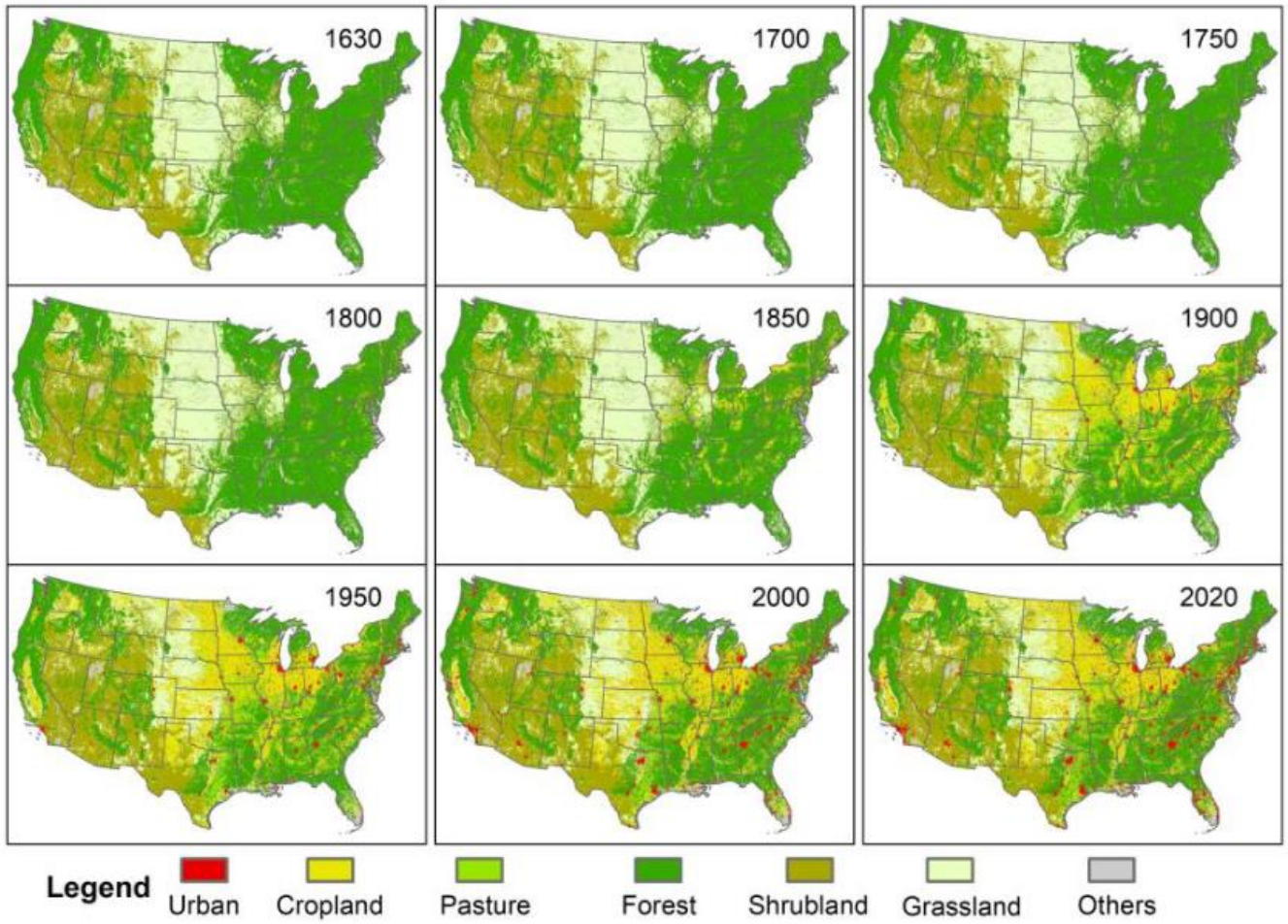



*Figure 1.1. Spaciotemporal patterns of land use and land cover in the conterminous United States during 1630-2020 by Li, X., et al, 2022.*

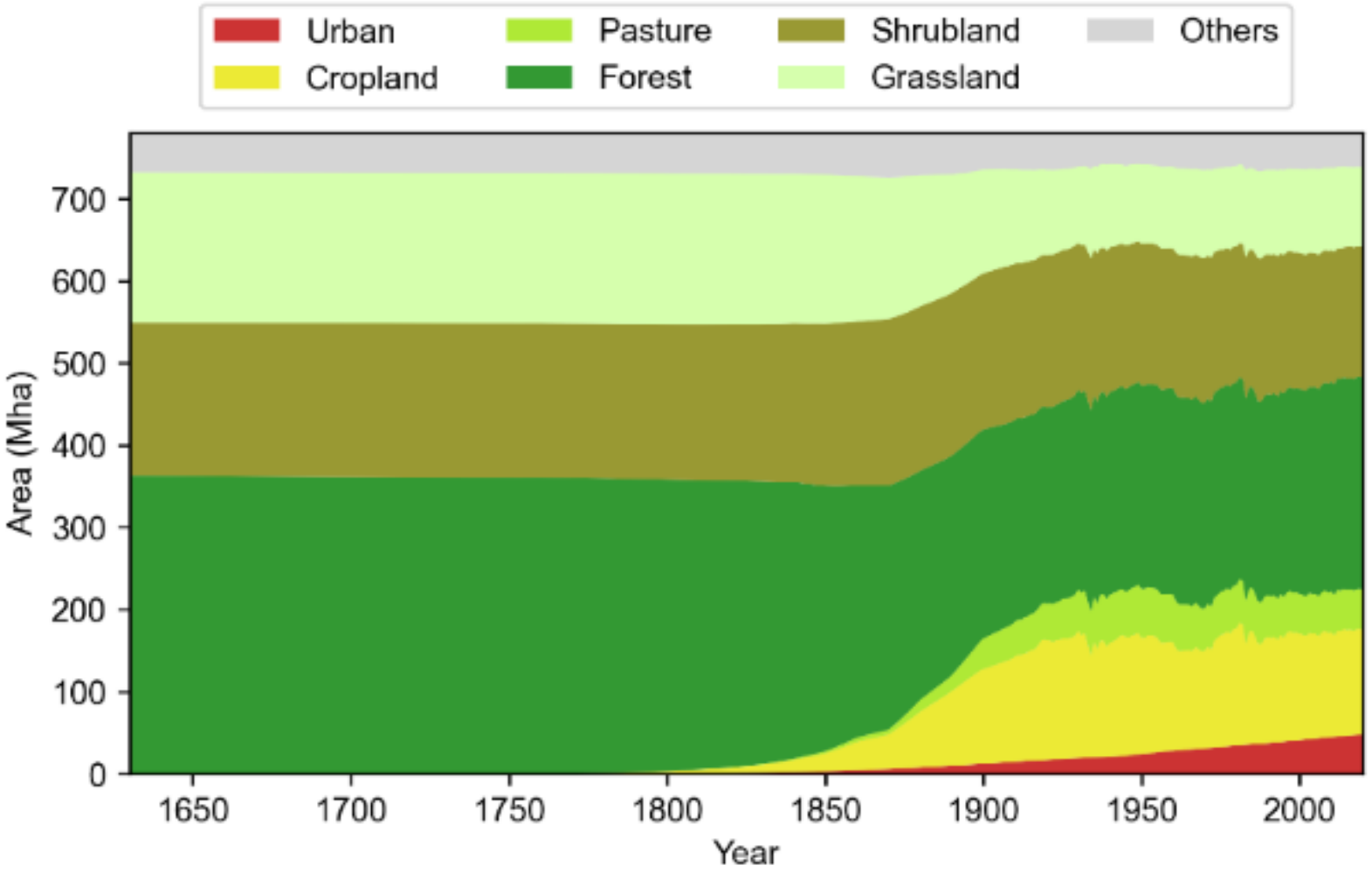



*Figure 1.2. Changes in areas of land use in the conterminous United States from 1630 to 2022 by Li, X., et al, 2022.*

### 1.1.c Urban Sprawl

As city centers become saturated and life outside the metropolitan is desired, population growth extends out into rural areas. Urban sprawl is generally defined as "the extension of low-density residential, commercial, and industrial development into areas beyond a city's boundaries that occurs in an unplanned or uncoordinated manner" (LibreTexts, 2021). The main driving factor behind metropolitan growth and nonmetropolitan decline is reclassification of nonmetropolitan area to metropolitan (Johnson and Lichter, 2020); therefor rather than existing urban areas solely becoming more densely populated, rural areas are being converted to urban land. Despite the majority percentage of the United States' population's urban status and the continued conversion of land use, only 3% (106,386 square miles) of the United States' land surface area is considered urban (see Figure 1.3) (University of Michigan Center for Sustainable Systems, 2021). Metropolitan and micropolitan areas are more prevalent and telling of the deforestation that occurs when urbanization takes place on large- and small-scale sites (Figure 1.4).

### 1.1.d Economic Benefits of Urban Areas

As mentioned above, within urban areas, there are numerous environmental benefits of the urban forest, but a large focus of benefits of urbanization lie with economics (Fan et al., 2022). Urban areas are the engines of growth, being depended upon for the sustainability of population increases (Sridhar, 2016). Moving from rural into urban areas is touted for many health benefits including improved sanitation, opportunity for education, access to health care, opportunity for jobs with higher wages and social support systems (Jattan et al., 2020; Singh, 2019; State of Tennessee, 2022). The urban wage premium is a phenomenon of significantly

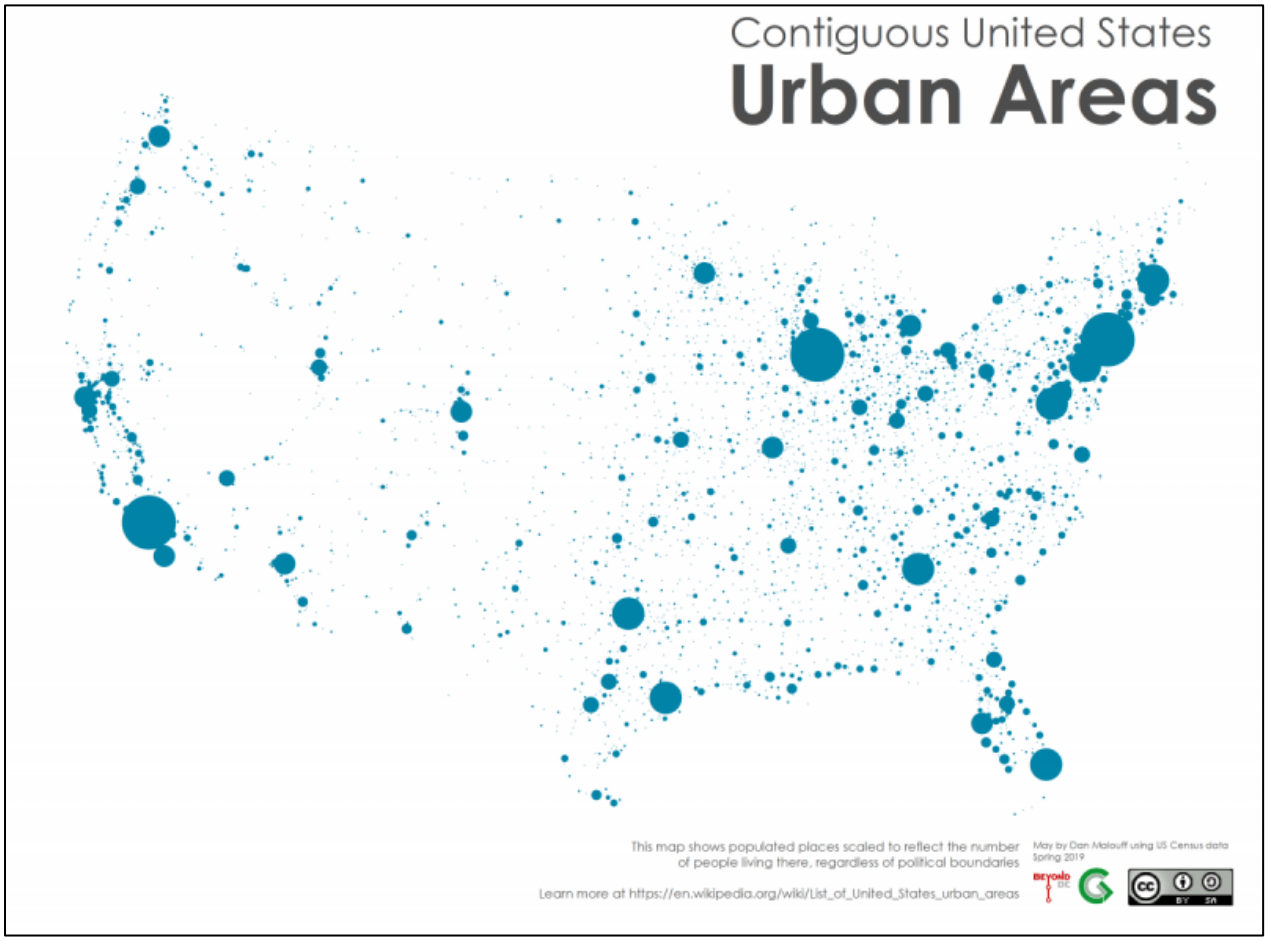



*Figure 1.3. Urban Areas of the Contiguous United States by Dan Malouff, Beyond DC, Spring 2019, using United States Census data by Dan Malouff (2019).*

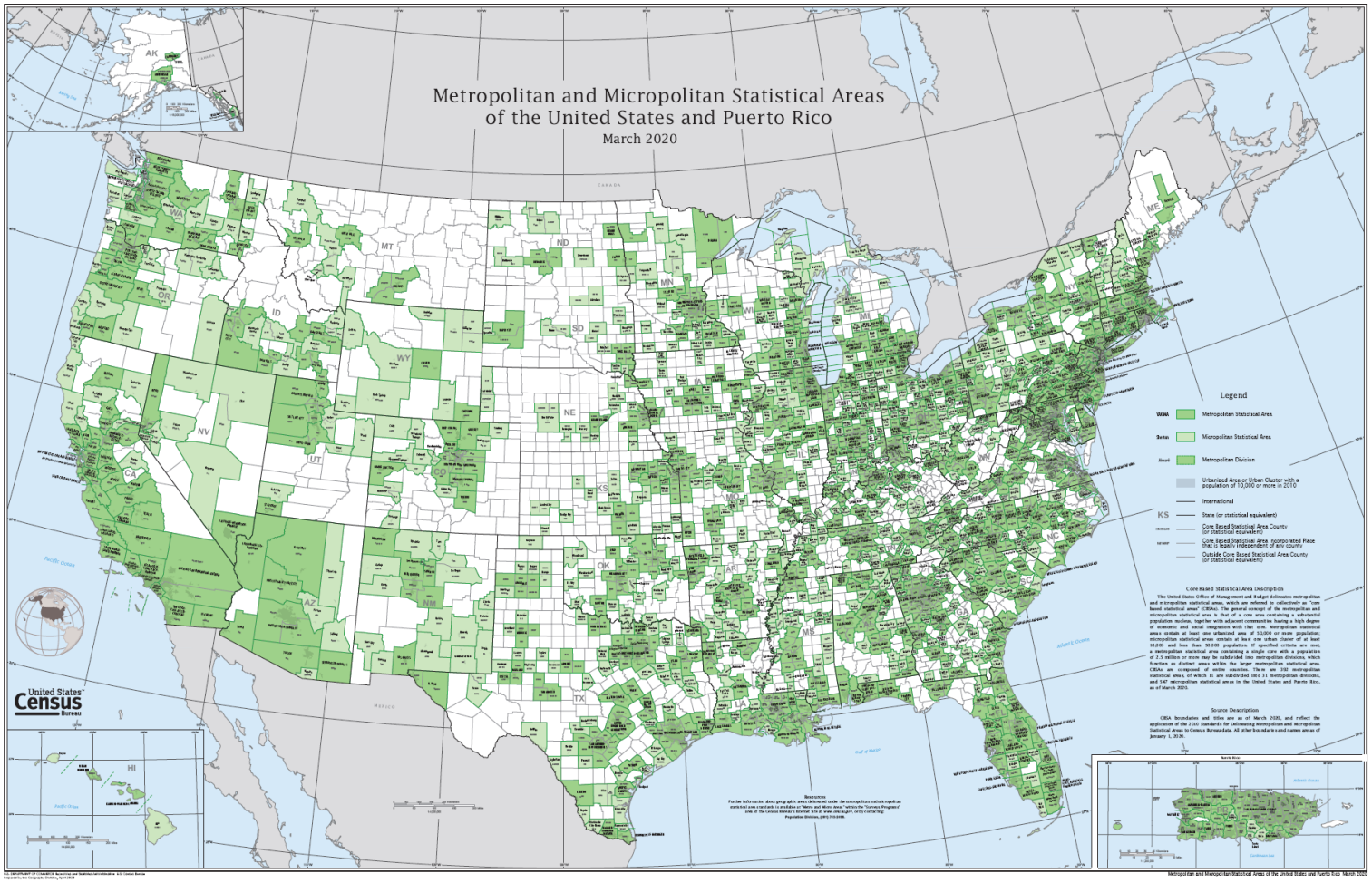



*Figure 1.4. Metropolitan and Micropolitan Statistical Areas of the United States and Puerto Rico by the United States Census Bureau (2020).*

higher pay in metropolitan areas, explained by dense labor markets that create greater competition (Hirsch, 2022; Shutters and Applegate, 2022).

### 1.1.e Urbanization Social Problems

Urbanization has its net negative problems, from large international-scale forced migration resulting from armed conflicts (Camargo et al., 2020). A current example would be the Syrian conflict resulting in water scarcity, multiyear crop failure and subsequent mass migration of rural families to urban areas, which led to overcrowding, increased inequality and ultimately full-blown political unrest (Abel et al., 2019). Migration can cause great political tensions and therefore needs to be realistically and logically planned. From the United States Southern border, asylum seekers entering the U.S. from Latin American countries crossing the Mexico, U.S. border are being bused across the country to urban areas like Washington D.C., Chicago, and New York City. Southern U.S. border communities have been overwhelmed by increasing numbers of migrants (Sylla, 2022; Scribner, 2022; Office of the Texas Governor, 2022). Operation Lone Star is the current Texas Governor Greg Abbott's answer to federal policies that he describes as inadequate for the rapid growth from immigration. While New York City blames insufficient communication about the transfer of people from Texas for overwhelmed intake centers where 50 to 100 people are arriving by bus daily (The Official Website of the City of New York, 2022). The global increase in population and transition of people around the world emphasizes the need for proper planning to accommodate the most basic needs of humans everywhere, while conserving the environment and the numerous benefits it provides.

### 1.1.f Challenges in Urban Areas

Clean air, water, food, and shelter are basic human necessities. Can they all exist in the same place for millions of humans for an extended amount of time? This is the question that

humans are pushing at a greater and possibly unsustainable rate. The most urbanized area of the world is Tokyo, Japan. Tokyo is home to over 38 million humans, but decline in the population has been reported and is expected to be a continued trend due to decreasing birth rates (United Nations, 2014). Despite this decline in population in the most urban area, our world population is projected to continue growing by 2 billion people in the next 30 years (United Nations, 2023). Current estimates show global population over 7 billion and rising. In an effort to promote prosperity to all, the United Nations have outlined 17 objectives in the Sustainable Development Goals plan. The collective goals tackle hunger, water scarcity, human rights inequalities, and environmental issues (United Nations, 2020).

### 1.1.g Urbanization Environmental Effects

Increased urbanization and subsequent deforestation world-wide are well-documented issues. In Europe, virgin forests of Romania and the World Heritage Bialowieza forest of Poland face deforestation due to hurricane damage, invasive pests like bark beetle, and logging activities (Stokstad, 2018; Zbierska, 2022). Unsustainable development and environmental pollution are driven by deforestation and urbanization in South and Southeast Asia regions (Arshad et al., 2020). Refugee-driven landscape changes contribute to conversion of forest cover to agricultural cropland in Africa (Maystadt et al., 2020). Extensive deforestation in the Brazilian Amazon contributes to biodiversity loss, rising regional and global temperatures, extreme weather event intensification, and the spread of emerging infectious diseases (Ellwanger et al., 2020; MacDonald and Mordecai, 2019). Even legislative action like Queensland's Vegetation Management Act, cannot stop persistent deforestation rates on private Australian land (Simmons et al., 2018).

Urbanization has created a significant transformation of the natural environment and water cycles (Saadi et al., 2020). It is difficult to imagine that 84% of United States' human population lives on just 3% of United States' land surface area. Having dense human settlements has brought unintended consequences. These effects range from large scale atmospheric changes to microscopic impacts. Concentrated humans and the accompanying environment built to accommodate their lives create Urban Heat Island Effects (UHIE), when temperatures are greater within the city centers than the surrounding suburban and rural areas. Additional factors that increase UHIE is the lack of evapotranspiration due to the lack of vegetation and bodies of water (QIU et al., 2013). The UHIE is amplified by urban agglomerations, multiple urban areas that are located close together (Chen et al., 2020). Statistical analysis of carbon dioxide emissions for a panel of 44 Sub-Saharan Africa countries for the period 1984–2016 showed statistically significant causation from urbanization, which is blamed on energy inefficiency (Salahuddin, et al., 2018). The UHIE is the mixture of complex variables that continue to give cities a higher temperature than surrounding vegetation dominated areas. This drives up energy use in increasingly demanding summer high temperatures, which inadvertently increase the energy cost, disproportionately effecting low income urban areas (Nelson, et al., 2021).

Urbanization not only effects human well-being, the diversity of freshwater macroinvertebrates is negatively impacted by urbanization (Gál et al., 2019). Further, microplastic levels and structural sizes in freshwater macroinvertebrates suggest these animals have bioaccumulation of microplastic the closer they are to and downstream from an urban setting, its stormwater outfalls and wastewater plants (Simmerman and Wasik, 2020). Spatial and regression analysis in urban areas show a high correlation between areas with less tree canopy coverage and urban flooding (Liu et al., 2018). As vegetative cover decreases and

impervious surface cover increases, soil quality decreases and the potential for contamination increases (Zambon et al., 2018; Bonilla-Bedoya et al., 2021).

### 1.1.h Urban Forest Ecosystem Services

The urban forest provides many ecosystem service benefits (Figure 1.5). Geographic Information Systems (GIS) data analyzation confirms a significant positive correlation between loss of vegetation cover and increasing land surface temperature (Kafy et al., 2022). This phenomenon has gained momentum as impervious surfaces perform less evapotranspiration than their natural counterparts, trees, grass and soil, all components of the urban forest. The urban forest lessens stormwater impacts and mitigates heat loads at the micro- and meso-climate levels (Agaja et al, 2020). Trees provide comfort to humans, protecting from the sun's harsh rays on hot days. Humans use less energy to cool themselves when trees provide shade and reduce heat. Increasing vegetation can contribute to alleviation of UHIE (Liu et al., 2018).

### 1.1.i Tree Equity

With the emergence of urban forest ecosystem services valuation, the concept of tree equity was born to address the unequal distribution of urban forests and their benefits. Factors including income and race have been found to correlate with vegetation cover distribution, leaving vulnerable communities feeling the effects of climatological changes (Anderson et al., 2019; Lanza 2019; Saverino 2021). Poverty intensifies extreme heat vulnerability, while it is reduced by higher income (Lim and Skidmore, 2020). In an effort to address the health disparities associated with extreme heat vulnerability and tree equity, the Inflation Reduction Act of 2022 includes $1.5 billion for urban forests and $3 billion for the Neighborhood Access and Equity Grant Program "to mitigate or remediate negative impacts on the human or natural environment from a facility […] in a disadvantaged or underserved community through […]

infrastructure and natural features to reduce or mitigate urban heat island hot spots (Congress, 2022).

### 1.1.j Urban Forest Spatial Data Analysis

Land cover is the makeup of components that are present on any given surface of the Earth and visible in satellite imagery (U.S. NOAA, 2023). Land cover data plays a vital role in land use planning (Balaji and Muthukannan, 2020). Understanding land cover allows better decision making in land development, preservation, and conservation. The National Land Cover Database is a collection of imagery generated with the Multi-Resolution Land Characteristics Consortium that is led by the United States Geological Survey. Spatial analysis can be used to evaluate the effects of urbanization in terms of habitat loss and habitat fragmentation (Liu et al., 2016). Analysis of long-term urbanization data sets can be studied for urban centers to gain insight for urbanization ecological effects assessments. Optimal tree canopy coverage for urban areas is a debated figure that has been in the spotlight for the last ten years. Recent figures highlight that the U.S. urban and community forest areas are losing an estimated 175,000 acres of tree cover annually, which adds up to approximately $96 million lost from ecosystem service benefits (Nowak and Greenfield, 2018).

### 1.1.k Arboreta in the United States and Other Countries

With decreased forest cover in emerging urban areas, it is important to invest in green spaces that are properly managed and maintained. An arboretum is meant to create a natural environment where students, community members, and guests can receive outreach, enjoy scholarship and education about woody plants, their environments, their cultivation and conservation, and their history and importance on earth. The first recognized arboretum in the United States predates the country itself, having been established in 1773 by Humphry Marshall

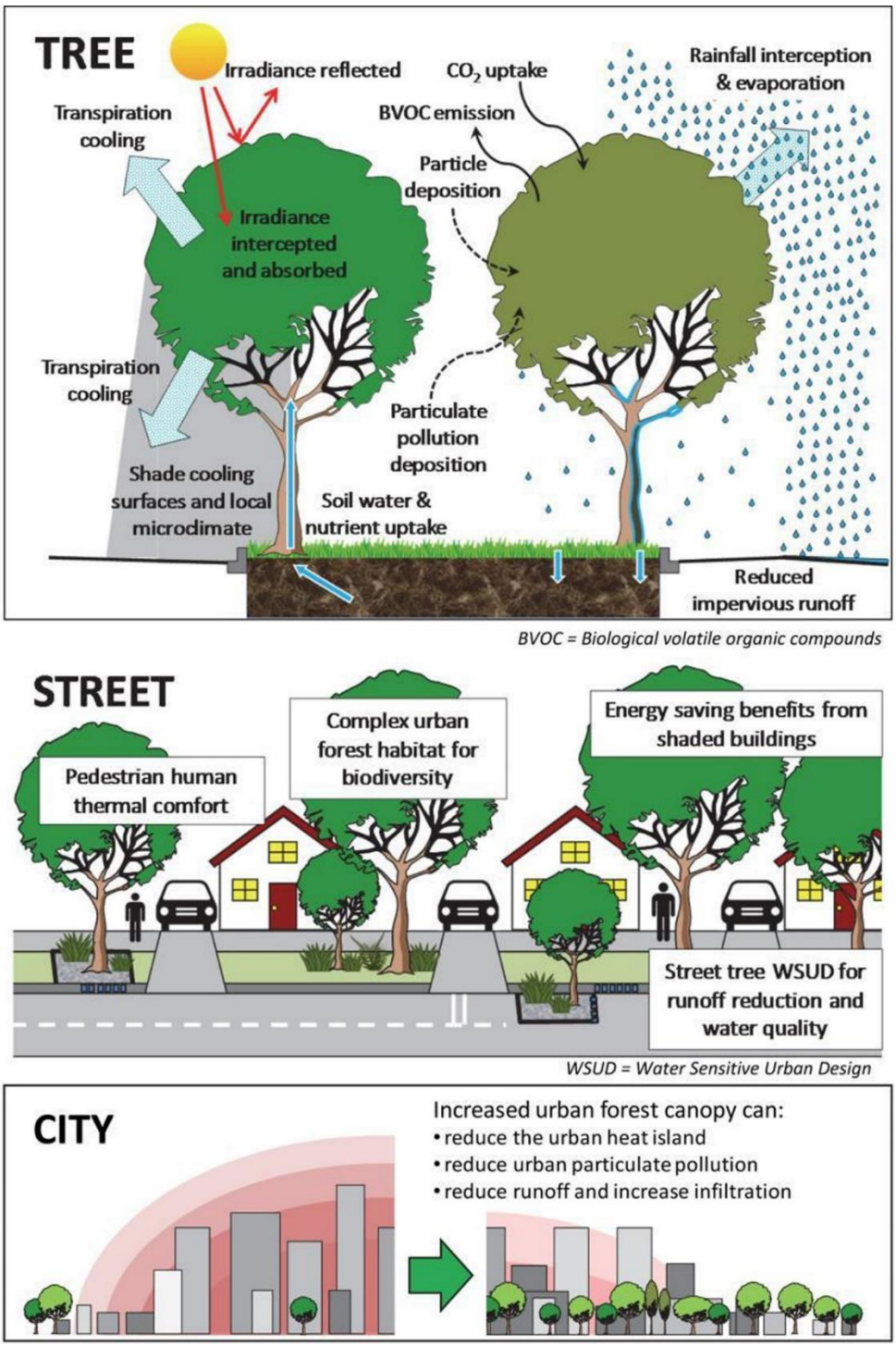



*Figure 1.5. Urban forest ecosystem service and function: at the tree, street, and city scale by Livesley et al., 2016.*

in Marshallton, Pennsylvania on his private estate (Day, 2022). The American Public Gardens Association, which includes arboreta among its 600 institutions, currently serves over 120 million visitors annually (American Public Gardens Association, 2022). The benefits of arboreta can best be categorized as biological or communal. The biological benefits include ecosystem service benefits, conservation, research, and protection of native species. The communal benefits include education, recreation, entertainment and wellness.

In an arboretum, trees are identified and labelled for visitors to learn about the biological specimens around them. Each arboretum is an outdoor science laboratory! The unique landscapes, geographic features of the land and different tree species with which an arboretum is established makes each arboretum an inimitable chance to educate everyone who visits it. Arboreta provide the ultimate opportunity to utilize the urban forest for community extension and education. New and established residents alike should know the value of the urban forest to their daily lives. Landowners play a large role in maintaining Tennessee's forested land, with 83% of Tennessee forests being privately owned (Tennessee Division of Forestry, 2023).

Beyond being educational resources, arboreta have great potential to promote physical and mental well-being in urban areas. It has been found that a daily visit to urban forests provides benefits for stress reduction, the urban forest supports a social cohesion of the younger population, and that an arboretum is a suitable environment for perceiving physical and mental wellbeing (Vujcic and Tomicevic-Dubljevic, 2018). An example would be the Westonbirt Arboretum of England where they apply a multifaceted approach to promoting wellbeing that combines social, woodland craft, creative and sensory activities that engage those with mental health, addiction, autism, and behavioral problems (O'Brien, 2018). Participants from this study described the atmosphere as calming, peaceful, stress-free and tranquil. In addition, visitors of a

university botanical garden survey reported stress relief and relaxation, improved quality of life, and increased fun and enjoyment of life, as a result of being in the green space (Wassenberg et al., 2015).

In addition to wellness respites and education facilities, biological collections provide solutions to the plant extinction crisis that our world is currently facing (Westwood et al., 2021). Arboreta are unique opportunities to promote biodiversity of native trees in a controlled outdoor setting. Pests, like the emerald ash borer and Asian long-horned beetle, infiltrated America and largely destroyed trees undetected until it was too late to mitigate the damage already caused. Ellie Barham of Botanic Gardens Conservation International proposed that arboreta could be used to monitor native species across the globe for changes in plants. She said, “Botanic gardens and arboreta are unique resources that can help provide [early warning of new and emerging plant pests and pathogens] and are, currently, often overlooked within plant health” (Barham, 2016, pp. 377). Durango, Colorado Arborist Matt Besecker was “surprised and thrilled” when a local middle school discovered chestnut trees that have thrived despite the blight that destroyed most of the beloved American species (Burney, 2022). Urban forestry conservation and research efforts can be greatly furthered when utilizing a network of likeminded professionals and managed green spaces.

Despite being such wonderful resources, research data on the benefits and value of arboreta is limited. An economic value was estimated for Sylva Untan Arboretum of Indonesia using three different methods that determined the tangible values were exceeded by service benefits (intangible) provided by the arboretum (Roslinda et al., 2020). Cortese (2018), found that arboreta specimen appraisal was also an important aspect of managing land resources for research and education.

### 1.1.l Tennessee Division of Forestry and Tennessee Urban Forestry Council Arboreta Certification Program

Arboretum certification is meant to equip organizations to stay organized and use their accreditation to gain visitors and financial support. In 1991, the urban forestry section of the Tennessee Division of Forestry (TDF) organized their first Tennessee Urban Forestry Council (TUFC) meeting (TUFC, 2023). TUFC is a nonprofit organization supported by members that include urban forest and arboriculture practitioners, educators, businesses, and lay persons with an interest in urban forestry. The mission of the TUFC is to promote healthy and sustainable urban and community forests in Tennessee.

As a way to promote urban forestry, the TUFC began offering the arboreta certification program, in partnership with the TDF. Their program mission is to develop a network of arboreta across Tennessee that are well-maintained, open to the public and proactively utilized for experiential education about trees and the important role they play in communities. Their program vision aspires to have a TUFC certified arboretum that is within a 30-minute drive of every Tennessee community (TUFC, 2022).

## 1.2 Statement of Problem

Tennessee's urban forest is valuable and in need of increased management attention, including baseline data assessments. TDF's 2020-2030 Forest Action plan lists 1) enhancing forest health and resiliency and 2) maintaining and improving connected landscapes as two of its four objectives. The connection between increased developed cover, socioeconomic status, and UHIE across Tennessee is undergoing continued exploration. Outdoor education centers known as arboreta are a treasured resource of the urban forest. There is currently insufficient research defining the parameters of arboretum management. There is also a lack of arboriculture

educational resources for citizen scientists or volunteer leaders who are establishing arboreta in Tennessee.

Urbanization is having disadvantageous impacts on the environment and public health, especially in areas of low socioeconomic status. Urban areas are defined as cities with a population of over 50,000 (Bureau of the Census, Department of Commerce, 2021). The implementation of remote working has redefined the desirability of proximity to cities for job purposes (Lenzi and Perucca, 2022). A recent influx of migration to Tennessee, determined by U-Haul and based on the net gain of one-way moving trucks entering a state over the calendar year of 2020, occurred just before Nashville, Tennessee experienced one of its hottest summers on record in 2022 (National Weather Service, 2022). Several factors have converged to make Tennessee a desirable residential destination for people moving out of large urban areas in other parts of the country. Tennessee's cost of living is, on average, an index of 87.6 in comparison to the United States average of 100, most influenced by its low housing index of 71.2 (Best Places, 2022).

There is no existing exploration of Tennessee arboretum manager interests and needs. In Chapter Two, I address the research question, "How can arboretum managers be better supported by the Tennessee Urban Forestry Council?" In Chapter Three, I investigate current reach and accessibility of TUFC certified arboreta across the state of Tennessee. Specifically, I address the research question, "How many Tennessee communities are within a 30-minute drive to any TUFC certified arboretum?" Lastly within Chapter Four, I evaluate the urban forest from a spatial perspective in Tennessee, by investigating the variability in mean evapotranspiration in relation to developed land cover and socioeconomic factors using GIS and generalized linear

regression. This work addresses the research questions, “Where do heat islands exist in Tennessee?” and “What disparities exist in Tennessee tree equity?”

### 1.4 Dissertation Organization

This dissertation consists of five parts, three of which are individual manuscripts prepared for submission to peer-reviewed journals. Chapter Two is a study that uses statistical analysis to explore Tennessee Urban Forestry Council certified arboretum managers’ interests and needs. Chapter Three is a study that uses spatial analysis to assess the baseline data for TUFC’s vision of having a TUFCCA within a 30-minute drive of every community in Tennessee. Chapter Four is a study that utilizes Tennessee spatial data to discover meaningful connections between impervious surface land cover, socioeconomic factors, and the urban heat island effect. Chapter Five will synthesize all three manuscripts and discuss future directions of Tennessee urban forest research.

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# CHAPTER TWO

# EXPLORING OPPORTUNITIES AND BARRIERS FOR ARBORETA MANAGEMENT ACROSS TENNESSEE

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**Abstract**

Since arboreta are important institutions of the urban forest that provide environmental, social, and educational benefits to over 100,000 Tennessee residents and visitors annually, their effective and proper utilization play an important role in communicating conservation information from the Tennessee Division of Forestry. The Tennessee Urban Forestry Council (TUCF) nonprofit collaborates with the Tennessee Division of Forestry to manage a statewide arboretum certification program. There were no previous studies that used evaluative methods to assess the interests and needs of representatives of arboreta that participate in the TUFC arboretum certification program. This research will define the parameters of Tennessee arboretum representatives' needs. A questionnaire was developed to gather baseline data about current management practices, education initiatives, and manager satisfaction with arboretum operations. The questionnaire was conducted via Qualtrics and sent to all TUFC certified arboretum (TUFCCA) managers. With data showing representatives' desire for better communication and specific training programs, formal training materials can be created to allow arboretum representatives to learn and implement new arboretum management strategies. A statewide training program will also allow TDOF initiatives, like Firewise safety, riparian zone conservation and tree pest and disease guidelines, to be disseminated to general community audiences consistently.

Keywords: urban forest(ry), arboretum(a), urban forest facility, human dimensions, manager

## 2.1 Introduction

Communities are enriched with biological, communal, and ecosystem service benefits by arboreta (Wassenberg et al., 2015; O'Brien, 2018; Vujcic and Tomicevic-Dubljevic, 2018; Cavender and Gerard, 2019, Turner-Skoff and Cavendar, 2019; Stevenson et al., 2020). Urban forest information can be disseminated to visitors through effective and properly managed outdoor education facilities (USDA ARS, 2023). The first recognized arboretum in the United States predates the country itself, having been established in 1773 by Humphry Marshall in Marshallton, Pennsylvania on his private estate (Day, 2022). The American Public Gardens Association, which includes arboreta among its 600 institutions, currently serves over 120 million visitors annually (American Public Gardens Association, 2022). The benefits of arboreta can best be categorized as biological or communal. The biological benefits include ecosystem service benefits, conservation, research, and protection of native species. The communal benefits include education, recreation, entertainment and wellness.

In an arboretum, trees are identified and labelled for visitors to learn about the biological specimens around them. Each arboretum is an outdoor science laboratory! The unique landscapes, geographic features of the land and different tree species with which an arboretum is established makes each arboretum an inimitable chance to educate everyone who visits it. Arboreta provide the ultimate opportunity to utilize the urban forest for community extension and education. Beyond being educational resources, arboreta have great potential to promote physical and mental well-being in urban areas (Vujcic and Tomicevic-Dubljevic, 2018). A multifaceted approach to promoting wellbeing at the Westonbirt Arboretum of England that combined social, woodland craft, creative and sensory activities proved engaging for those with mental health, addiction, autism, and behavioral problems (O'Brien, 2018). Participants from this

study described the atmosphere as calming, peaceful, stress-free and tranquil. Visitors of a university botanical garden survey reported stress relief and relaxation, improved quality of life, and increased fun and enjoyment of life, as a result of being in the green space (Wassenberg et al., 2015).

Arboreta are composed of naturally occurring and cultivar biological species, the determining factor of calling an area an arboretum is accreditation by a certifying body, at the national or international level. ArbNet, an interactive community of arboreta, formed the Arboretum Accreditation Program and certifies over 2200 arboreta worldwide. ArbNet has four different certification levels with increasing requirements for number of tree species, arboretum personnel, strategic management and public offerings including research, education, and conservation (Figure 2.1.a). Across the state of Tennessee, 13 arboreta are accredited through ArbNet at various certification levels, while the majority of arboreta in Tennessee are certified through statewide arboretum program administered through the Tennessee Urban Forestry Council (TUFC). Certification requirements for TUFC are less extensive and more attainable for novice urban forest enthusiasts (Figure 2.1.b).

There are formal processes for establishing an arboretum, but there is no formal training or "one stop shop" for prospective arboretum managers about how to establish or manage an arboretum. While an arboretum can add value with educational resources, ecosystem service benefits, and entertainment, it must be properly maintained (Tankersley et al., 2015). Liability exists if hazardous trees are improperly cared for and cause injury to any person. Trees should be assessed for any routine or special care that would be needed.

| ArbNet | LEVEL I | LEVEL II | LEVEL III | LEVEL IV |
|---|---|---|---|---|
| Arboretum plan | ■ | ■ | ■ | ■ |
| Organizational or governance group | ■ | ■ | ■ | ■ |
| Labeled tree and woody plant taxa | | | | |
| 25+ | ■ | | | |
| 100+ | | ■ | | |
| 500+ | | | ■ | ■ |
| Staff or volunteer support | | | | |
| Volunteer or paid | ■ | | | |
| Paid management | | ■ | ■ | ■ |
| Curator | | | ■ | ■ |
| Scientific or conservation staff | | | | ■ |
| Public dimension | | | | |
| Public access and at least one event per year | ■ | ■ | ■ | ■ |
| Enhanced public and educational programs | | ■ | ■ | ■ |
| Substantial educational programming | | | ■ | ■ |
| Collections policy | | ■ | ■ | ■ |
| Collaboration with other arboreta | | | ■ | ■ |
| Collections data sharing with networked collections | | | ■ | ■ |
| Agenda for tree science, planting, and conservation | | | ■ | ■ |
| Collections conservation | | | | ■ |
| Conservation role in Global Trees Campaign | | | | ■ |

| TUFC | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| Labelled Trees | | | | |
| 30-59 | • | | | |
| 60-89 | | • | | |
| 90-119 | | | • | |
| 120+ | | | | • |
| Map of Tree Locations Available to the Public | | • | • | • |
| Staff or Volunteers Available for Tours | | | • | • |
| Biannual Publication of an Educational Newsletter | | | | • |

*Figure 2.1.a ArbNet Certification Level Requirements (2022) b. TUFC Certification Level Requirements (2022)*

Limited data exists in demographic and perception information from arboretum managers, and Tennessee arboretum manager information has not been previously explored. To address the current void in research about arboreta management in Tennessee, this research study investigated arboretum manager needs to optimize arboretum operations. The objectives of this study were to gain insight about successful arboreta management strategies, to explore options for arboreta financial support sources, and to understand how arboreta managers managed the effects of the COVID-19 pandemic on their programs.

## 2.2 Methods

### 2.2.a Target Population

Arboretum managers from Tennessee Urban Forestry Council Certified Arboreta (TUFCCA) were the target audience for the digital research questionnaire. Arboretum manager contact information was provided by the Tennessee Urban Forestry Council. Of the complete contact list, email information was available for 60 arboreta. The online questionnaire (Qualtrics) was remotely administered to the test population of 60 arboreta managers. Because of the small total population size for this study, a total population study was chosen over a limiting sampling technique. A control population was not used because questions are only relevant to arboretum managers.

### 2.2.b Study Advertisements

Invitations to participate in the online research survey (Appendix B) were sent out via initial email to TUFCCA managers on September 16, 2022. After 7 days, on Friday, September 23, 2022, a list was generated of the test population with information about who had already completed the questionnaire, who had started the questionnaire, anyone who had not started the questionnaire, and email addresses that did not work. TUFCCA managers with phone

information available were called to remind them about the research survey, ask if they received the initial email, and encourage them to participate in the study before the deadline. Any erroneous email addresses and phone numbers were updated in an excel sheet and input to the survey system. The following Tuesday, September, 27, 2022, a final email reminder communication was emailed to arboretum managers encouraging them to participate in the research questionnaire before the September 30, 2022 deadline.

### 2.2.c Design Considerations

Members of the target population are located all across the state of Tennessee so logistics and the COVID-19 pandemic made in person interviews expensive, time consuming, and potentially a health hazard. Time constraints make video chat or phone interviews undesirable as well. Participation in the study was confidential. The questionnaire was distributed using Qualtrics.com. This digital application protects participant responses with encryption. Qualtrics also removes personally identifying information like IP addresses to anonymize responses. Although participant names and email addresses were collected to send survey advertisements, this information was stored securely. No personally identifiable information was connected to individual data.

### 2.2.d Survey Instrument

The questionnaire contained sections for demographics about the managers and their arboreta, strategic management and arboreta operations, interest in future offerings, and effects of COVID-19 pandemic. The instrument was field-tested using arboretum managers in states bordering, but outside of Tennessee. The 67-question questionnaire was designed to gather a wide range of information that could be studied and used in urban forest decision and policy

making beyond the scope of the results and conclusions of this manuscript. A transcript of the instrument can be found in Appendix C.

### 2.2.e Ethical Considerations

The Institutional Review Board of the University of Tennessee reviewed this research proposal for use of human subjects and deemed the application eligible for exempt review and fully approved (Appendix D). A consent agreement for involvement in the study was required before respondents could proceed with participation (Appendix A). All researchers associated with this study have completed all federally required certifications for training to use human subjects in research. The research activities present no known risk to participants. Participation in the study was confidential, while respondents' data was completely anonymous.

### 2.2.f Data Analysis

Before analysis began, the Qualtrics questionnaire was closed. Descriptive statistics and frequencies of survey data for respondents was generated using Qualtrics. The research data collection was exported as a SPSS Statistics Data document and analyzed using SPSS software. The data table was streamlined to remove columns used for identification (name, email, IP address, etc.) with missing values since the data was anonymized and those values were not recorded. True missing values for questions that were seen but unanswered were left empty and individually removed for each question, rather than excluding the whole survey response from the entire data set. Responses with insufficient data were removed from consideration. Data with "yes" or "no" responses were recoded as 0 and 1 for easier readability during analysis. Descriptive statistics used were mean, median, and percentage. The demographic information included was role at the arboretum (owner, stakeholder, manager, program staff, volunteer), number of years in current position, education level, arboretum certifications, and TUFC

arboretum certification level. Further statistical analysis with crosstabulations included chi-square for groups with two categorical variables, Mann-Whitney U for ordinal and categorical variables, Spearman's correlation for two ordinal variables, and T-tests for scale and categorical values.

Inferential statistics were not used because this study was a survey of a specific population. The first open-ended question asked was "What can be improved with the TUFC arboretum certification program/process?' Of the 32 respondents, provided written comments. These comments were analyzed by looking for key themes. Key themes were reported in tabular form and described (Appendix E).

This study used an instrument that was developed to address the research questions. The instrument employed several Likert scales, with responses for satisfaction, interest, probability, importance, agreeance, contribution, and effect.

## 2.3 Results

### 2.3.a Population

Of the 60 arboretum managers who were initially emailed a link to participate in the research study, 1 email failed and 3 emails bounced. Fifty-seven (N=57) is the total population of arboretum managers who received an email link, after e-mail address corrections and follow up emails were sent. One participant started the survey after agreeing to the consent statement, but did not complete any questions. Another respondent completed 7% of the survey, mainly the demographic information that would not be relevant to the research questions. Thirty-four participants at least partially completed a survey. Twenty-five participants totally completed the survey. Of the total 25 completed and 9 partly completed, 56.1% (32 (N=32) respondents of 57 email recipients) completed all demographic questions and were included in the analysis and

results. Calling the population that had not completed a survey was an effective tool in gaining accurate contact information and giving credence to the random email request they received a week ago. Then, sending a reminder email more than doubled the response rate in the second week.

2.3.b Demographics

Arboreta can be certified at four different levels by the TUFC (Figure 2.1.b). Fifty-seven percent of respondents were from level 1-certified arboreta, 25% were from level 2-certified arboreta, 10% were from level 3-certified arboreta, and 7% were from level 4-certified arboreta. One respondent reported being unsure of their arboretum's certification level. Level 1 arboreta were more likely to have plans of increasing their certification (62.5%) than Level 2 (14.3%) or Level 3 (33.3%). Twenty-five percent of respondents are from East Tennessee, 34.4% of respondents are from Middle Tennessee, and 40.6% of respondents are from West Tennessee.

Respondents (n = 32) were instructed to check all roles that apply to them and identified as stakeholders (9.4%), managers (62.5%), program staff (25%), volunteers (31.3%), and individual responses of board member over arboretum committee (3.1%), director (3.1%), master gardener (3.1%) who is the management committee chair, and retired (3.1%) (Table 2.2). The years of experience in their current position reported by respondents (N = 24) ranged from 1 to 20 years with a mean of 6.4 years. Fifty-six-point three percent of respondents (N = 32) have a graduate degree, 37.5% of respondents have a bachelor degree, and 6.3% have completed some college education. Arboretum certifications held by respondents (N = 32) include TUFC (90.6%), Tree City USA (15.6%), ArbNet (9.4%), American Public Gardens (6.3%), Tree Campus USA (6.3%), Conifer Reference Garden (3.1%), and 6.3% were unsure which certifications their arboretum held.

Table 2.1.

*Survey Respondents' Current TUFC Arboretum Certification Level*

| Level | Frequency | Percent |
|---|---|---|
| 1 | 22 | 68.8 |
| 2 | 4 | 12.5 |
| 3 | 4 | 12.5 |
| 4 | 2 | 6.3 |
| Total (N) | 32 | 100.0 |

Table 2.2.

*Respondents' Self-Identified Role with TUFC Certified Arboreta Program*

| **Respondent Arboretum Role** *(Check All That Apply)* | **N** (32) | **%** |
|---|---|---|
| Manager | 20 | 62.5 |
| Stakeholder | 3 | 9.4 |
| Volunteer | 10 | 31.3 |
| Program Staff | 8 | 25 |
| Board Member over Arboretum Committee | 1 | 3.1 |
| Director | 1 | 3.1 |
| Management Committee Chair (Master Gardener) | 1 | 3.1 |
| Retired | 1 | 3.1 |

2.3.c TUFC Certification Impact

Over 90% of respondents (N = 31) believe TUFC arboretum certification has been beneficial to their arboretum. When asked how TUFC arboretum certification has enhanced their arboretum, 80.8% responded increased recognition among stakeholders, 50% responded increased volunteerism, 42.3% responded increased media publications, 38.5% responded increased attendance, and 26.9% responded money added to budget. Four separate write-in responses included that they were allowed to be used for school tours and labs, garnered outside financial support, visitors enjoy finding listed trees when waiting for events at arboretum, and it provided grant money. When asked to consider the aforementioned benefits of being associated with TUFC, respondents reported a mean satisfaction of 3.76 with 1 being very dissatisfied, 3 being satisfied, and 5 being very satisfied. Forty-six-point nine percent of participants (N = 15) had missing values for this question. Of the 17 responses, 2 were very dissatisfied, 13 were satisfied, and 2 were very satisfied. Forty-point six percent of respondents provided write-in reporting for the question of what can be improved with the TUFC arboretum certification program/processes (Appendix E). Respondents were asked which aspects of the TUFC arboretum certification program have helped the arboretum. A table displays their encoded responses in Appendix E, which include: *recognition* (n = 10), *guidance* (n = 5), *tree care* (n = 5), *legitimization* (n = 4), *funding* (n = 2), and *unsure* (n = 2).

2.3.d Arboreta Specifications

Over 55% of arboreta (N = 29) have a board of directors or advisory board. The median area for respondents' (N = 23) arboreta is 37 acres, with answers ranging from 5 to 515 acres. The total estimated arboretum area for all respondents (N = 23) is 2,353 acres. Forty-four-point eight percent of respondents (N = 29) estimate there are more than 121 trees on their arboretum

Table 2.3.

*Certifications Held by Respondents' Arboreta* (N = 32)

| Certification Body | Percentage |
|---|---|
| TUFC | 90.6 |
| Tree City USA | 15.6 |
| Arbnet | 9.4 |
| American Public Gardens | 6.3 |
| Tree Campus USA | 6.3 |
| Conifer Reference | 3.1 |
| Unsure | 6.3 |

Table 2.4.

*Main Ways TUFC Arboretum Certification Has Enhanced Arboreta*

| TUFC Certification Benefits | Arboreta Enhanced |
|---|---|
| Increased Recognition Amount Stakeholders | 80.8% |
| Increased Volunteerism | 50% |
| Increased Media Publications | 42.3% |
| Increased Attendance | 38.5% |
| Money Added to Budget | 26.9% |

property, 13.8% estimate there are 91-120 trees, 13.8% estimate there are 61-90, 20.7% estimate there are 31-60, and 6.9% believe there are 1-30 trees on their property total. Arboreta (N = 27) have a median of 53 trees labelled at their arboreta with answers ranging from 31 to 250. Twenty-four-point one percent of managers (N = 29) are possibly planning to add more trees to their arboreta, 20.7% are probably planning to add more trees, and 55.2% committed to definitely planning to add more trees to their arboreta in the future. Forty-four-point four percent of respondents (N = 27) have plans to increase the TUFC arboretum certification level in the future.

More than 37% of respondents (N = 29) reported having paid employees working at their arboreta. Of those, one arboretum has 70 employees. The other respondents (n = 8) reported having 6 or less paid employees. Of the 62.1% of respondents (N = 29) who reported not having paid employees, 27.8% (n = 5) believe their volunteer staff is able to handle the current workload, 22.2% (n = 4) reported the arboretum lacks funding to pay employees, 11.1% (n = 2) stated the arboretum does not need employees, and 38.9% (n = 7) wrote in their own reason, shown below.

> "*County maintains the park. Master Gardener volunteers label and maintain the trees we plant and/or identify. We assist in clearing trail hazards, watering young trees, weeding around trees, etc...*"
>
> "*Our arboretum is taken care of by the staff/faculty/students of the College of Science, Technology, and Mathematics at Tusculum University*."
>
> "*Our garden club created the arboretum and we are all volunteers and do everything for free including the brochures which are handed out*"
>
> "*Parks Dept. maintain property*"

"*the arboretum is at a city park. So there are municipal employees*"

"*The arboretum is on private property that [employs] workers for many different reasons. [Therefor] the arboretum just falls under the umbrella of the total workload*."

"*The campus grounds have paid employees but not specifically the Arboretum*"

Over 78% of respondents (N = 28) reported their arboreta having volunteer workers. 90.9% of these have 50 or fewer annual volunteers, with 9% reporting 100 - 250 volunteers. The number of volunteer hours contributed to the arboretum annually is shown in Table 2.5. Of the 21.4% respondents (N = 6) who reported not having volunteer workers, 50% reported not needing volunteers and 16.7% responded that they did not know how to get volunteers. Two respondents provided other explanations listed below.

"*Our volunteers would be the staff/faculty/students who work at the arboretum in any way needed.*"

"*the arboretum is managed by the local parks and recreation department*."

When asked to rank arboretum functions by importance (1 being least important and 5 being most important), respondents (N = 28) placed most value on biodiversity protection of native biological species (4.32), conservation of urban forests (4.29), visitor entertainment (4.00), visitor wellness (3.93), visitor education (3.86), and least on research (3.32) (Table 2.6).

Only 7.4% of respondents (N = 27) have a visitation count system. With mostly no counting systems, respondents estimated approximate annual visitors. Of those with a visitation count system, 7.1% of respondents (n = 2) estimate 100,001 or more visitors, 3.6% (n = 1) estimate having 25,001-50,000 visitors, 3.6% (n = 1) estimate having 10,001-25,000 visitors, 21.4% (n = 6) estimate having 1,001-10,000 visitors, 10.7% (n = 3) estimate having 501-1000 visitors, 25% (n = 7) estimate having 101-500 visitors, and 10.7% (n = 3) estimate having 0-100

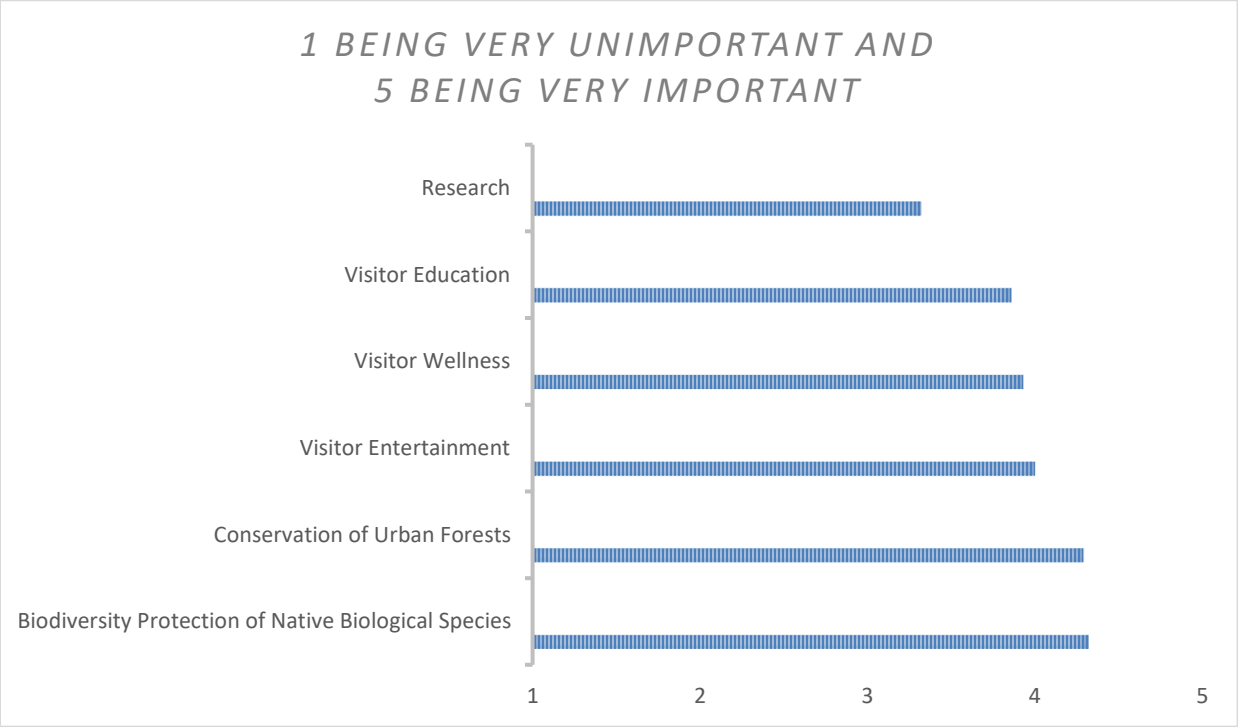
Table 2.5.

*Number of volunteer hours contributed to arboretum annually*

| Volunteer Hours Contributed to Arboretum Annually | N = 20 | Percentage |
|---|---|---|
| 1-50 | 4 | 20 |
| 51-100 | 4 | 20 |
| 101-500 | 7 | 35 |
| 501-1000 | 4 | 20 |
| 1000 or more | 1 | 5 |

Table 2.6.

*Perspectives of Arboretum Functions* (Rank of Importance of Arboretum Functions)



visitors annually. When asked to rank their satisfaction level with the arboreta's visitor volumes, respondents (N = 28) reported a mean of 3.82 on a scale of 1 to 5, 5 being the best. When asked to rank their interest level in help regarding visitor volume, respondents (N = 28) reported a mean of 2.54 on a scale of 1 to 5, 5 being the most. When asked how they would like to change their arboreta's attendance levels, 75% of respondents (N = 20) answered increase attendance and 25% of respondents answered control attendance.

2.3.e Educational Event Offerings

More than 64% of respondents (N = 28) host educational events (workshops, classes, etc.) at their arboreta. Those who hosted educational events (N = 18) described the frequency with which they normally host events annually (Table 3.8). A third (n = 6) answered 1-2 times a year, 38.9% (n = 7) answered 3-5 times a year, 16.7% (n = 3) answered 5-10, and 11.1% (n = 2) answered 10 or more. Those who hosted educational events (N = 18) described the number of people who typically attend educational events hosted at the arboretum (Table 2.7). Five-point six percent (n = 1) of respondents answered 6-10, 27.8% (n = 5) of respondents answered 11-15, 38.9% (n = 7) answered 16-20, and 27.8% of respondents answered 20 or more.

Respondents (N = 18) were asked what type of education events their arboreta host. The following categories were chosen: environmental education (n = 15), tree maintenance (n = 9), tree planting (n = 7), biodiversity (n = 7), ecosystem services (n = 6), and other (n = 7). The other written responses are: "Classes for children as well as adults", "Our arboretum is used in APSU biology and ecology curriculum", "Tree ID", "Tree ID Native flora Tree planting and maintenance for volunteers", "Tree ID, tree as host plants...", "Tree Walks/Talks", and "Wine and Walk Education Tours".

Table 2.7.

*Estimated Annual Arboreta Visitors*

| | Respondents | Percentage |
|---|---|---|
| 0-100 | 3 | 10.7 |
| 101-500 | 7 | 25.0 |
| 501-1,000 | 3 | 10.7 |
| 1,001-10,000 | 6 | 21.4 |
| 10,001-25,000 | 1 | 3.6 |
| 25,001-50,000 | 1 | 3.6 |
| 100,001 or more | 2 | 7.1 |
| I don't know | 5 | 17.9 |

Table 2.8.

*Number of Educational Events Hosted by Arboreta Annually*

| Annual Events Hosted | Responses | Percentage |
|---|---|---|
| 1-2 | 6 | 33.3 |
| 3-5 | 7 | 38.9 |
| 5-10 | 3 | 16.7 |
| 10 or more | 2 | 11.1 |
| Total | 18 | 100.0 |

Table 2.9.

*Arboretum Educational Events Typical Attendance*

| Participants at Events | Responses | Percentage |
|---|---|---|
| 6-10 | 1 | 5.6 |
| 11-15 | 5 | 27.8 |
| 16-20 | 7 | 38.9 |
| 20 or more | 5 | 27.8 |
| Total | 18 | 100.0 |

The 10 respondents who do not currently host educational events at their arboreta were asked why using a Likert scale with 1 being strongly disagree, 2 being moderately disagree, 3 being neither agree or disagree, 4 being moderately agree, and 5 being strongly agree (Table 2.10.). Respondents (N = 10) ranked "We don't have time to organize educational events" at 3.90; (N = 10) ranked "Lack of funding" at 3.00; (N = 9) ranked "Visitors are not interested in educational events." at 2.67; (N = 10) ranked "COVID-19 restrictions limited our ability to host educational events." at 2.30. (N = 10) ranked "We don't know how to organize educational events." at 2.30. (N = 10) ranked "Lack of space" at 2.20. (N = 10) ranked "We are not interested in hosting educational events." at 2.00.

2.3.f Guided Nature Tour Offerings

Over 42% of arboreta (N = 28) currently offer guided nature tours. Those who offer guided nature tours (N = 12) described the frequency they host guided tours annually as 1-2 times a year (n = 3, 25%), 3-5 times a year (n = 4, 33.3%), and 5-10 times a year (n = 5, 41.7%). The number of people who typically attend these guided nature tours are groups of 5-10 participants (n = 3, 25%), 10-15 participants (n = 4, 33.3%), 15-20 participants (n = 3, 25%), and 20 or more participants (n = 2, 16.7%). The respondents who do not currently offer guided tours (N = 16) were asked why using a Likert scale with 1 being strongly disagree, 2 being moderately disagree, 3 being neither agree or disagree, 4 being moderately agree, and 5 being strongly agree (Table 3.11.). Respondents (N = 16) ranked "We don't have anyone with time to lead guided nature tours." at 3.50; "Lack of Funding" at 3.00; "We don't have anyone with knowledge to lead guided nature tours." at 2.69; "Visitors are not interested in guided nature tours." at 2.44; "We are not interested in hosting guided nature tours." at 2.37; "Lack of Space" at 1.94; and

Table 2.10.

*Reasons for Not Hosting Educational Events*

| | N | Minimum | Maximum | Mean |
|---|---|---|---|---|
| We don't have time to organize educational events | 10 | 1 | 5 | 3.90 |
| Lack of funding | 10 | 1 | 4 | 3.00 |
| Visitors are not interested in educational events. | 9 | 1 | 3 | 2.67 |
| COVID-19 restrictions limited our ability to host educational events. | 10 | 1 | 5 | 2.30 |
| We don't know how to organize educational events. | 10 | 1 | 4 | 2.20 |
| Lack of space | 10 | 1 | 5 | 2.20 |
| We are not interested in hosting educational events. | 10 | 1 | 3 | 2.00 |

Table 2.11.

*Reasons Arboreta Don't Host Guided Nature Tours*

| | N | Minimum | Maximum | Mean |
|---|---|---|---|---|
| We don't have anyone with time to lead guided nature tours. | 16 | 1 | 5 | 3.50 |
| Lack of Funding | 16 | 1 | 5 | 3.00 |
| We don't have anyone with knowledge to lead guided nature tours. | 16 | 1 | 5 | 2.69 |
| Visitors are not interested in guided nature tours. | 16 | 1 | 4 | 2.44 |
| We are not interested in hosting guided nature tours. | 16 | 1 | 5 | 2.37 |
| Lack of Space | 16 | 1 | 4 | 1.94 |
| COVID-19 restrictions have caused us to be temporarily unable to host guided nature tours. | 16 | 1 | 3 | 1.88 |

"COVID-19 restrictions have caused us to be temporarily unable to host guided nature tours." at 1.88.

2.3.g Arboretum Planning and Management

Respondents use the following methods to manage their arboreta's tree inventories: paper (n = 4, 14.3%), electronic spreadsheet (n = 23, 82.1%), and the electronic application plantmaps.com (n = 1, 3.6%). Sixty-four-point three percent of respondents (N = 28) have a tree and vegetation maintenance plan. Those who do not have a tree and vegetation and maintenance plan (N = 10) were asked to rank their level of interest on a scale at a mean of 3.40 out of 1 to 5 (1 being not at all interested, 2 being slightly interested, 3 being moderately interested, 4 being very interested, and 5 being extremely interested).

Only 22.2% of respondents (N = 27) have a written organizational master plan. Those who do not have a written organizational master plan (N = 21) were asked to rank their level of interest on a scale at a mean of 3.40 out of 1 to 5 (1 being not at all interested, 2 being slightly interested, 3 being moderately interested, 4 being very interested, and 5 being extremely interested) (Table 2.12). 9.5% of respondents (n = 2) were not at all interested, 33.3% of respondents (n = 7) were slightly interested, 23.8% of respondents (n = 5) were moderately interested, 23.8% of respondents (n = 5) were very interested, and 9.5% of respondents (n = 2) were extremely interested.

Half of respondents (N = 28) have organizational long-term goals. Long-term goals that were shared by 12 respondents (Table E.3.) were encoded with the relevant categories include: (Increase Biodiversity (n = 7); Plant Trees (n = 6); Improve Communication with Visitors (n = 5); Increase TUFC Arboretum Certification Level (n = 4); Improve Facilities (n = 4); Maintain

Table 2.12.

*Respondents' level of interest in written organizational master plan help*

| **Level of Interest** | | **Percentage** |
|---|---|---|
| Not at All Interested | 2 | 9.5 |
| Slightly Interested | 7 | 33.3 |
| Moderately Interested | 5 | 23.8 |
| Very Interested | 5 | 23.8 |
| Extremely Interested | 2 | 9.5 |
| Total | 21 | 100.0 |

TUFC Arboretum Certification (n = 2); Tree Maintenance (n = 2); Host More Events (n = 2); Continue Education (n = 2); and Strategic Planning (n = 1)). 85.7% of respondents who do not currently have long-terms goals (N = 14) expressed at least slight interest in getting help developing long-term goals. Fourteen-point three percent of respondents (n = 2) were not at all interested, 42.9% of respondents (n = 6) were slightly interested, 21.4% of respondents (n = 3) were moderately interested, 21.4% of respondents (n = 3) were very interested, and 21.4% of respondents (n = 3) were extremely interested.

80.8% of respondents (N = 26) have organizational short-term goals. Short-term goals that were shared by 21 respondents (Appendix E) and encoded with the relevant categories (Tree Inventory (n = 4), Signage (n = 9), Undesirable Plant Removal (n = 4), Increase Attendance (n = 2), Plant Trees (n = 8), Maintenance (n = 12), Continuing Education (n = 1), Increase Program Offerings (n = 2), Strategic Planning (n = 4), Plant Garden (n = 10), Improve Communication with Visitors (n = 5), Improve Facilities (n = 2)). Only respondents who reported not having short-term goals were asked about their interested in developing short-term goals (N = 5); 60% of respondents express slight interest (n = 3). The remaining 40% (n = 2) were not at all interested.

2.3.h Financial Management

25% of respondents (n = 8) do not have a budget. Of those who did have a budget, 43.8% (n = 7) have a budget up to $1,000; 18.8% (n = 3) have a budget up to $5,000; 12.5% (n = 2) have a budget up to $10,000; 12.5% (n = 2) have a budget up to $25,000; 6.3% (n = 1) have a budget up to $50,000; and 6.3% (n = 1) have a budget up to $100,000. Seventy-three-point one percent of respondents (N = 26) do not have an annual revenue stream. The 7 respondents with a revenue stream were asked the amount of money coming from different common revenue

sources with a Likert scale with: 1 (not at all), 2 (a little), 3 (some), 4 (a fair amount), and 5 (a lot) (Table 2.13). The mean value of each figure can be found in Table 2.13. At least 88.5% of respondents (N = 26) expressed interest in additional financial assistance to support their current arboretum efforts. Half of respondents answered very interested (n = 5) or extremely interested (n = 8).

2.3.i Arboretum Offerings

96.2% of respondents (N = 26) expressed interested in getting assistance identifying ecosystem services to validate arboretum benefits. 92.3% of respondents (N = 26) expressed interested in reporting changes in tree health at their arboretum as an early alert of pests or diseases. Of those interested in reporting on their trees' health (N = 24), 83.3% (n = 20) identified as needing help learning about tree health and pest identification to begin reporting changes in tree health. Those who were not interested in reporting tree health information (N = 2) described their reasoning as lack of knowledge and lack of applicability for their facility.

2.3.j COVID-19 Pandemic Impact

69.2% of respondents (N = 26) reported their arboretum being in some way effected by the COVID-19 pandemic. Those affected rated the impacts as slightly affected (34.6%, n = 9), moderately affected (30.8%, n = 6), greatly affected (7.7%, n = 2), and extremely affected (3.8%, n = 1) (Table 2.14). All respondents (N = 26) reported staying open throughout the pandemic. Three-point eight percent of respondents (n = 1) changed their hours of operation after the pandemic began. Hours of operation have returned to normal for this facility. Seven-point seven percent of respondents (n = 2) limited visitor attendance at some point during the pandemic. Nineteen-point two percent of respondents (N = 26) report that pandemic restrictions inhibit school groups from visiting. Most respondents (92.3%, n = 24) reported that they did not

Table 2.13

*Arboreta Revenue Stream Sources*

| | N | Minimum | Maximum | Mean |
|---|---|---|---|---|
| Fundraisers | 7 | 1 | 5 | 2.86 |
| Other Source | 3 | 1 | 4 | 2.67 |
| Donations | 7 | 1 | 5 | 2.57 |
| Endowment Fund | 7 | 1 | 5 | 2.43 |
| Other Source | 2 | 1 | 3 | 2.00 |
| Merchandise Sales | 7 | 1 | 4 | 1.71 |
| Grants | 7 | 1 | 2 | 1.57 |
| Workshop/Seminar Fees | 7 | 1 | 2 | 1.14 |
| Ticket Sales | 7 | 1 | 1 | 1.00 |

make any accommodations or restrictions during the pandemic that were still in effect. One respondent reported that their indoor restrooms were closed and portable toilet facilities were currently in use as an accommodation for the COVID-19 pandemic. Forty-eight percent of respondents (N = 25) believe the pandemic did not alter their attendance (Table 2.15). 32% (n = 8) believe the pandemic increased attendance. Twenty percent (n = 5) believe the pandemic decreased their attendance.

2.3.k Additional Respondent Comments

Written responses were submitted by 8 participants and encoded to a table in Appendix E. Categories included: Desire to Increase Visitor Educational Offerings (n = 2), Desire to Improve Facilities (n = 2), Desire to Improve Technology (n = 3), COVID-19 Pandemic Comment (n = 2), Ease of Certification Process (n = 2), Difficulty with Certification Process (n = 2), Desire for Better TUFC Communications (n = 1), Visitor Restrictions (n = 1), Satisfaction with TUFC (n = 3), Financial Hardship (n = 1), and Satisfaction with TAEP Grant (n = 1).

2.3.l Crosstabulations

All crosstabulation results are available in Appendix F. Of the arboreta that have a board of directors, 80.0% (n = 12, N=15) host educational events such as workshops and classes. Of the arboreta that do not have a board of directors, only 46.2% (n=6, N=13) host educational events. 0.114. The results of the chi square test are $X^2 = 3.475$, df=1, p=0.114. No statistical significance was found. The size of the arboretum does not impact whether educational events are hosted (U = 0.341, p = 0.141).

Of the arboreta that have a board of directors, 46.7% (n = 7, N = 15) offer guided nature tours. Of the arboreta that do not have a board of directors, only 38.5% (n = 5, N = 13) offer guided nature tours. The results of the chi square test are $X^2 = 0.191$, df = 1, p = 0.718. No

Table 2.14.

*Respondents' Perceived Impact of the COVID-19 Pandemic on Arboretum*

| | Frequency | Percentage |
|---|---|---|
| None at All | 8 | 30.8 |
| Slightly Effected Arboretum | 9 | 34.6 |
| Moderately Effected Arboretum | 6 | 23.1 |
| Greatly Effected Arboretum | 2 | 7.7 |
| Extremely Effected Arboretum | 1 | 3.8 |
| Total | 26 | 100.0 |

Table 2.15.

*Ways the COVID-19 Pandemic Altered Attendance at Arboretum*

| | Frequency | Percentage |
|---|---|---|
| Increased attendance | 8 | 32.0 |
| Decreased attendance | 5 | 20.0 |
| No change in attendance | 12 | 48.0 |
| Total | 25 | 100.0 |

statistical significance was found. The size of the arboretum does not impact whether guided nature tours are offered (U = 35.000, p = 0.126).

Respondents' interest in learning about ecosystem service benefits does not differ based on whether they have a board or not (t = -0.627, df = 24, p = 0.536). There was no significant correlation between size of the arboretum and interest in the ecosystem service benefits program (rho=0.341, p=0.141).

Respondents' interest in reporting tree pests and diseases does not differ based on whether they have a board or not (t = 0.723, df = 24, p = 0.477) or the size of the arboretum (rho = -0.017, p = 0.943).

Of the arboreta that have a board of directors, 60.0% (n = 9, N = 15) have a tree and vegetation maintenance plan. Of the arboreta that do not have a board of directors, 69.2% (n = 9, N = 13) have a tree and vegetation maintenance plan. The results of the chi square test are $X^2$ = 0.258, df = 1, p = 0.705. No statistical significance was found. The size of the arboretum does not correlate to having a vegetation maintenance plan (U = 38.500, p = 0.238).

Of the arboreta that have a board of directors, 28.6% (n = 4, N = 14) have a written organizational master plan. Of the arboreta that do not have a board of directors, 15.4% (n = 2, N = 13) have a written organizational master plan. The results of the chi square test are $X^2$ = 0.678, df = 1, p = 0.648. No statistical significance was found. The size of the arboretum does not correlate to having a written organizational plan (U = 9.000, p = 0.080).

Of the arboreta that have a board of directors, 66.7% (n = 10, N = 15) have organizational long-term goals. Of the arboreta that do not have a board of directors, only 30.8% (n = 4, N = 13) have organizational long-term goals. The results of the chi square test are $X^2$ = 3.590, df = 1, p =

0.128. No statistical significance was found. The size of the arboretum does not correlate to having long-term goals (U = 56.500, p = 0.797).

100% of respondents with a board of directors have short term goals (n = 13, N = 13). Only 61.5% of respondents who do not have a board of directors have short term goals (n = 13, N = 13). The results of the chi square test are $X^2 = 6.190$, df = 1, p = 0.039 (exact significance 0.039). Those with a board of directors are more likely to have short term goals. The size of the arboretum does not impact whether they have short-term goals (U = 22.000, p = 0.765).

Having a board of directors does not impact the size of the aboretum's budget (U = 63.000, p = 0.649). There is a relationship between annual budget and the size of the arboretum in acres (rho=0.606, p=0.008). As the size of the arboretum increases, the annual budget tends to increase.

Of the arboreta that have a board of directors, 38.5% (n = 5, N = 13) have an annual revenue stream. Of the arboreta that do not have a board of directors, only 15.4% (n = 2, N = 13) have an annual revenue stream. The results of the chi square test are $X^2 = 1.759$, df = 1, p = 0.378. No statistical significance was found. The size of the arboretum does not impact its revenue stream (U = 19.000, p = 0.062).

Of the arboreta that have a board of directors, 31.3% (n = 5, N = 16) are located in the East Region, 25.0% (n = 4, N = 16) are located in the Middle Region, and 43.8% (n = 7, N = 16) are located in the West Region. Of those who do not have a board of directors, 23.1% (n = 3, N = 13) are located in the East Region, 46.2% (n = 6, N = 16) are in the Middle Region, and 30.8% (n = 4, N = 16) are in the West Region. The results of the chi square test are $X^2 = 1.423$, df = 1, p = 0.585. No statistical significance was found. The size of the arboretum is not impacted by the region in which it is located (KW = 2.945, df = 2, p = 0.229).

2.3.m Limitations

This study was limited to representatives of arboreta that were actively certified through the TUFC. A survey of this type had never been attempted. The results cannot be generalized to arboretum representatives in other states. With over a 56% response rate, findings of this study are valid and applicable only to representatives of TUFCCA. In future studies, the sample population could be done on a state, national, or international level. The latter increases external validity with the expansion of generalizability to all arboretum representatives.

## 2.4 Discussions and Recommendations

Results suggest that TUFCCA managers are interested in expanded offerings from TUFCCA management and illustrate the need for a formal arboretum manager training program. A net benefit is provided to participants and communities from leadership programs (Tuck et al., 2020). Graduates of the Municipal Forestry Institute's continuing education course experienced measurable impacts and outcomes on participants personal and professional lives (Ries, 2019). Arboretum managers who do not currently host educational workshops or guided nature tours say they do not have time to organize the events. TUFC can implement uniform community outreach educational workshop materials focusing on managers who have expressed interest in learning. A large majority of respondents expressed some level of interest in getting help with tree care and maintenance planning.

The Human Relations Management Theory highlights how interacting with employees and allowing them to feel seen and heard motivates them to perform at a higher level (Anteby and Khurana, n.d.). While arboreta managers are the respondents of the survey, in this situation it is proposed that the arboreta managers are viewed more as employees of a greater organization, the Tennessee Urban Forestry Council. At present, the arboretum managers may or may not be

implementing strategic planning or investing in outreach operations at their facilities in general. Once the "employees" become aware of the interest in their facilities through participating in the survey, the Hawthorne Effect has begun (Anteby and Khurana, n.d.). Three- and five-year survey follow-up interviews can determine if attention to certified arboreta results in better community engagement.

Having consistent arboreta education initiatives is a logical way to reach land owners so they can make decisions with their forested lands that produce optimal benefits for the environment and our communities. Visitor surveys can be completed before and after arboretum manager training events to learn about the impacts of changes in arboretum offerings and manager training.

## 2.5 Conclusions

TUFCCA managers are interested in learning more about strategic planning, urban forest ecosystem service benefit evaluation, and tree disease and pest identification. The broader societal value of this study is ultimately the improvement of arboreta facilities in Tennessee. TDF and TUFC can work to streamline a planning process and formal training for its certified arboreta. This will ultimately lead to increased arboreta attendance and enriched visitor experiences across the state. Getting more people into the urban forests of their communities improves the welfare of humanity.

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# CHAPTER THREE

# USING SPATIAL ANALYSIS TO DETERMINE ARBORETUM ACCESSIBILITY: A TENNESSEE CASE STUDY

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**Abstract**

The Tennessee Urban Forestry Council (hereafter TUFC) manages an arboretum certification program for organizations and individuals in Tennessee. TUFC's vision for the arboretum program is to increase accessibility to arboreta, ensuring there is a TUFC certified arboretum within a 30-minute drive of every Tennessee community. ArcGIS Pro was used to determine accessibility and conduct generalized linear regression analysis. More than one third of Tennessee communities need arboretum accessibility assistance through outreach and promotion of arboretum establishment near these areas. As accessibility to arboreta increases, communities are more densely populated, are more racially diverse, have higher income, and have lower percentage of forested land cover.

*Keywords*: urban forest(ry), spatial analysis, arboretum accessibility, arboreta, urban forest facilities, forest accessibility, tree equity

## 3.1 Introduction

Arboreta are an important component of the urban forest that provide biological, communal, and ecosystem service benefits to communities (Wassenberg et al., 2015; O'Brien, 2018; Vujcic and Tomicevic-Dubljevic, 2018; Cavender and Gerard, 2019, Turner-Skoff and Cavendar, 2019; Stevenson et al., 2020). Effective and proper management can provide outdoor education facilities to disseminate urban forest information to visitors (USDA ARS, 2023). The "Urban Forests Act of 2021" introduced to the U.S. House of Representatives, prioritized the management of urban forest natural resources (United States Congress, 2021). Specifically, the act stated, "1) *identify strategies to increase equitable access to urban forests through existing programs and authorities; 2) coordinate existing forestry programs; 3) conduct research on benefits of urban forests for air quality, heat island mitigation, energy burden reduction, and enhanced shading for heat-resilient housing and active transit; and 4) conduct research on improving coordination between the agencies to address insects, disease, and non-native invasive species in urban and community areas*." In addition, the "Infrastructure Investment and Jobs Act" establishes the "Healthy Streets program" which will provide grants to expand tree canopy coverage with an emphasis on use in underserved communities (United States Congress, 2021.) Focus on equitable distribution of urban forest natural resources has come to the forefront of national legislation recently with the Inflation Reduction Act of 2022 that includes the Neighborhood Access and Equity Grant Program (United States Congress, 2023). Specific to the state of Tennessee, the Tennessee Forest Action Plan for 2020-2030 highlights 1) Enhancing Forest Health and Resiliency, 2) Expanding Market Diversification, 3) Maintaining and Improving Connected Landscapes, and 4) Strengthening Wildlife Resistant Communities as their Tennessee Forest Objectives (Tennessee Department of Agriculture, 2020).

Arboreta across the state of Tennessee exist in densely populated areas, and offer sociological and biological benefits to the communities in which they are located (Wassenberg et al., 2015; O'Brien, 2018; Vujcic and Tomicevic-Dubljevic, 2018; Cavender and Gerard, 2019). The Tennessee Urban Forestry Council (TUCF) was established in 1991 with the mission to inspire and empower people to plant, grow and sustain healthy urban and community forest." (TUFC, 2023). For more than twenty years, TUFC has collaborated with the Tennessee Division of Forestry (TDF) to manage the statewide arboretum certification program. Through this partnership, TDF and TUFC established a vision- to have a certified arboretum within a 30-minute drive of all Tennessee communities (TUFC, 2023). This study will assess the current accessibility of arboreta in Tennessee communities; and conduct generalized linear regression with socioeconomic and land cover data of Tennessee communities in proximity to the arboreta.

## 3.2 Methodology

Tree equity can be measured in different ways. For the purpose of this study, Tennessee community proximity to TUFCCA is a measure of urban forest facility accessibility. An address list of TUFCCA was input as map points in ArcGIS OnLine that were analyzed with various demographic and land cover data. The hypothesis was that many Tennessee communities would be located more than a 30-minute drive from a TUFCCA. Spatial analysis was completed using ArcGIS Pro to identify underlying factors that impact arboreta accessibility.

### 3.2.a Study Area

The study area is the state of Tennessee in the United States of America. TUFFCCA includes all arboreta in the state currently certified by the Tennessee Urban Forestry Council.

3.2.b Map Layers and Demographics

GIS data was obtained from Environmental Systems Research Institute (ESRI), National Land Cover Database (NLCD) and the TUFC, each representing the best available source of the geographic information.

*Community Location Data*

A community has been defined as "a group of people with diverse characteristics who are linked by social ties, share common perspectives, and engage in joint action in geographical locations or settings" (MacQueen, 2001). For the purpose of this methodology, Tennessee "communities" were given parameters using Topologically Integrated Geographic Encoding and Referencing system (TIGER) Line 2018 Places shapefile, sourced from the United States Census Bureau and identified by the Tennessee State Data Center. These communities are highlighted in orange over a grayscale base map of Tennessee (Figure 3.1). These Census Designated Places (CDP) are not legally incorporated under the laws of Tennessee, but rather are settled concentrations of population that are identifiable by name. Local partners work with the Census Bureau to define CDP boundaries as part of the Participant Statistical Areas Program. The metadata standard used for this data set was ISO 19139. All Census Bureau generated shapefiles are in Global Coordinate System North American Datum of 1983 (GCS NAD83).

*TUFCCA*

TUFC provided an excel sheet with certified arboreta names and location information (Appendix F).

*Demographic Data*

The human data used in this study were population density, median household income, and diversity index. All demographic data was obtained from ESRI and available on ArcGIS.

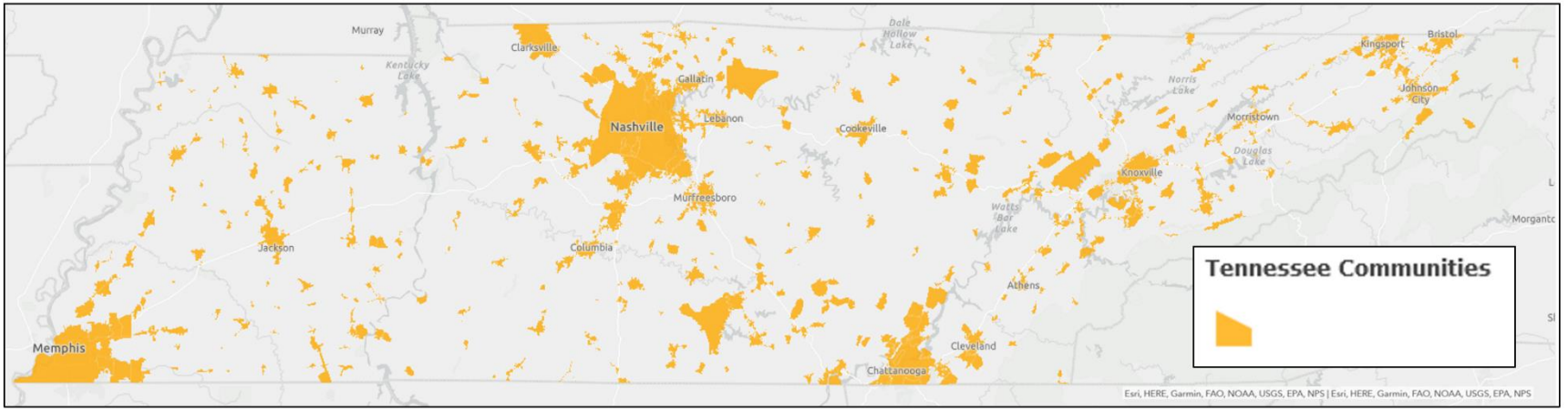



*Figure 3.1. Geographic Boundaries of Tennessee Communities*

The population density is an estimate of total population within the geographic area divided by the total land area, measured in square miles. Median household income is the amount that divides household income of each household earner (aged 15 years or more) into two groups, with half the population having a higher income than median, and the other half having a lower income than median. The diversity index is a summary of racial and ethnic diversity, which indicates the likelihood that any two individuals who are chosen at random from the same area would belong to the same race or ethnic group. This value ranges from 0 (no diversity) to 100 (highest diversity).

*Land Cover Data*

Land cover data was obtained from NLCD, supplied through ESRI Living Atlas (MRLC 2022). NLCD generates products through the Multi-Resolution Land Characteristics Consortium (MRLC). The MRLC Consortium is a large partnership of federal agencies including the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency, the U.S. Department of Agriculture, the U.S. Forest Service, the National Park Service, the U.S. Fish and Wildlife Service, the Bureau of Land Management and the USDA Natural Resources Conservation Service. Although it is described as having information “to present”, the most recent data available is 2019. Unsigned Char is the pixel type utilized. The cell size is 30 / 30 meter. The spatial reference information for the NLCD is North America albers projection. Developed land cover percentage and forest land cover percentage were the land cover classes used for this study.

3.2.c GIS Analysis

The list of TUFCCA addresses was turned into points in ArcGIS Online (Figure 3.2). In order to define the area within a 30-minute drive of all the arboretum points, a feature layer was

generated by running the Summarize Within solution. The arboreta addresses were summarized (Figure 3) within Travel_from_Centroids_for_TIGER_Line_2018_Places_(30_Minutes).
The Tennessee communities' layer was enriched with center point locations to create a consistent starting travel point in each community (Figure 3.3). Next, a feature layer was created from running the Create Drive Times Areas analysis. This layer displayed a 30-minute driving area away from the center point of each Tennessee community. The final feature layer was generated by running the Summarize Within analysis to determine which communities were less than an estimated 30-minute drive from any TUFCCA. The "Arboretum" data set (the list of TUFCCA addresses) was summarized within Travel_from_Centroids_for_TIGER_Line_2018_Places_(30_Minutes) to create the map layer "Communities that are within a 30-minute drive to TUFCCA" (Figure 3.4). This data was exported as an excel file and saved as a CSV. The map layer "Communities that are within a 30-minute drive to TUFCCA" was enriched with the CSV. The Join Features analysis was used by matching the unique GEOID values for the communities of each layer. Last, the map was styled to show all communities outside a 30-minute drive in burnt orange and all communities within a 30-minute drive in bright green (Figure 3.5).

3.2.d Variables of Arboretum Accessibility Spatial Analysis

Spatial statistical analysis was used in ArcGIS Pro to discover relationships between arboretum accessibility in Tennessee and other related factors. The dependent variable was the "Count of Points" value that represents the number of arboreta within a 30-minute drive of the community's center point. The explanatory variables used were median household income, population density, diversity index, and forested land cover. The variables were analyzed using a generalized linear regression (GLR) count Poisson model.




*Figure 3.2 Tennessee Urban Forestry Council Certified Arboreta Locations*

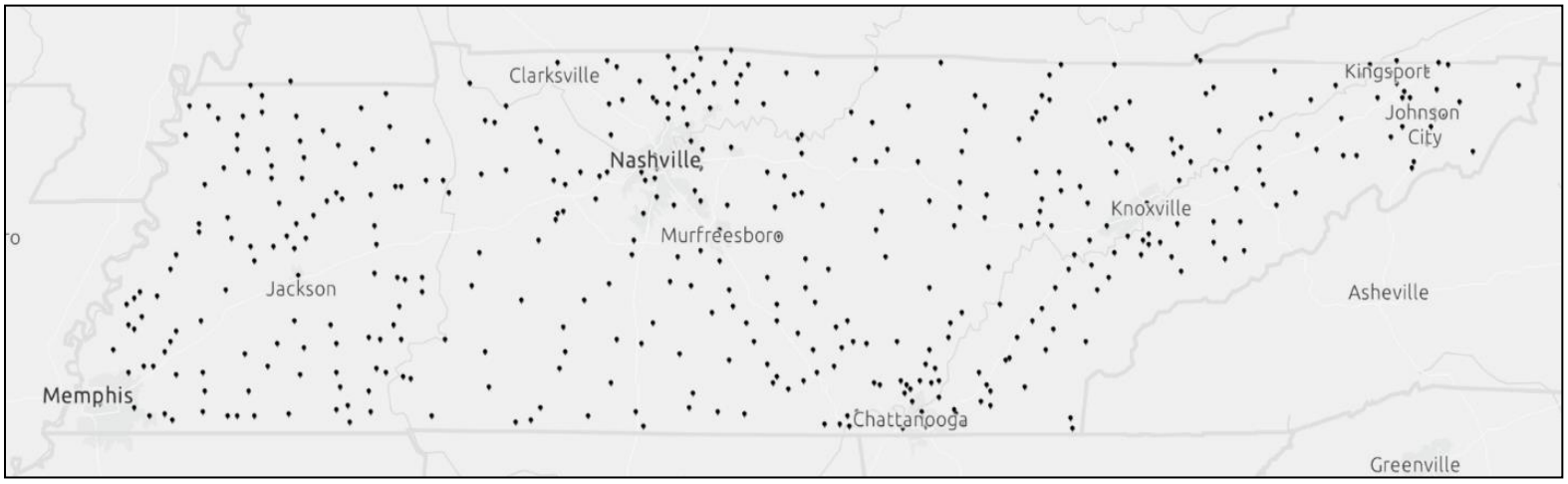



*Figure 3.3. Tennessee Community Center Points*

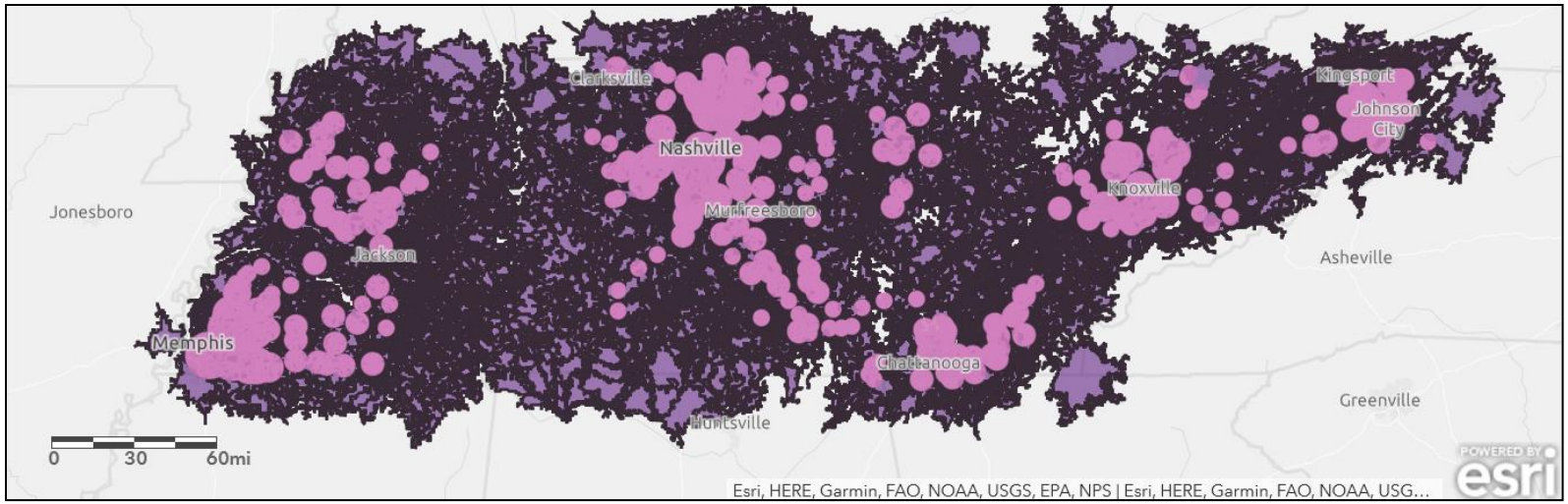



*Figure 3.4. Communities that are within a 30-minute drive to TUFCCA*

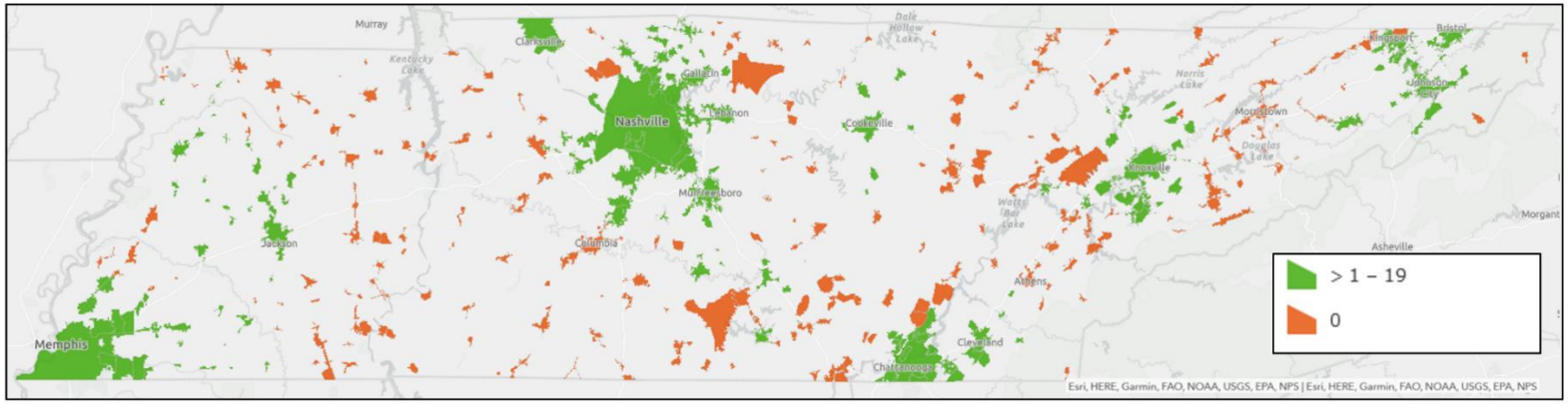



*Figure 3.5. Tennessee Communities with and without Access to TUFCCA*

## 3.3 Results

There are 429 communities total in Tennessee. Analysis of the data show that 167 (38.93%) Tennessee communities' central points are located more than a 30-minute drive from any TUFC certified arboretum (Appendix H). Figure 4 shows increasingly large pink dots for each community whose center point was within a 30-minute drive to one or more TUFCCA. Pink dots are concentrated over urban centers Memphis, Jackson, Clarksville, Nashville, Murfreesboro, Cookeville, Chattanooga, Knoxville, Johnson City and Kingsport.

### 3.3.a Generalized Regression Analysis Results

There was no statistical significance between the three grand regional divisions (East, Middle, and West) when examining variables of the size of arboreta when looking at both their levels of certification and the number of arboreta in each region. The GLR relationship values between Count of Points and explanatory variables were 0.47 (median household income), 0.77 (population density), 0.61 (diversity index), and -0.22 (forested land cover). The $X^2$ is -1.137 with 4 degrees of freedom and p=0.000000, showing statistical significance. As accessibility to TUFCCA increased, areas were more densely populated, more racially diverse, had higher income, and had lower forested land cover percentage.

## 3.4 Discussion

Densely populated areas in Tennessee are the areas with the most TUFCCA accessibility. More accessibility to arboreta being correlated to more urbanicity is logical as the focus of TUFC is urban forests. With the ever-increasing population of Tennessee, more rural land is being developed and urbanized (TN State Data Center, 2022). Since arboretum accessibility is positively correlated to areas with higher income, densely populated areas with lower income should be given priority for arboretum establishment in the future. GIS analysis creates

comprehensive outdoor education site selection processes, reducing excessive choices to specific options that suit the project's needs (Morgan and Barlow, 2019). The need for both objective and subjective measures has been recommended to understand and plan for the equitable distribution of high-quality parks with diverse users (Larson et al., 2022).

### 3.5 Conclusions

The results of this study show that the Tennessee Urban Forestry Council is more than halfway to their goal of having a certified arboretum within a 30-minute drive of every community in Tennessee. Board members for the Tennessee Urban Forestry Council can use this analysis to focus their efforts on community outreach in strategic areas within the 167 communities that lack accessibility. Further analysis can be done to determine specific areas that would be optimal geographic locations for future certified arboreta so that the least amount of certified arboreta additions can impact the most amount of Tennessee communities. Variables to consider would be the number of communities that would gain accessibility to a TUFC certified arboretum with each additional location, the population of the communities, economically disadvantaged communities, and communities that are the greatest distance from any TUFC certified arboretum.

### Acknowledgements

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# CHAPTER FOUR

# SPATIAL MODELING OF URBAN HEAT ISLANDS AND TREE EQUITY IN TENNESSEE

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**Abstract**

In recent decades, Urban Heat Island Effects have become more pronounced and more widely examined. Despite great technological advances, our current societies still experience great spatial disparity in urban forest access. Urban Heat Island Effects are measurable phenomenon that are being experienced by the world's most urbanized areas, including increased summer high temperatures and lower evapotranspiration from having impervious surfaces instead of vegetation and trees. Tree canopy cover is our natural mitigation tool that absorbs sunlight for photosynthesis, protects humans from incoming radiation, and releases cooling moisture into the air. Unfortunately, urban areas typically have low levels of vegetation. Vulnerable urban communities are lower-income areas of inner cities with less access to heat protection like air conditioners. This study uses mean evapotranspiration levels to assess the variability of urban heat island effects across the state of Tennessee. Results show that increased developed land surface cover in Tennessee creates measurable changes in atmospheric evapotranspiration. As a result, the mean evapotranspiration levels in areas with less tree vegetation is significantly lower than the surrounding forested areas. Central areas of urban cities in Tennessee had lower mean evapotranspiration recordings than surrounding areas with less development. This work demonstrates the need for increased tree canopy coverage.

*Keywords:* Spatial analysis; Land cover; Urban Heat Island Effect (UHIE); Evapotranspiration; Tree Canopy; Impervious Surface; GIS Prediction Model; GIS Machine Learning

## 4.1 Introduction

### 4.1.a Urban Heat Island Effect

Urban areas are hot! Data from 1985 - 2018 in the conterminous Unites States shows the differences in land surface temperature (LST) between urban and nonurban areas are increasing (Xian, 2021). This phenomenon of highly populated areas with mostly impervious surface cover having higher temperatures than surrounding rural areas is known as the Urban Heat Island Effect (UHIE). UHIE is caused by developed areas having less vegetation and bodies of water to provide shade and cooling evapotranspiration; more impervious surfaces that absorb and emit the sun's heat; decreased air flow from metropolitan building configurations, anthropogenic heat from vehicles, buildings, and industrial operations; and any time calm, clear weather allows solar energy to reach urban areas and remain unless strong winds move the stagnant air (United States Environmental Protection Agency (US EPA[1], 2022). A 20-year study showed there is a significant positive exponential relationship between impervious surfaces and land surface temperature (Xu et al., 2013). Data analysis from eastern China shows that the bigger the urban agglomeration, the greater the UHIE (Chen et al., 2020). International LST data analysis confirms that UHIE is a global issue (Yamamoto and Ishikawa, 2019; Portela et al., 2020; Knight et al., 2021; Shahfahad, 2022). The intensification of UHIE can be countered by increasing tree canopy coverage, which can have a greater magnitude cooling effect than impervious cover has heating effect (Wang et al., 2019). Evapotranspiration is recognized as an indicator for agricultural, ecological, and water resources management practices (Mmbando and Kleyer, 2018).

According to the National Centers for Environmental Information, "The nine years spanning 2013 through 2021 rank among the 10 warmest years on record" (Lindsey and

Dahlman, 2021). While the increased heat of UHIE is impactful for humans during the day, the real noticeable difference is felt at night. After the sun has set, impervious surfaces in cities slowly release the heat of the day. As days go by in spring and summer, this lingering heat begins to compound. Each day begins at a higher temperature which increases the overall heat in these areas. Differences in temperature may vary by as much as 12.2 °C (22 °F) and are notably higher when an urban area has less green space and more impervious surfaces. The UHIE is not just compounding over the course of days, each year as ground cover transitions to more impervious surfaces, the intensity of this phenomenon is increasing (Sultana and Satyanarayana, 2020). Further, heat waves can intensify night UHIE, which could be explained by increased surface solar radiation (Jiang et al., 2019). With expected rising urban populations, independent extreme heat events are predicted to increase and become compounded, with the greatest impact being seen in urban areas (Liao et al., 2021; Wang et al., 2021).

Heat islands contribute to higher daytime temperatures, reduced nighttime cooling, and higher air-pollution levels. These, in turn, contribute to heat-related deaths and heat-related illnesses such as: general discomfort, respiratory difficulties, heat cramps, heat exhaustion, and non-fatal heat stroke (U.S. EPA[2], 2022). Vulnerable populations are also at risk of worsening mental health during extreme heat events (American Psychiatric Association, 2021). Worst of all, from 2004-2018, the United States Center for Disease Control counted an average of 702 heat related deaths each year (U.S. CDC, 2022). Heat was the top, weather-related cause of fatalities in the United States in 2021 (National Weather Service[1], 2022). Because of their relative surface area and rate of metabolism, children are at a higher risk than adults of overheating (U.S. EPA[3], 2022). Lack of tree cover or appropriate shade can impact outdoor recreation. A study showed the highest surface temperatures in Phoenix, Arizona were found on

children's recreational playground equipment (Vanos et al., 2016). Playground steps made out of black powder coated metal were recorded at over 57°C (136°F).

With dangerously high temperatures, humans rely on air conditioners and fans to keep themselves safe and comfortable, with United States government advisement precautioning the strongest protective factor against heat-related illness is air conditioning (National Weather Service[2], 2022). Heat islands increase both overall electricity demand, as well as peak energy demand. Peak demand generally occurs on hot summer weekday late afternoons, when offices and homes are running air-conditioning systems, lights, and appliances (Pennsylvania-New Jersey-Maryland Interconnection, 2020). During extreme heat events, which are exacerbated by heat islands, the increased demand for air conditioning can overload systems and require a utility to institute controlled, rolling brownouts, which are named for the decreased energy causing lights to dim or blackouts that completely turn off power to avoid or are a result of power outages (Auffhammer et al., 2017). The increased energy consumption during extreme heat leads to elevated emissions of air pollutants and greenhouse gases, which contribute to more ground level ozone (U.S. EPA[2], 2022). The viscous cycle is complete as this smog is a contributing factor of more UHIE.

Despite the worldwide nature of UHIE and severe impact it is having on a large number of people, the design of much-needed mitigation procedures is still mostly in the development phase (Shen et al., 2022; Bosch et al., 2020; Susca and Pomponi, 2020). Five factors that contribute to the UHIE are: increased anthropogenic heat (which is heat that is generated by humans, such as buildings, cars, industrial processes, or humans themselves), reduced evaporation, increased heat storage, increased net radiation, and reduced convection (Gartland, 2012). While green and cool roofs can create substantial improvement of universal thermal

climate index at the roof surface level, there is not substantial improvement of human thermal comfort at pedestrian level (Imran et al., 2018). Although cool pavement coating applied to asphalt decreased surface temperature, it also decreased human thermal comfort because the mean radiant temperature was higher as a result of increased net radiation (Anand and Sailor, 2021). Permeable pavement is a promising development for its evaporative cooling effects in wet conditions; unfortunately, during dry conditions, it is hotter than traditional asphalt (Buyung and Ghani, 2017). Permeable pavements' primary thermal mitigation function is thermal evaporation in windy conditions (Wu et al., 2017). Strategically designed tree and vegetation planting efforts in urban areas provide shade and evapotranspiration that effectively reduce LST (US EPA[4], 2022). Variables such as having grass or asphalt beneath trees, different sized trees, tree crown density, leaf shape, etc. all change the impact of urban green spaces on UHIE (Rahman et al., 2020). Benedict and McMahon (2006) define green infrastructure as "a strategically planned and managed network of wilderness, parks, greenways, conservation easements, and working lands with conservation value that supports native species, maintains natural ecological processes, sustains air and water resources, and contributes to the health and quality of life for America's communities and people." The lengthy description is warranted by the multi-faceted, comprehensive approach that must be explored with all that is encompassed by green infrastructure.

In contrast, gray infrastructure typically consists of manmade functional elements that provide a service to the environment and community. This type of impervious surface cover has inadequate vegetative cover to stabilize consequences of unsustainable land use practices like general low tree canopy coverage in urban areas. Nashville, Tennessee has already committed to supporting the urban forest with an ordinance to establish a dedicated revenue stream for the

restoration and maintenance of the city's tree canopy (Nashville Mayor's Office, 2021). With the development of green infrastructure to mitigate UHIE in areas who are most impacted and typically considered disadvantaged, socioeconomic benefits include decrease of anthropogenic energy usage and emissions creation. General community health and wellness will improve with water cycle normalization and less extreme heat wave events.

Studies surrounding anthropogenic climatological changes and their impacts on urban areas have increasingly become the focus of Tennessee research to address the many gaps in knowledge for this area, but are still limited in comparison to larger cities (Shepherd et al., 2002; Hass et al., 2016; Ellis et al, 2017; Howe et al., 2017; Tirpak et al., 2018; Hass et al, 2022; Gichuhiend and Gamage, 2023). Unlike most UHIE studies, evapotranspiration was the focus of this research, instead of temperature. The increase of evapotranspiration in cities, using vegetation, urban agriculture, and bodies of water has been accepted as an effective mitigation tool against urban heat islands (Qiu et al., 2013). Evapotranspiration is the most significant component of the hydrological budget after precipitation (Hanson, Ronald, 1991). Urban parks have been found to have a greater average cooling efficiency than surrounding impervious surfaces (Blachowski and Hajnrych, 2021).

4.1.b Tree Equity

Tree equity dialogue is an up and coming trend that began emerging and receiving attention in the last 15 years, that inequality exists in vegetation cover based on variables such as average income and race (Memon, 2009). Spatial analysis reports support that areas of lower income are feeling greater heat (Anderson and McMinn, 2019). The concept of tree equity is best simplified as a mission to ensure there are trees in every part of every city (American Forests[1], 2022). This theory is supported in many urban areas with analysis of land cover data maps with

census tract information for income and race. American Forests defines the goal of tree canopy coverage, based off natural biome baseline targets they selected in conjunction with the United States Department of Agriculture Forest Service, as 40% in forested areas, 20% in grasslands, and 15% in deserts (American Forests[2], 2022).

An assessment of spatial distribution of a heat wave in Richmond, Virginia showed areas occupied by minority groups and people of low socioeconomic status disproportionately experienced extreme heat, in addition to the corresponding impacts of their quality of life and health (Saverino et al., 2021). People living in a condition of socioeconomic disadvantage (in terms of higher education and income) are those effected the most by urbanization diseconomies when compared to those living in the same condition of socioeconomic disadvantage who are living in a rural setting (Lenzi and Perucca, 2022). In this study, it was noted that affluent individuals with higher education were able to take advantage of the many industries housed in large cities while people with lower socioeconomic status instead experienced the costs of urbanization. Extreme heat vulnerability is reduced by higher income and intensified by poverty (Lim and Skidmore, 2020).

There are consequences of tree inequity, and one of the most noticeable and measurable phenomena is the direct temperature effects of tree canopy cover. An increase of tree canopy coverage is connected to a lower summer average temperature, which has health implications for those who reside in areas with less tree canopy coverage. Children and elderly residents are populations who are more at risk of health complications resulting from extreme high temperatures. In addition, since energy consumption is greater in these areas, those at a lower socioeconomic status feel the demand for air conditioning the greatest.

The National Oceanic and Atmospheric Administration, in partnership with fourteen cities and counties, is actively mapping heat inequities across communities (Schmitz and Thomas, 2022). Knoxville, Tennessee was chosen to participate, and these efforts will form a collaborative network that includes researchers, city government officials, nonprofit organizations, students, and community members, Knoxville Heat Equity Coalition, is working to raise awareness about heat risk, educate about heat adaptation and mitigation strategies, and provide research.

American Forests' Tree Equity Score tool uses land cover and census data to allow analyzing the data with many different variables, including income, employment, race, health, age, and population density (American Forests[1], 2022). Tree Equity Score users can observe the lowest tree equity score by percentage of elderly residents, children, people of color, income and historically redlined areas (where date is available). Tree equity can be measured in different ways. For the purpose of this study, tree equity will be examined with mean evapotranspiration levels in Tennessee with median household income and residents with central air conditioner.

The objective of this paper is to investigate trends between Tennessee land cover, evapotranspiration, and socioeconomic factors of residents living within highly populated urban areas (Appendix I). Specifically, the relationship between urban heat islands and tree equity will be explored. Spatial and statistical analysis was conducted on existing data sets to quantify the urban heat island effect in Tennessee. The proposed hypothesis is that areas that are predominantly impervious surface cover will have lower mean evapotranspiration readings and lower-income areas are communities that are vulnerable to UHIE in comparison to medium- and higher-income areas in urban and rural settings and lower-income areas in rural settings.

## 4.2 Materials and Methods

### 4.2.a Study Area

This study focuses on the area inside the political boundary of Tennessee in the United States of America, focusing on urban areas. The term "urban area" is defined as urbanized areas of 50,000 or more humans in the population and urban clusters of at least 2,500 but no more than 50,000 humans in the population (United States Bureau of the Census, 2010). Tennessee is home to twelve urban areas (Table 4.1.) that are differentiated from rural areas because they each have a population of more than 50,000 humans (Robert M. Groves, 2011).

Data changes from 2000 to 2010 shown in Table 4.2 confirm an overall trend of steady growth for all but one reported urban area (United States Bureau of the Census, 2010). Urbanization has impacted land cover in Tennessee (Figure 4.1). Aside from the majority of land being forested, a large area of West Tennessee is cropland, and Middle and East Tennessee both have areas of pasture and cropland. Overall, clumps of red signify development and increased impervious surface amongst a predominantly forested land cover.

### 4.2.b Data Acquisition and Manipulation

*Population Data*

The human data used in this study was median household income and population data, both obtained from the 2020 American Community Survey (ACS) 5-year data set (2018-2022) (ArcGIS, 2022). The U.S. Census defined poverty thresholds in 2021 as annual incomes lower than $13,788 for one person, $17,529 for two people, and $21,559 for three people (U.S. Census, 2022). Thresholds are defined in increments of one person up to nine people or more in the family. Values vary slightly for the number of children accounted in the household total. The population layer has been symbolized by ESRI to show the percentage of the population whose

Table 4.1.

*Tennessee Urban* Areas by Population* (Tennessee Department of Health, 2022)

| Rank | City | County | 2015 Estimate |
|---|---|---|---|
| 1 | Memphis | Shelby | 655,780 |
| 2 | Nashville | Davidson | 654,610 |
| 3 | Knoxville | Knox | 185,291 |
| 4 | Chattanooga | Hamilton | 176,588 |
| 5 | Clarksville | Montgomery | 149,176 |
| 6 | Murfreesboro | Rutherford | 126,118 |
| 7 | Franklin | Williamson | 72,639 |
| 8 | Jackson | Madison | 66,975 |
| 9 | Johnson City | Washington, Carter, Sullivan | 66,027 |
| 10 | Bartlett | Shelby | 58,579 |
| 11 | Hendersonville | Sumner | 56,018 |
| 12 | Kingsport | Sullivan, Hawkins, Washington | 53,014 |

*Note: Defined as urban by having population of 50,000 or more.

Table 4.2

*Tennessee Urban Area Population Change from 2000 to* 2010 (United States Census, 2010)

| Urban Area | 2010 population | 2000 population | 2000-2010 population change | 2000-2010 population percentage change |
|---|---|---|---|---|
| Knoxville, TN | 558,696 | 419,830 | 138,866 | 33.08 |
| Clarksville, TN-- KY | 158,655 | 121,775 | 36,880 | 30.29 |
| Nashville-Davidson, TN | 969,587 | 749,935 | 219,652 | 29.29 |
| Bristol, TN--VA | 69,501 | 58,472 | 11,029 | 18.86 |
| Johnson City, TN | 120,415 | 102,456 | 17,959 | 17.53 |
| Cleveland, TN | 66,777 | 58,192 | 8,585 | 14.75 |
| Kingsport, TN | 106,571 | 95,766 | 10,805 | 11.28 |
| Chattanooga, TN-- GA | 381,112 | 343,509 | 37,603 | 10.95 |
| Jackson, TN | 71,880 | 65,086 | 6,794 | 10.44 |
| Memphis, TN-- MS--AR | 1,060,061 | 972,091 | 87,970 | 9.05 |
| Morristown, TN | 59,036 | 54,368 | 4,668 | 8.59 |
| Murfreesboro, TN | 133,228 | 135,855 | (2,627) | -1.93 |

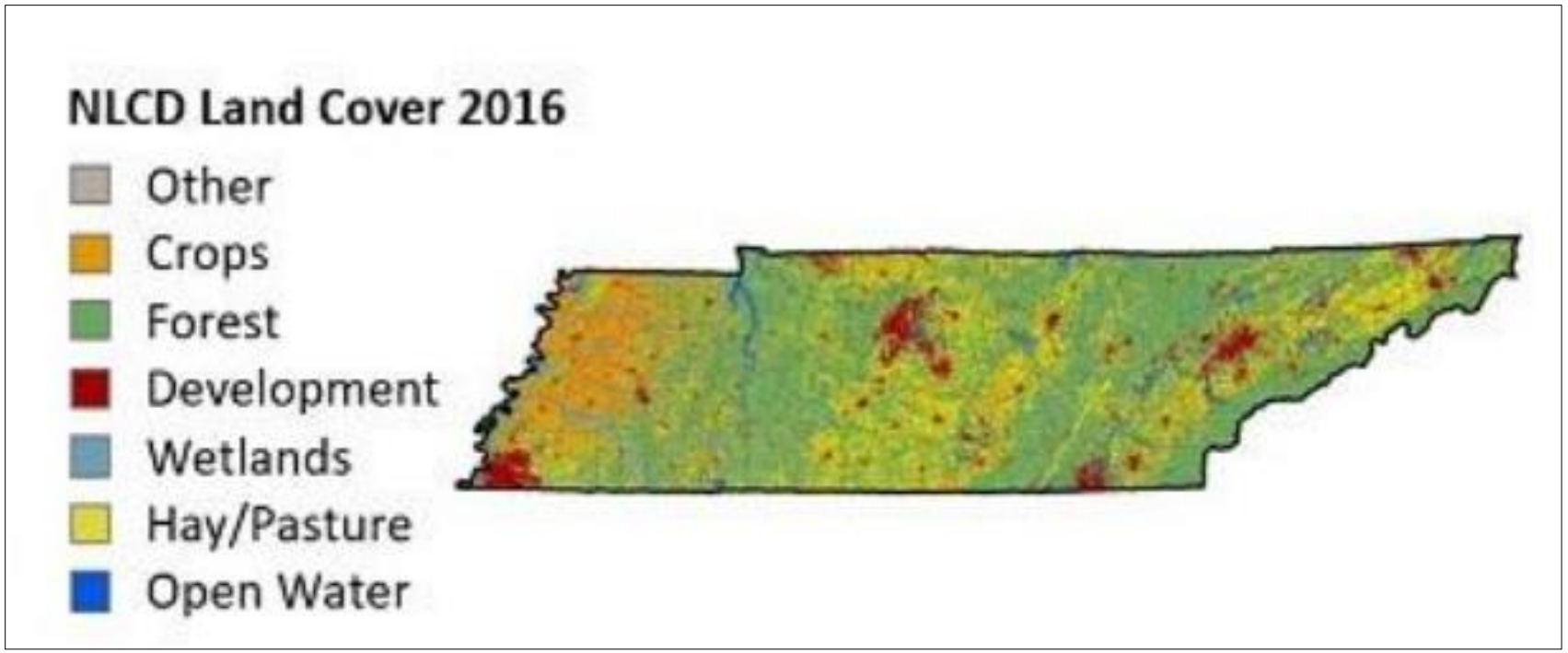



*Figure 4.1. Tennessee National Land Cover Data Set 2016 (USDA, 2016).*

income falls below the Federal poverty line. Racial diversity data is percentage of the population that identify as black and having Hispanic background. Boundaries in this data set come from the US Census TIGER geodatabases.

*Land Cover Data*

Land cover data was obtained from the National Land Cover Database (NLCD), supplied through ESRI Living Atlas (MRLC, 2022). NLCD produces products through the Multi-Resolution Land Characteristics Consortium (MRLC). The MRLC Consortium is a large partnership of federal agencies including the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency, the U.S. Department of Agriculture, the U.S. Forest Service, the National Park Service, the U.S. Fish and Wildlife Service, the Bureau of Land Management and the USDA Natural Resources Conservation Service. Although it is described as having information “to present”, the most recent data available is 2019. Unsigned Char is the pixel type utilized. The cell size is 30 / 30 meter. The spatial reference information for the NLCD is North America albers projection. Developed land cover percentage and forest land cover percentage were the land cover classes used for this study.

*Road Density Data*

Road density data was obtained from ESRI. An inverse of this variable was used to reflect the greater coverage of impervious surface cover from roadways. Spatial and temporal characteristics of road networks and correlations with urban expansion are used for optimization of development (Zhao et al., 2017). Road density should also be considered for its impact on microclimate.

*Evapotranspiration Data*

Data showing mean evapotranspiration levels was obtained from the Operational Simplified Energy Balance (SSEBop) (Senay et al., 2020). SSEBop is a remote-sensing based model that provides actual evapotranspiration estimates using the SSEBop model and evapotranspiration fractions from the National Atmospheric Space Administration's Moderate Resolution Imaging Spectroradiometer and predefined parameters for operational applications. This live feed is automatically updated monthly. Mean evapotranspiration units are in millimeter per month. Cell size is 0.01 degrees (~1 km). The source type is stretched. The pixel type is 16 Bit Integer. The data and mosaic projections are both Geographic Coordinate System World Geodetic System 1984 (GCS WGS84) with global extent. The source is United States Geological Survey Famine Early Warning Systems Network (USGS – FEWS Net) Monthly Actual Evapotranspiration (ET).

4.2.c Data Analysis

Map layers containing data from ACS, NLCD, and SSEBop were added to a map in ArcGIS Online (hereafter AGOL). The base map was enriched with evapotranspiration, land cover (forest and developed), and average household income data. A spatial analysis was performed to display the relationship of the percent of forested land cover (NLCD) and the percent of developed land cover (NLCD). A map was created to display mean evapotranspiration levels across the state at the Census tract level with areas of most evapotranspiration being dark blue and going lighter at the evapotranspiration level approaches zero (Figure 4.2). Regression analysis was completed using the Hot Spot Analysis Tool and mean evapotranspiration and poverty level as variables. When predicting mean evapotranspiration, multiple variables were

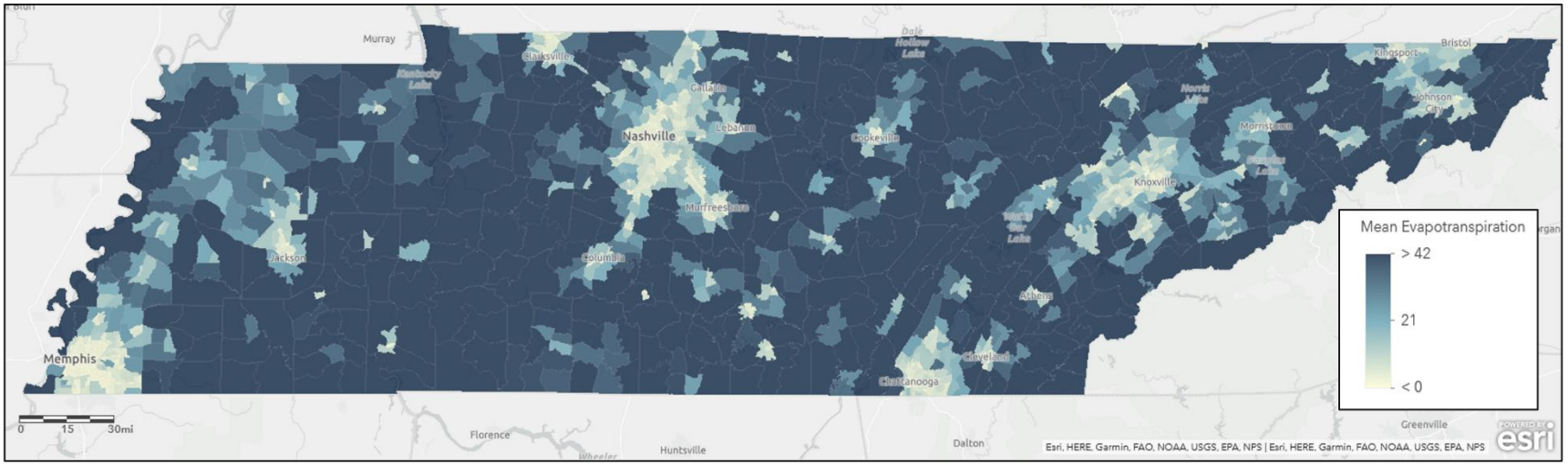



*Figure 4.2. Mean Evapotranspiration Levels across Tennessee (SSEBop, 2022).*

entered into the model. The percent of population that had an air conditioner unit, population density, road density, the percent of land developed and the percent of forest. The variables were chosen to model and predict mean evapotranspiration because they had the highest Adjusted R2 predictive value and lowest AICc when entered into an exploratory regression model. A generalized linear regression model (or OLS) was then run. Next, Global Moran's I was used to test spatial autocorrelation. Spatial relationships were conceptualized using K-nearest neighbors clustering value of 8. Multivariate clustering was then used to see where different levels of evapotranspiration grouped with income, percent developed land, income and air conditioner ownership and population density.

Due to persistent existent of spatial autocorrelation, a new model was created aggregating variables by county. The variables 1) population density, 2) median household income, 3) road density, 4) residents with central air conditioning, 5) developed land cover, and 6) forested land cover were evaluated as potential predictors of mean evapotranspiration by county. All variables were then used in an exploratory regression model to determine which variables had the most impact on mean evapotranspiration. The model with the highest r2, lowest AICc, and most explanatory value was chosen to predict mean evapotranspiration. The variables chosen to predict mean evapotranspiration were then modeled in a generalized linear regression model.

The model was tested for spatial autocorrelation. With spatial autocorrelation removed, a geographically weighted regression model (Spatial autoregressive model) was then used to predict evapotranspiration.

**4.3 Results**

The state of Tennessee is mostly green, representing heavily forested land with low levels of development (Figure 4.3). 1,701 Census tract values show a minimum level of 2.5% and a

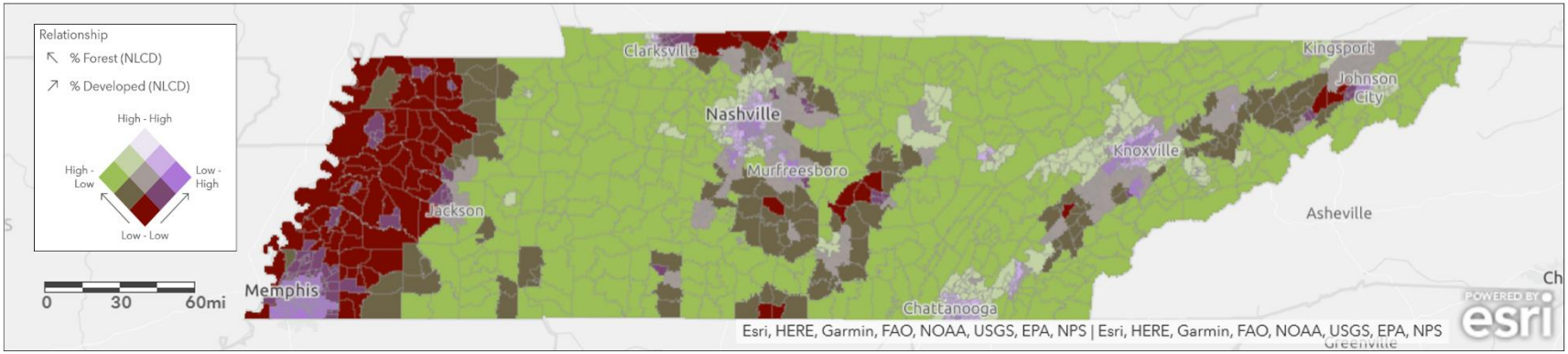



*Figure 4.3. Relationship between Forested and Developed Land Cover in Tennessee (NLCD 2022).*

maximum of 94.8% forested area. The average of Tennessee is 34.83% forested area. In urban areas of significant development that are purple, there are low levels of vegetation and high levels of impervious surface cover. The minimum developed cover is 1.2%, with a maximum of 94.8%. The average developed land cover is 31.41%. Forested land cover is categorized as "low" with less than 23%, a mid-range between 23% and 43% and "high" with greater than 43% forested. Developed land cover is categorized as "low" with less than 11%, a mid-range between 11% and 35% and "high" with greater than 35% developed. Agricultural land that is used for crops and pasture are shown as maroon and represent low levels of vegetation and low levels of impervious surface cover. Northwest Tennessee has a thick band of maroon coming up out of the purple urban center of Memphis in the most Southwest corner of Tennessee. Moving East, forest cover increases, revealed by dark green that turns to bright green and covers most of the state. Areas of exception are purple urban agglomeration Clarksville in North Midwest Tennessee, Nashville, Murfreesboro and Franklin, with maroon areas of agriculture above and below. In Southeast Tennessee, Chattanooga is purple with low forest cover and high developed land cover. Moving Northeast, agricultural land surrounding interstate 75 is shown with deep green and a speckle of maroon just before the purple of Knoxville. Continuing up interstates 40 and 81, agricultural land, and the impervious cover provided by the urban area Morristown are seen with dark green, and grey that is neutral and holds no extreme cover one way or the other. Johnson City provides a last area of low forest cover and low developed cover. Aligned by forest cover at the most Northeast corner of Tennessee, Kingsport and Bristol show up as grey as well.

Low evapotranspiration levels across Tennessee are highlighted in Figure 4.2, showing high evapotranspiration levels in blue as low evaporation levels get lighter as they approach zero. 1,701 values are present with a minimum mean evapotranspiration level of 0 millimeters per

month (mm/month) and a maximum of 97.1 mm/month. The average mean evapotranspiration is 20.92 mm/month. Most areas with forest cover and bodies of water have mean evapotranspiration levels greater than 30 millimeters per month, which create a dark blue backdrop for the state. Nine major areas lacking evapotranspiration get lighter in color as the evapotranspiration levels decrease, turning white as they approach 0 mm per month. Starting in the most Southwest corner of Tennessee, Memphis is the area with the largest white spot, indicating the lowest evapotranspiration levels, which is surprising considering its proximity to the Mississippi River. A band of light blue reaches the top of the state due to agricultural land cover and sinks down into a white spot on Jackson. Due west of the middle of the Northern boundary of the state, Clarksville has a white spot indicating its low evapotranspiration levels. In the middle of the state, Nashville is the center of an urban agglomeration highlighted with light blue and white over Columbia, Murfreesboro, Lebanon, and Gallatin, starting at the bottom and moving up counter clockwise. Moving east, Cookeville shows a small white spot. In the southeast area, Chattanooga and Cleveland are highlighted in white and light blue. Moving northeast, Athens is highlighted in white before the large area surrounding Knoxville that is low in evapotranspiration, including Oak Ridge and Morristown. In the northeast area of the state, the Tri-cities (Johnson City, Kingsport, and Bristol are highlighted with light blue and white.

The relationship between mean evapotranspiration levels and developed land cover is displayed in Figure 4.4 where the bold orange symbolized the top seven urban ranked areas from Table 4.1 (Memphis, Nashville, Knoxville, Chattanooga, Clarksville, Murfreesboro, and Franklin). Evaporation is categorized as “low” with less than 5 mm/month, a mid-range with more than 5 mm/month and less than 24 mm/month, and “high” with greater than 24 mm/month. Developed land cover is categorized as “low” with less than 11%, a mid-range between 11% and

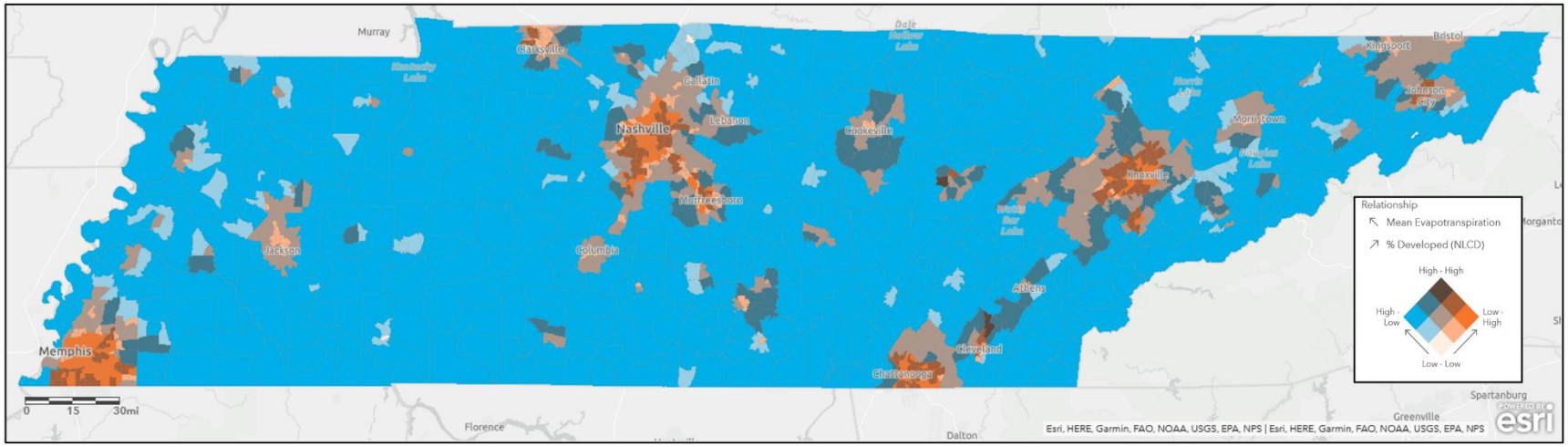



*Figure 4.4. Relationship between Evapotranspiration and Developed Land Cover in TN (SSEBop; NLCD 2022).*

35% and “high” with greater than 35% developed. In addition, these urban areas have the least evapotranspiration when compared to less developed, more forested land cover. Two outliers exist where there is high evapotranspiration and high developed land cover. The first occurrence in the Crossville area can be explained by a large body of water near the city, Lake Holiday. The second occurrence in the Cleveland area where development built up around the Hiwassee River.

Hot Spot Analysis (Appendix J) using the variables mean evapotranspiration and developed land cover in Tennessee created hot spots with 99% confidence in the southwest corner of Tennessee encompassing Memphis. The largest cold spot is over Nashville in the northern area of middle Tennessee, extending past Nashville proper to surrounding communities like Franklin to the southwest, Murfreesboro to the southeast, and Gallatin to the northeast. Due east, Knoxville Tennessee and surrounding areas like Oak Ridge to the northwest create a cold spot rivaling Nashville. In southeast Tennessee, Chattanooga has a cold spot with half in the 99% confidence level. A small cold spot with 95% confidence is over Kingsport in northeast Tennessee.

Unlike the clear patterns of difference for mean evapotranspiration and developed versus forested land cover, households living below poverty level in Tennessee are more randomly dispersed across both urban and rural areas. Urban areas do seem to have central areas with dark red collections that indicate high levels of poverty, with suburban areas showing lower levels of residents living below poverty level.

The relationship between mean evapotranspiration and 2020 households with income below poverty level appears to have more random distribution of high and low levels of the variables across the state. Evaporation is categorized as “low” with less than 5 mm/month, a mid-range with more than 5 mm/month and less than 24 mm/month, and “high” with greater than

24 mm/month. Upon closer inspection at each urban area, Memphis shows the center has a deep orange scheme that displays low levels of evapotranspiration with high levels of the population living below poverty level with smaller tracts of the population living in low evapotranspiration levels that live above poverty level. Jackson and Clarksville each have sections of the population living in low evapotranspiration levels that are living below poverty level. Nashville exhibits a web-like pattern of orange and white (indicating low evapotranspiration levels in areas that are above and below the poverty level) that outline the locations of the several interstates that connect Nashville with the rest of Tennessee in every direction. A large area of Knoxville is orange, showing high levels of poverty and low levels of evapotranspiration. In northeast Tennessee, Morristown, Kingsport, Bristol, Johnson City, Elizabethton, and Erwin all showed orange areas with low levels of evapotranspiration and high rates of poverty. Chattanooga and Cleveland showed several tracts with low evapotranspiration and high rates of poverty.

Hot Spot analysis with mean evapotranspiration levels and rate of poverty created five hot spots with at least 95% confidence. Memphis was the largest hot spot with most of the city showing as a 99% confidence level hot spot. Nashville had the next largest 99% confidence level hot spot. Knoxville had one are with 99% confidence hot spot. Chattanooga and the Tri-cities area near Bristol each had small hot spots with 95% confidence. These areas indicate statistically significant tracts of land.

The generalized linear regression model (or OLS) results showed statistical significance with an adjusted $R^2$ value of 0.55 $F(6,1994) = 349.14$. Spatial clustering and spatial autocorrelation were indicated by significance of the Koenker (BP) Statistic (370.718). In addition, the Jarque Bera Statistic was also significant (125.196), which indicates that the residuals are not normally distributed.

Global Moran's I results were significant, showing significant spatial clustering at multiple distances. Spatial autocorrelation was not removeable at the tract level. Multivariate clustering used the pseudo f test to indicate that the data in the case portioned most effectively into three groups. The variable distribution to the k-means clustering ranged from $R^2$ values between 0.59 and 0.41. The first cluster had 744 census blocks, the second cluster had 437 census blocks and the third cluster had 520 blocks (Table 4.3). Areas in blue represent the highest mean evapotranspiration levels, the lowest percentage of developed land, a relatively low level of median household income, a mid-level of households with central air conditioner, and the lowest level of population density (Figure 4.5). Areas in blue represent the highest level of median household income, the greatest number of households with central air conditioner, a mid-level of developed land cover, low evapotranspiration, a mid-level of population density. Areas in green represent the lowest median household income, the highest level of developed land, the lowest evapotranspiration levels, the lowest percentage of households with central air conditioner, and the highest population density. Areas in green are considered the communities that are most vulnerable to urban heat island effects.

County level analysis was completed using percentage of developed land, percentage of forested land, road density, households with a central air conditioner, households living below poverty level, and race as variables (Appendix K). When variables were modeled using ordinary least squares regression to determine which variables had the most impact on mean evapotranspiration at the county level, spatial autocorrelation was no longer significant for K nearest neighbors = approximately 35. The 95 features resulted in $R^2 = 0.822$, AICc = 660.106, degrees of freedom = 77.488.

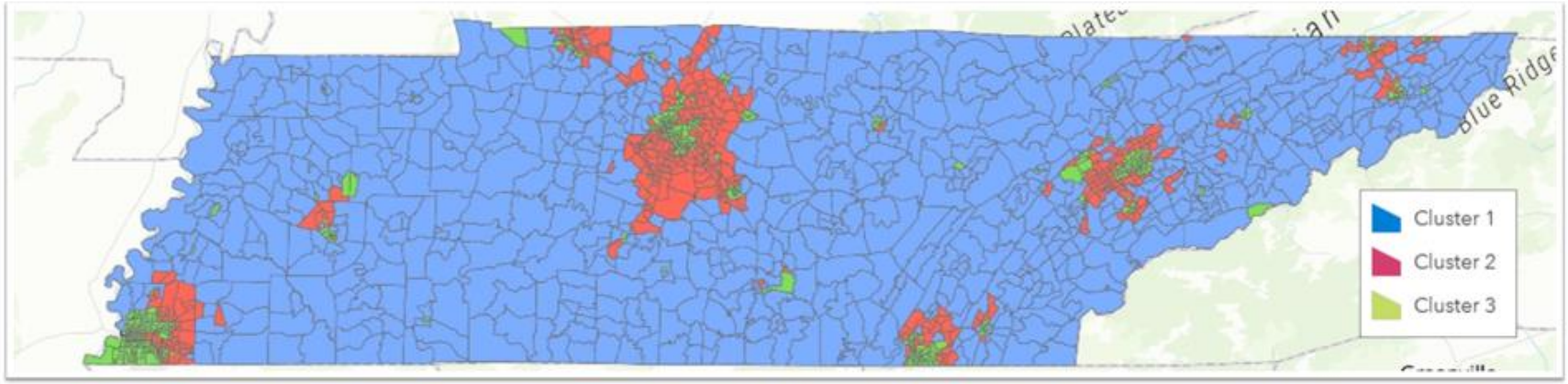
### 4.4 Discussion

The ordinary least squares regression model shows statistical significance for predicting mean evapotranspiration at the county level using population density, residents with central air conditioning, forested land cover, developed land cover, median household income, and road density. Meta-analysis has revealed significant income-based inequity in urban forests and highlights the impact of accounting for spatial autocorrelation (Gerrish and Watkins, 2018). Poisson regression has previously shown that forest characteristics, age, race and urbanicity have a significant influence on county heat mortality (Walton et al., 2015). Further, a Poisson regression model on using Memphis data from 2008-2017 found higher cardiovascular mortality risk in heatwave days where the maximum daily temperature is greater than the $95^{th}$ percentile for more than two consecutive days (Li et al., 2019). Their results indicated that socioeconomic status, race and urbanicity did not impact the mortality rate. In contrast, heat illness data from Florida shows that high income counties consistently have lower health risks of dehydration, heat-related illness, acute renal disease, and respiratory disease, and socioeconomic demographic variables were significantly associated with the magnitude of heat-related health risks (Jung et al., 2021).

Active urban forest management with focuses on responsible urban growth, land use planning, and urban forest cultivation should be the goals of all urban areas in Tennessee for improved climate stability and community health. Municipalities should be encouraged to create Tree Boards whose purpose includes monitoring tree canopy, ensuring tree equity across all socioeconomic communities, proposing legislation protecting native trees when necessary and

Table 4.3. Cluster Group Analysis Results

| Cluster ID (Group By) | Alias | Mean | Standard Deviation | Median | Count | Coefficient of Variation |
|---|---|---|---|---|---|---|
| 1 | 2020 Median HH Income (ACS 5-Yr) | $49365.6 | 12136.14 | 48001 | 744 | 0.25 |
| 1 | % Developed (NLCD) | 9.6 | 6.05 | 7.6 | 744 | 0.63 |
| 1 | Mean Evapotranspiration (in mm) | 39.2 | 19.59 | 38.3 | 744 | 0.50 |
| 1 | 2022 HH Has Central Air Conditioner: Percent | 44.8 | 5.33 | 45.07 | 744 | 0.12 |
| 1 | 2020 Population Density | 192.6 | 250.70 | 99.5 | 744 | 1.30 |
| 2 | 2020 Median HH Income (ACS 5-Yr) | $88692.1 | 30987.00 | 79948 | 437 | 0.35 |
| 2 | % Developed (NLCD) | 35.3 | 19.86 | 29.7 | 437 | 0.56 |
| 2 | Mean Evapotranspiration (in mm) | 9.7 | 7.88 | 7.4 | 437 | 0.81 |
| 2 | 2022 HH Has Central Air Conditioner: Percent | 53.1 | 5.25 | 54.11 | 437 | 0.10 |
| 2 | 2020 Population Density | 1389.2 | 1048.73 | 1121.5 | 437 | 0.75 |
| 3 | 2020 Median HH Income (ACS 5-Yr) | $40191.8 | 17544.00 | 39483 | 520 | 0.44 |
| 3 | % Developed (NLCD) | 59.3 | 25.25 | 62.7 | 520 | 0.43 |
| 3 | Mean Evapotranspiration (in mm) | 4.1 | 5.20 | 2.5 | 520 | 1.25 |
| 3 | 2022 HH Has Central Air Conditioner: Percent | 33.6 | 9.10 | 35.06 | 520 | 0.27 |
| 3 | 2020 Population Density | 3099.6 | 2439.89 | 2701.4 | 520 | 0.79 |




| Variable | Cluster 1 Mean Values | Cluster 2 Mean Values | Cluster 3 Mean Values |
|---|---|---|---|
| **Evapotranspiration** | 39.2 mm | 9.7 mm | 4.1 mm |
| **Developed Land Cover** | 9.6% | 35.3% | 59.3% |
| **Population Density** | 192.6/mi$^2$ | 1389.2/mi$^2$ | 3099.6/mi$^2$ |
| **HH Income** | $49,365.60 | $88,692.10 | $40,191.80 |
| **Has Central Air** | 44.8% | 53.1% | 33.6% |

*Figure 4.5. Multivariate Cluster Grouping Analysis with Household Income, Developed Land Cover, Evapotranspiration Levels, Households with Central Air and Population Density (ACS 2020, NLCD 2022, SSEBop 2022).*

holding land developers accountable for responsible natural resources management. Municipalities should also have a professional or team of professionals focusing on urban green space planning. Green spaces containing predominantly vegetation can significantly reduce land surface temperature in urban areas that surround them (Yao et al., 2021; Loughner et al., 2012).

Green infrastructure development investment will benefit disadvantaged residents in low-income areas who currently disproportionately feel the effects of urban heat islands. Tennessee's most vulnerable communities are the areas with the highest need for UHIE mitigation assistance. A group of Census tracts were identified as vulnerable communities and should be the focus of tree equitability remediations. Tree equity can come into balance through the municipal implementation of green infrastructure. Future directions of research and policy development should consider focus on historically low-income urban areas and underserved communities. Municipal occupation records can be evaluated for structures that are chronically unused or unusable. Planning grants can be offered to property owners who have strategies to take their unused structure and make it of use through occupation or destruction and conversion to a different, functional land cover. An evaluative instrument could be created to give buildings a score for their communal and environmental function. A minimum threshold can be determined for further investigation into properties. Impervious surfaces create an increased need for anthropogenic energy use to keep humans and their things comfortable and safe from extreme heat. This costs money and adds emissions that further fuel UHIE. Urban forests should be planned with surrounding building height, tree location, and vertical leaf area in mind (Yun et al., 2020). For shade cooling of common urban

surfaces, surface material surrounding trees created a greater impact than tree species (T.U.N. et al., 2020). Mature trees are better than younger saplings; when evaluating climate regulating ecosystem services, trunk circumference has been found to be a valuable indicator for estimation (Helletsgruber et al., 2021).

Collaborative efforts should be pursued from government agencies with community members who will ultimately interact with the urban forest and benefit from it. It is important to learn residents' perspectives, interests, and desires for the urban forest, since community involvement bolsters the chances of successful urban forest management (Van Herzele et al., 2005; Sheppard et al., 2017; Tran et al., 2017; Butt et al., 2021). Implementation and planning funding, lack of community and nongovernmental organizational support, development pressure in urban and greenfield areas, and law and policy establishment are among the biggest urban forest governance challenges (Wirtz et al., 2021).

### 4.5 Conclusions

This work provides an overview of geospatial methods for UHIE assessment. Increased tree canopy coverage in urban areas of Tennessee is necessary to mitigate urban heat island effects, including decreased mean evapotranspiration. The most urbanized areas that are farther from forest land cover, with the greatest amount of impervious cover and road density are most impacted by urban heat island effects. Among these inner-city areas are vulnerable communities, predominantly inhabited by higher rates of the population with the lowest median household income levels in Tennessee, who also have the least number of central air conditioners in their households, meaning people with the least amount of financial resources are most susceptible to harmful urban heat island effects. These findings

demonstrate that in addition to UHIE mitigation efforts, considerations should be made for vulnerable communities of resource allocation and collaborative management (residents and municipalities) of urban forests. Evapotranspiration levels can be predicted by changing variables of forested land cover, developed land cover, road density, and population density, giving policy makers and land use planners the ability to estimate expected climatological changes from anthropogenic impacts.

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# CHAPTER FIVE
# DISCUSSION AND CONCLUSIONS

This multidimensional study explored several challenges and opportunities for Tennessee's urban forest. Issues of accessibility, tree equity, and urban heat island effects are emerging topics confronting arboreta managers and urban foresters across the state. Overall, this study was designed to initiate a conversation about arboreta's role in urban forest health and fill in gaps in our knowledge. Urban heat islands were identified in Tennessee along with the inequity of tree canopy coverage associated with socioeconomic factors. With the emergence of information highlighting the critical necessity of sustaining healthy urban forests, the importance of arboreta's role is expanding. To best shape the growth of the network, arboreta accessibility was identified and assessed through socioeconomic and geographic contexts. The barriers for effective operation and opportunities for program improvement were investigated through a thorough process.

The identity of land cover in Tennessee has evolved from grasslands and natural forest to forest cover with many urban areas with impervious surfaces, pastures, and cropland. The changes lead to urban heat islands that have higher temperatures and lower evapotranspiration levels than surrounding nonurban areas during summer months. The results of the urban heat island effect spatial study in Chapter Four show that a lack of urban forest in the most urbanized areas of Tennessee means the population of those areas will not receive as many ecosystem service benefits. Resource allocation will help build the urban forest for those without the resources to do it themselves.

Overall, active urban forest management with focuses on responsible urban growth, land use planning, and urban forest cultivation should be the goals of all urban areas in Tennessee. Municipalities should be encouraged to create Tree Boards whose purpose

includes monitoring tree canopy, ensuring tree equity across all socioeconomic communities, proposing legislation protecting native trees when necessary and holding investors accountable for responsible natural resources management. Municipalities should also have a professional or team of professionals focusing on urban green space planning. With the development of green infrastructure to mitigate UHIE in areas who are most impacted and typically considered disadvantaged, socioeconomic benefits include decrease of anthropogenic energy usage and emissions creation. General community health and wellness will improve with water cycle normalization and less extreme heat wave events.

Future directions for UHIE research include spatial analysis to discover connections between heat-related emergency department visits, the percentage of developed area and average income using statewide data for Tennessee (TN DOH). In addition, Hot Spot analysis can be done with mean evapotranspiration levels and new variables including aggregate household income, race, households with residents who have disabilities, and other disadvantage indicators. This will allow policies and programs to identify the areas with the highest need for UHIE mitigation assistance. Future directions can include city-specific, tract-level analysis to potentially remove spatial autocorrelation and identify the areas most in need of help to cultivate an effective urban forest. A list of the communities from each of the twelve urban areas (Table 2.2) should be created, with those having the lowest tree equity scores and being the most in need of resources including education and tree canopy development, to overcome tree inequity.

With regards to Tennessee Urban Forest Council's arboretum program, the purpose of the study was to establish baseline information about arboretum managers to identify their

current needs and interests to give direction to managers resource creation. First, data analysis showed no statistical difference in managers up who used formal planning and those who did not, with manager satisfaction with arboretum operations, attendance levels and budget amounts. Arboretum managers did express interest in getting help developing management plans. Creating master, maintenance and strategic plan templates for reference is the suggested area of focus for an outreach initiative. Second, data analysis showed no statistical difference in managers up who used formal planning and those who did not, with how much respondents felt the COVID-19 pandemic had an effect on their arboretum. Since strategic planning did not impact manager satisfaction, circumstances of program organization seem to be more impactful that manager organization strategies. In general, results suggest that TUFCCA managers are unsatisfied with current program management protocol for TUFCCA. This illustrates the need for an arboretum manager training program and better communication protocol for TUFC. Arboretum managers who do not currently host educational workshops or host guided nature tours say they do not have time to organize the events. TUFC can implement uniform community outreach educational workshop materials focusing on areas managers expressed interest in learning. Further testing can be completed before and after arboretum manager training events using questions about changes in arboretum offerings and management since the first survey. Three- and five-year survey follow-up interviews can determine if attention to certified arboreta results in better community engagement.

Arboreta have to potential to become information disseminators for the Tennessee Division of Forestry. Having consistent arboreta education initiatives is a logical way to reach

land owners so they can make decisions with their forested lands that produce optimal benefits for the environment and our communities. The results of the third study show that the Tennessee Urban Forestry Council is less than halfway to their goal of having a certified arboretum within a 30-minute drive of every community in Tennessee. 167 out of 429 Tennessee communities are located outside the desired proximity of the arboreta network. Board members for the Tennessee Urban Forestry Council can use this analysis to focus their efforts on community outreach in strategic areas within these 167 communities. Further analysis can be done to determine specific areas that would be optimal geographic locations for future certified arboreta so that the least amount of certified arboreta additions can impact the most amount of Tennessee communities. Variables to consider would be the number of communities that would gain accessibility to a TUFC certified arboretum with each addition, the population of the communities, and communities that are the greatest distance from any TUFC certified arboretum. An arboretum network is an opportunity to cultivate statewide public urban forest facilities. Each arboretum contains a unique historical group of biological specimens that encourage outdoor recreation, learning, and socialization. The impact of such facilities can, perhaps, be greatest felt when visited by family forest owners.

In conclusion, the results of these studies show that efforts should be focused on growing the urban forest in Tennessee's most developed areas, while being mindful of outreach opportunities in areas of high poverty rates; cultivating an arboretum manager training program to teach urban foresters tree disease and pest identification, fundraising, strategic management, and uniform state education initiatives for community outreach. While

tree planting should be focused in urban areas, arboretum establishment is needed in less urban areas to increase accessibility to residents and visitors of every Tennessee community.

# APPENDICES

## APPENDIX A

## CONSENT FOR RESEARCH PARTICIPATION

**Research Study Title:** Tennessee Urban Forestry Council (TUFC) Arboreta Research Survey

**Researchers:** Jillian Gorrell, PhD Student, University of Tennessee at Knoxville
Dr. Sharon Jean-Philippe, PhD, University of Tennessee at Knoxville

You are being invited to participate in this research study because of your affiliation with an arboretum that is certified through the Tennessee Urban Forestry Council. You must be age 18 or older to participate in the study. The information in this consent form is to help you decide if you want to be in this research study. Please take your time reading this form and contact the researcher(s) to ask questions if there is anything you do not understand.

Why is the research being done?

The purpose of this research study is to gain insight about successful arboreta management strategies, identify arboreta needs, and understand how arboreta managed the effects of the COVID-19 pandemic on their programs. This research survey can be a useful tool in improving arboreta and possibly useful for petitioning the state's Division of Forestry for grant funding to support the Tennessee Urban Forestry Council's arboreta program in the future.

What will I do in this study?

If you agree to the terms and participate in the study, you will be asked to complete an online research survey. The research survey includes questions about arboretum use and management plans and should take you about 20 minutes to complete. You can skip any questions that you do not want to answer.

Can I say "No"?

Being in this study is up to you. You can stop up until you submit the research survey. After you submit the research survey, we cannot remove your responses because we will not know which responses came from you.

Are there any risks to me?

The risk is minimal in the study. The research survey is anonymous, and no one will be able to link your responses back to you. Your responses to the research survey will not be linked to your computer, email address or other electronic identifiers. Please do not include your name or other information that could be used to identify you in your research survey responses. Contact information will be coded through the electronic platform, Qualtrics. Information provided in this research survey can only be kept as secure as any other online

communication. Information collected for this study will be published and possibly presented at scientific meetings. Contact information received from the Tennessee Urban Forestry Council and input to the research survey code key will be removed as soon as the data collection phase is complete. Only the de-identified dataset containing research survey responses will be kept in a password-protected computer with personal access to project only for further data analysis purpose.

Are there any benefits to me?

Potential benefits include more focused resources for arboretum managers. Once the greatest needs are assessed, a path forward for help can be created.

Are there any benefits to society?

It is our hope that increased and improved arboreta programming can keep our communities more engaged with the urban forest.

Who can answer my questions about this research study?

If you have any questions or concerns about this study, contact the researchers.

Jillian Gorrell, PhD. Student
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Jwester8@vols.utk.edu

Dr. Sharon Jean-Philippe, PhD.
865-974-2946
jeanphil@utk.edu

For questions or concerns about your rights or to speak with someone other than the research team about the study, please contact:

Institutional Review Board
The University of Tennessee, Knoxville
1534 White Avenue
Blount Hall, Room 408
Knoxville, TN 37996-1529
Phone: 865-974-7697
Email: utkirb@utk.edu

Statement of Consent

I have read this form, been given the chance to ask questions and have my questions answered. If I have more questions, I have been told who to contact. By clicking “I agree to

participate" below, I am providing my signature by electronic means, indicating that I am at least 18 years old, and agree to be in this study. I can print or save a copy of this consent information for future reference. If I do not want to be in this study, I can select "I Do Not Agree" to exit out of the research survey.

☐ I agree to participate.

☐ I do not agree to participate.

## APPENDIX B

## RESEARCH SURVEY RECRUITMENT COMMUNICATIONS

### Initial Email

Hello TUFC Certified Arboretum Manager,

My name is Jillian Gorrell, and I am a PhD Candidate at the University of Tennessee at Knoxville in the Forestry, Wildlife, and Fisheries department. I have created a short research survey to gain insight about successful arboreta management strategies, explore options for arboreta financial support sources, and understand how arboreta are managing the effects of the COVID-19 pandemic on their programs. This research survey can be a useful tool in improving arboreta and possibly useful for petitioning the state's Division of Forestry for grant funding to support the Tennessee Urban Forestry Council in the future. Please complete this research survey by [deadline] so that it can included in my results. I will send a follow up email and call as helpful reminders.

Please let me know if you have any questions or need additional information.

Best regards,
Jillian Gorrell

### Telephone Follow Up

Good Morning/Afternoon, my name is Jillian Gorrell. I am a PhD Candidate at the University of Tennessee, concentrating on urban forestry. On [date of email], I sent an email requesting your participation in a research survey. The purpose of this research survey is to gather information from Tennessee Urban Forestry Council certified arboretum managers to enhance the program and gain traction on petitioning the state’s Division of Forestry for grant funding to support the program and its artboreta in the future. Did you receive the survey, or do I need to resend it? I would greatly appreciate your participation as it is my PhD dissertation research focus. [Date] will be the last day to participate in this research survey. Is there anything I could do to help you such as verbally submitting the survey over the phone?

### Final Email

Hello TUFC Certified Arboretum Manager,

My name is Jillian Gorrell, and I am a PhD Candidate at the University of Tennessee at Knoxville in the Forestry, Wildlife, and Fisheries department. I sent you a short research survey on [Date] to gain insight about successful arboreta management strategies, explore options for arboreta financial support sources, and understand how arboreta are managing the effects of the COVID-19 pandemic on their programs. This research survey can be a useful tool in improving arboreta and possibly useful for petitioning the state's Division of Forestry

for grant funding to support the Tennessee Urban Forestry Council in the future. Please complete this research survey by [deadline] so that it can included in my results. This is the final reminder that will be sent to you.

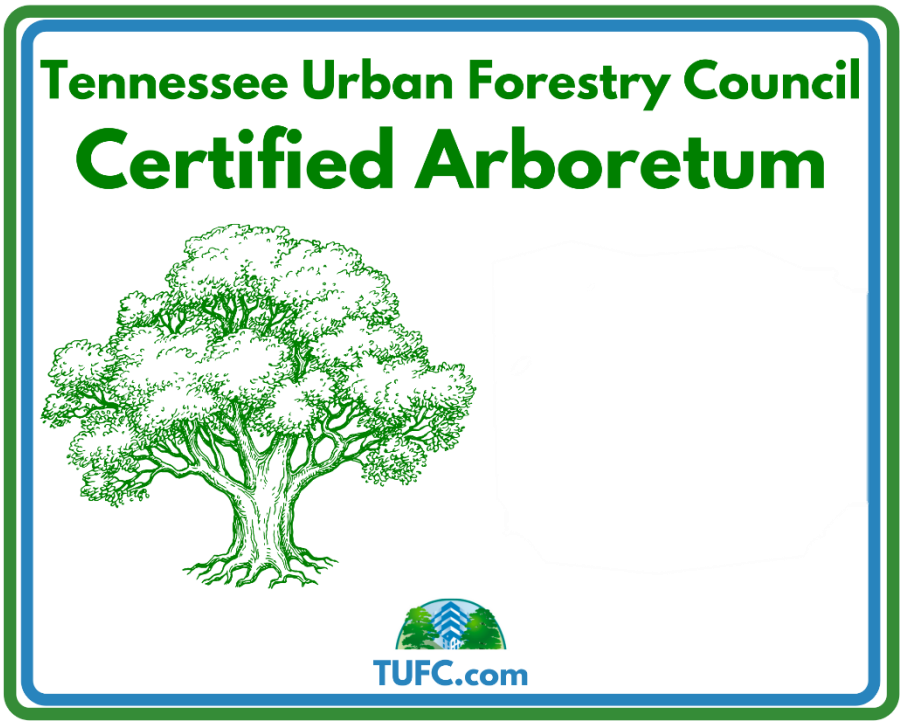
Please let me know if you have any questions or need additional information.

Best regards,
Jillian Gorrell

**APPENDIX C**

**SURVEY INSTRUMENT**

# Tennessee Urban Forestry Council (TUFC) Arboreta Research Survey




THE UNIVERSITY of TENNESSEE

TENNESSEE URBAN FORESTRY COUNCIL

**Throughout this survey "the arboretum" refers to the Tennessee Urban Forestry Council certified arboretum where you currently work or volunteer for which you are completing this survey.**

1. **What is your main role at the arboretum?** *(Check all that apply)*
   - ☐ Owner
   - ☐ Stakeholder
   - ☐ Manager
   - ☐ Program Staff
   - ☐ Volunteer
   - ☐ Other _____

2. **How many years have you been in your current position?**
   _____

3. **What is your highest level of education?**
   - ☐ High school or below
   - ☐ Some college
   - ☐ Technical certificate completed
   - ☐ Associate degree completed
   - ☐ Bachelor degree completed
   - ☐ Some graduate school
   - ☐ Graduate degree completed

4. **What certifications does the arboretum hold?** *(Check all that apply)*
   - ☐ Tennessee Urban Forestry Council (TUFC)
   - ☐ American Public Gardens
   - ☐ Arbnet
   - ☐ Tree City USA
   - ☐ Tree Campus USA
   - ☐ Other_____
   - ☐ None
   - ☐ Not certain

5. **Do you believe the TUFC arboretum certification has been beneficial to your arboretum?**
   - ☐ Yes**, go to 6**
   - ☐ No**, go to 7**

6. **How has TUFC arboretum certification enhanced the arboretum?**

*(Check all that apply)*

☐ Increased attendance
☐ Increased media publications
☐ Increased volunteerism
☐ Money added to budget
☐ Increased recognition among stakeholders
☐ Other_____

**7. Considering the aforementioned benefits of being associated with TUFC, how satisfied are you with the TUFC certification program?**

☐ Very Dissatisfied
☐ Dissatisfied
☐ Neutral
☐ Satisfied
☐ Very Satisfied

**8. What can be improved with the TUFC arboretum certification program/process?**

_____

**9. What aspects of the TUFC arboretum certification program have helped the arboretum?**

_____

**10. What is the arboretum's TUFC certification level?** *(If level 4, move to Question 12)*

☐ Level 1
☐ Level 2
☐ Level 3
☐ Level 4
☐ I don't know
☐ The arboretum does not have TUFC certification

**11. Do your arboretum have plans to increase the TUFC certification level in the future?**

☐ Yes
☐ No

**12. What is the total size in acres of the arboretum property?** *(Estimate if unknown)*

_____

**13. How many trees are on the property total?**

☐ 1-30

☐ 31-60
☐ 61-90
☐ 91-120
☐ 121 or more

**14. How many trees are labelled in the arboretum?**

_____

**15. Do your arboretum have plans to add more trees to the arboretum in the future?**

☐ Definitely Not
☐ Probably Not
☐ Possibly
☐ Probably
☐ Very Probably
☐ Definitely

**16. Does the arboretum have a board of directors or advisory board?**

☐ Yes
☐ No

**17. Does the arboretum have paid employees?**

☐ Yes**, go to 18**
☐ No**, skip to 19**

**18. How many paid employees currently work at the arboretum?**

_____

**19. Why are there no paid employees at the arboretum?**

☐ Our volunteer staff is sufficiently handling the workload.
☐ Our arboretum does not need employees.
☐ The arboretum lacks funding to pay employees.
☐ Other, please explain _____

**20. Does the arboretum have volunteer workers?**

☐ Yes**, go to 21**
☐ No**, skip to 22**

**21. How many people volunteer at the arboretum each year?**

_____

**22. How many volunteer hours are contributed to your arboretum annually?**

☐ 0
☐ 1-50
☐ 51-100
☐ 101-500
☐ 501-1000
☐ 1000 or more
☐ I don't know

**23. Why are there no volunteers at the arboretum?**

☐ We don't need volunteers.
☐ We don't know how to get volunteers.
☐ COVID-19 has changed our ability to utilize volunteers.
☐ Other, please explain _____

**24. Arboreta serve many biological and communal purposes. Please indicate how important or unimportant the following purposes are to the arboretum.**
(1 being least important, 5 being most important)

| Arboretum Purposes | Very Unimportant | Somewhat Unimportant | Neither Important of Unimportant | Somewhat Important | Very Important |
|---|---|---|---|---|---|
| Conservation of Urban Forests | 1 | 2 | 3 | 4 | 5 |
| Research | 1 | 2 | 3 | 4 | 5 |
| Biodiversity Protection of Native Biological Species | 1 | 2 | 3 | 4 | 5 |
| Visitor Entertainment | 1 | 2 | 3 | 4 | 5 |
| Visitor Education | 1 | 2 | 3 | 4 | 5 |
| Visitor Wellness | 1 | 2 | 3 | 4 | 5 |

**25. Does the arboretum have a visitation count system?**

☐ Yes**, go to 26**
☐ No**, skip to 27**

**26. Which of the following best describes the approximate number of visitors at your arboretum annually?**

☐ 0-100
☐ 101-500
☐ 501-1,000
☐ 1,001-10,000

- ☐ 10,001-25,000
- ☐ 25,001-50,000
- ☐ 50,001-100,000
- ☐ 100,001 or more

**27. Are you satisfied with the arboretum's visitor volume?**

- ☐ Yes**, skip to 29**
- ☐ No**, go to 28**

**28. How interested are you in help regarding visitor volume management?** *(If not at all interested, skip to Question 30)*

- ☐ Not at All Interested
- ☐ Slightly Interested
- ☐ Moderately Interested
- ☐ Very Interested
- ☐ Extremely Interested

**29. How would you like to change your attendance?**

- ☐ Increase
- ☐ Control/Decrease

**30. Do you host educational events (workshops, classes, etc.) at the arboretum?**

- ☐ Yes**, go to 31**
- ☐ No**, skip to 34**

**31. How many educational events do you host annually?**

- ☐ 1-2
- ☐ 3-5
- ☐ 5-10
- ☐ 10 or more

**32. How many people typically attend each educational event at the arboretum?**

- ☐ 1-5
- ☐ 6-10
- ☐ 11-15
- ☐ 16-20
- ☐ 20 or more

**33. What type of educational events does your arboretum host?** *(Go to Question 35 after)*

☐ Tree Planting
☐ Tree Maintenance
☐ Environmental Education
☐ Ecosystem Services Education
☐ Biodiversity
☐ Other (Please describe)

**34. Which of the following options describe why the arboretum does not host educational events?** *Strongly agree/strongly disagree*

| Reasons for Not Hosting Educational Events | Strongly Disagree | Moderately Disagree | Neither Agree or Disagree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|
| Visitors are not interested in educational events. | 1 | 2 | 3 | 4 | 5 |
| Lack of space | 1 | 2 | 3 | 4 | 5 |
| Lack of funding | 1 | 2 | 3 | 4 | 5 |
| We don't know how to organize educational events. | 1 | 2 | 3 | 4 | 5 |
| We don't have time to organize educational events | 1 | 2 | 3 | 4 | 5 |
| We are not interested in hosting educational events. | 1 | 2 | 3 | 4 | 5 |
| COVID-19 restrictions limited our ability to host educational events. | 1 | 2 | 3 | 4 | 5 |

**35. Are there guided nature tours at the arboretum?**
☐ Yes**, go to 34**
☐ No**, skip to 36**

**36. How many guided nature tours are hosted at the arboretum annually?**
☐ 1-2
☐ 3-5
☐ 5-10
☐ 10 or more

**37. How many people typically attend each guided nature tour?**

- ☐ 1-5
- ☐ 5-10
- ☐ 10-15
- ☐ 15-20
- ☐ 20 or more

**38. Why are there no guided nature tours at the arboretum? Strongly agree/disagree**

| Reasons for Not Hosting Educational Events | Strongly Disagree | Moderately Disagree | Neither Agree or Disagree | Moderately Agree | Strongly Agree |
|---|---|---|---|---|---|
| Visitors are not interested in guided nature tours. | 1 | 2 | 3 | 4 | 5 |
| We don't have anyone with knowledge to lead guided nature tours. | 1 | 2 | 3 | 4 | 5 |
| We don't have anyone with time to lead guided nature tours. | 1 | 2 | 3 | 4 | 5 |
| Lack of Space | 1 | 2 | 3 | 4 | 5 |
| Lack of Funding | 1 | 2 | 3 | 4 | 5 |
| We are not interested in hosting guided nature tours. | 1 | 2 | 3 | 4 | 5 |
| COVID-19 restrictions have caused us to be temporarily unable to host guided nature tours. | 1 | 2 | 3 | 4 | 5 |

**39. What is your preferred system of managing the arboretum's tree inventory?**

- ☐ Paper
- ☐ Electronic Spreadsheet
- ☐ Electronic Application _____

**40. Does the arboretum have a tree and vegetation maintenance plan?**

- ☐ Yes**, skip to 42**
- ☐ No**, go to 41**

**41. How interested are you in getting help developing a tree and vegetation maintenance plan?**

- ☐ Not at All Interested
- ☐ Slightly Interested
- ☐ Moderately Interested
- ☐ Very Interested
- ☐ Extremely Interested

**42. Does the arboretum have a written organizational master plan?**

- ☐ Yes**, skip to 44**
- ☐ No**, go to 43**

**43. How interested are you in getting help developing a written organizational master plan?**

- ☐ Not at All Interested
- ☐ Slightly Interested
- ☐ Moderately Interested
- ☐ Very Interested
- ☐ Extremely Interested

**44. Does the arboretum have organizational long-term goals?**

- ☐ Yes**, go to 45**
- ☐ No, **skip to 46**

**45. Please share your long-term goals.**

_____

_____

_____

_____

**46. How interested are you in getting help developing long-term goals?**

- ☐ Not at All Interested
- ☐ Slightly Interested
- ☐ Moderately Interested
- ☐ Very Interested
- ☐ Extremely Interested

**47. Does the arboretum have organizational short-term goals?**

- ☐ Yes**, go to 48**
- ☐ No**, skip to 49**

**48. Please share your short-term goals.**

_____
_____
_____
_____

**49. How interested are you in getting help developing short-term goals?**

- ☐ Not at All Interested
- ☐ Slightly Interested
- ☐ Moderately Interested
- ☐ Very Interested
- ☐ Extremely Interested

**50. What is the arboretum's annual budget?**

- ☐ We do not have a budget
- ☐ Up to $1,000
- ☐ $1,001-$5,000
- ☐ $5,001-$10,000
- ☐ $10,001-$25,000
- ☐ $25,001-$50,000
- ☐ $50,001-$100,000
- ☐ $101,001 or more
- ☐ I don't know

**51. Does your arboretum have an annual revenue stream?**

- ☐ Yes**, go to 52**
- ☐ No**, skip to 53**

**52. How much do the following sources contribute to arboretum revenue?**

| Reasons for Not Hosting Educational Events | Not at All | A Little | Some | A Fair Amount | A lot |
|---|---|---|---|---|---|
| Donations | 1 | 2 | 3 | 4 | 5 |
| Ticket Sales | 1 | 2 | 3 | 4 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| Fundraisers | 1 | 2 | 3 | 4 | 5 |
| Grants | 1 | 2 | 3 | 4 | 5 |
| Workshop/Seminar Fees | 1 | 2 | 3 | 4 | 5 |
| Merchandise Sales | 1 | 2 | 3 | 4 | 5 |
| Endowment Fund | 1 | 2 | 3 | 4 | 5 |
| Other (Please Explain) | 1 | 2 | 3 | 4 | 5 |

Other _____

**53. How interested are you in additional financial assistance to support your current efforts?**

☐ Not at All Interested
☐ Slightly Interested
☐ Moderately Interested
☐ Very Interested
☐ Extremely Interested

**54.** "Urban forests are integral components of urban ecosystems, which could generate significant ecosystem services, such as offsetting carbon emission, removing air pollutants, regulating the microclimate, and recreation." (Jim and Chen, 2009)[1]

**How interested are you in getting assistance identifying ecosystem services to validate arboretum benefits?**

☐ Not at All Interested
☐ Slightly Interested
☐ Moderately Interested
☐ Very Interested
☐ Extremely Interested

**55.** It has been proposed that arboreta could be used to monitor native species across the globe for changes in plants to identify diseases or pests like the emerald ash borer. (Barham, 2016)[2]

**How interested are you in reporting changes in tree health at the arboretum as an early alert of pests or diseases? (***If not at all interested, skip to Question 57)*

☐ Not at All Interested
☐ Slightly Interested
☐ Moderately Interested
☐ Very Interested

☐ Extremely Interested

**56. Would you need help learning about tree health and pest identification to begin reporting changes in tree health?**

☐ Yes
☐ No

**57. Which of the following reasons describe why you do not want to report changes in tree health?** *(Check all that apply)*

☐ I don't believe this would help anything.
☐ I don't have time to do this.
☐ I don't know enough about trees to accurately report.
☐ Other, please explain. _____

**58. Do you feel the COVID-19 pandemic had an effect on the arboretum?**

☐ None at All
☐ Slightly Effected Arboretum
☐ Moderately Effected Arboretum
☐ Greatly Effected Arboretum
☐ Extremely Effected Arboretum

**59. Did the arboretum remain open during the COVID-19 pandemic?**

☐ Yes**, skip to 61**
☐ No**, go to 60**

**60. How long did the arboretum remain closed during the COVID-19 pandemic?**

_____

**61. Did the hours of operation change after COVID-19 pandemic began?**

☐ Yes
☐ No

**62. Are arboretum hours still limited?**

☐ Yes
☐ No

**63. Did the arboretum limit the volume of visitors allowed to attend?**

☐ Yes
☐ No

**64. Are school groups allowed to visit the arboretum currently?**

□ Yes
□ No

**65. Did the arboretum make any COVID-19 accommodations or changes that currently effect operations?** *(Indoor visitor restrictions, etc.)*

☐ Yes, please explain_____
☐ No

**66. Did the COVID-19 pandemic alter attendance?**

☐ Increased attendance
☐ Decreased attendance
☐ Other_____
☐ Why do you feel this change occurred? _____

**67. Please share any thoughts you have about TUFC's arboretum certification program, how the COVID-19 pandemic effected your arboretum, or anything else you think is relevant to help your and other arboreta.**

_____
_____
_____

# APPENDIX D

# IRB OUTCOME LETTER




August 25, 2022

Sharon Rose Jean-Philippe
UTIA - UTIA - Forestry, Wildlife and Fish

**Re: UTK IRB-22-07071-XP**
**Study Title:** Tennessee Urban Forestry Council Certified Arboreta Manager Survey

Dear Sharon Rose Jean-Philippe:

The Human Research Protections Program (HRPP) reviewed your application for the above referenced project and determined that your application is eligible for **exempt** review under 45 CFR 46.101, Category 2.
Your application has been determined to comply with proper consideration for the rights and welfare of human subjects and the regulatory requirements for the protection of human subjects.

Therefore, this letter constitutes full approval of your application version 1.2 as submitted and approved. You are approved to enroll a maximum of 200 participants. Approval of this study will be valid from 08/25/2022.

**Approval Information:**

- Exempt cat. 2
- Waiver of documentation of consent
- N=200
- Application v. 1.2
- Tennessee urban forestry council arboreta manager survey consent statement v. 2.0
- Jillian UTK survey LOS v. 1.0
- Tennessee urban forestry council arboreta manager survey final follow up email v. 2.0
- Tennessee urban forestry council arboreta manager survey phone script for first follow up after initial survey distribution email v. 2.0
- Tennessee urban forestry council arboreta manager survey initial email v. 2.0
- Tennessee urban forestry council arboreta manager survey final draft v. 1.1

Any revisions in the approved application, consent forms, instruments, recruitment materials, etc., must be submitted to and approved by the IRB prior to implementation. In addition, you are responsible for reporting any unanticipated serious adverse events or other problems involving risks to subjects or others in the manner required by the local IRB policy.

Approval of this study is valid for three years. If a Study Update Form is not submitted in iMedRIS and approved by the IRB prior to 08/24/2025, the study will be automatically closed by the IRB and no further study activity will be permitted until a Study Update Form is received. Please be sure to also submit a Study Closure Request (Form 7) when all research activity, including data analysis, has been completed.

Sincerely,

Institutional Review Board | Office of Research & Engagement
1534 White Avenue Knoxville, TN 37996-1529
865-974-7697 865-974-7400 fax irb.utk.edu

BIG ORANGE. BIG IDEAS.
Flagship Campus of the University of Tennessee System



Lora Beebe, Ph.D., PMHNP-BC, FAAN
Chair

Institutional Review Board | Office of Research & Engagement
1534 White Avenue Knoxville, TN 37996-1529
865-974-7697 865-974-7400 fax irb.utk.edu

BIG ORANGE. BIG IDEAS.
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## APPENDIX E

## ENCODING FOR WRITTEN COMMENTS

**Table E.1 Coding:**

1. *Communication* (n =12)
2. *Arboriculture Support/Resources* (n = 7)
3. *Signage* (n =3)
4. *Tree Identification Assistance* (n=3)
5. *Funding Assistance* (n =3)
6. *No recommendations* (n=2)

| Respondent Requests for TUFC Arboretum Certification Program and Processes Improvements | Codes |
|---|---|
| "A streamlined spreadsheet or program where all of our trees could be entered into a database. This database would also have notes for anything that needs to be updated or changed after an inspection." | 1, 2 |
| "Earlier preparing advice" | 1, 2 |
| "flexibility on identification markers. We want to use something less obtrusive. I think there is some talk of doing that or relaxing the requirements." | 3 |
| "Help finding certain trees to add to or replace in arboretum." | 1, 2, 4 |
| "[…] TUFC lost its state funding and we applied thru the UT Forestry Dept. I'm grateful for this!" | 5 |
| "Improved communication with TUFC staff - it is very hard to get ahold of someone to ask questions. At the time we applied (2020), the process was very confusing." | 1 |
| "In recent years, because of changes inside the TUFC staff, it has been difficult to get accurate or timely information about certification status. It would be very helpful for arboretum locations to receive annual updates about where they stand on certification, price changes and information about ongoing changes at the TUFC" | 1 |
| "Increased funding so full-time staff can expedite certification and respond to inquiries." | 1, 5 |
| "It would be helpful to have a list of all correct/TUFC-accepted scientific and common names of trees found in TN or at least found in TN arboretums. A single easy to use source for verifying correct/accepted scientific names and common names would be very helpful." | 1, 2, 4 |

| **Respondent Requests for TUFC Arboretum Certification Program and Processes Improvements** | **Codes** |
|---|---|
| More seminars, events, outreach at the Certified Arboretums | 1, 2 |
| Need more arborists to help certify. Volunteer tree teams to help identify trees for communities and groups. | 2, 4 |
| Not increase prices for small organizations as we totally support level I arboretum | 5 |
| Nothing I can think of | 6 |
| Nothing it is concise. | 6 |
| occasionally issue new signage...? | 3 |
| Over the last year-plus, the TUFC staff has not been very responsive to efforts to recertify the arboretum. Improve responsiveness and increase communications with arboretum managers. | 1 |
| TUFC website | 1 |
| Uniform signage between arboreta. Educational materials that can be adapted to individual sites. Volunteer guidance and recognition. | 1, 2, 3 |

**Table E.2 Coding:**

1. *Recognition* (n = 10)
2. *Guidance* (n = 5)
3. *Tree Care* (n = 5)
4. *Legitimization* (n = 4)
5. *Funding* (n = 2)
6. *Unsure* (n = 2)

| **Aspects of TUFC Arboretum Certification Program That Have Been Helpful** | **Codes** |
|---|---|
| Added status to our efforts to create and manage the arboretum with a completely volunteer staff in a county-maintained forested park setting | 1, 3, 4 |
| Advise, information sharing, informal consultations, network | 2 |
| All aspects! Especially the knowledge of those who have come to inspect b/c they have found trees on the property we had not yet included in the arboretum. Just having the certification helps in the awareness and legitimacy on our website, etc. | 1, 2, 4 |
| Assistance from TUFC staff when we have questions | 2 |
| Being able to work with TUFC staff to identify and label our trees. The framework and standards helped us decide how to create an arboretum with a good visitor experience. | 2 |

| Aspects of TUFC Arboretum Certification Program That Have Been Helpful | Codes |
|---|---|
| Certification makes arboretum status far more substantial. Any woodland can call itself an arboretum, but going thru the rigorous TUFC process gives credence. | 4 |
| direction, guidelines | 2 |
| It's the reason we are a recognized arboretum. | 1 |
| Legitimizes. Provides criteria so that anyone that has a 'tree or two' cannot claim an affiliation with TUFC. Makes a visit worth the trip for visitors. | 4 |
| More publicity through TUFC resulting in more financial support | 1, 5 |
| Not sure | 6 |
| Our arboretum has benefited from expertise of the program's staff and volunteers. We have recently obtained our first grant through the program. | 5 |
| Questionable | 6 |
| recognition and continuous improvement | 1 |
| Recognition of the arboretum. | 1 |
| revised awareness among stakeholders of our tree population | 1 |
| Safety | 3 |
| the arboretum certification has helped school leaders advocate for care of the trees on campus by the school district | 1, 3 |
| The arboretum is in a city park-like area. Certification has helped leverage more recognition from city council and city staff of both the arboretum area and the city's tree board which does almost all of the management of the arboretum except for mowing and removal of large trees. | 1, 3 |
| The new tree list with Latin name and Common name for all of TN. | 3 |
| We get public recognition from news releases on the arboretum that help to bring people to our campus to tour the arboretum | 1 |

**Table E.3 Coding:**

1. *Increase Biodiversity* (n = 7)
2. *Plant Trees* (n = 6)
3. *Improve Communication with Visitors* (n = 5)
4. *Increase TUFC Arboretum Certification Level* (n = 4)
5. *Improve Facilities* (n = 4)
6. *Maintain TUFC Arboretum Certification* (n = 2)
7. *Tree Maintenance* (n = 2)
8. *Host More Events* (n = 2)

9. *Continue Education* (n = 2)
10. *Strategic Planning* (n = 1)

| **Long-Term Goals** | **Codes** |
|---|---|
| Canopy Replacement Plan | 1, 10 |
| Continue to maintain Level 1 Arboretum which is in park and open 24 hours. Maintain health of trees, manage weeds, have brochures with map and list of trees always available inside library, encourage children and adults to tour all four seasons of year, and learn to recognize trees by buds, flowers, leaves, and bark | 3, 6, 7, 9 |
| Currently our only long-term goal is to reach Level 2 certification in the fall of 2024. We are considering adding some varieties of native fauna not already present but do not intend to manage formal beds. Our structure is quite informal. | 1, 2, 4 |
| enhancement/updates to infrastructure and collections | 2, 5 |
| Increase diversity of tree species in our arboretum and engage students and the broader community in planting trees and knowledge about trees. | 1, 3 |
| Increase the certification level to Level 2. This will be the highest we can go to to limited space for planting additional tree species. The city tree board is developing a city urban forest management plan which will govern the management of the arboretum as well as street trees and trees on other city lands. Specific arboretum goals, in addition to getting to Level 2, include more presence on the city website (which is currently extremely outdated and scheduled to be overhauled soon) and more arboretum-focused events. | 3, 4, 8 |
| Maintain Level I status for 2023 and maintain health of all trees on Campus Increase the arboretum to Level II by 2024 Give guided tours on TN Arbor Day and/or National Arbor Day Create brochures for interested parties | 3, 4, 6, 7, 9 |
| Plant more new species. | 1, 2 |
| Protect and restore native habitats Provide outdoor education programs for people of all ages Be a destination for enjoying the outdoors and connecting with nature Engage in citizen science to contribute to understanding of native ecosystems | 1, 2, 3, 5, 8 |

| Long-Term Goals | Codes |
|---|---|
| Thirty original trees were located growing in park. Thirty five new natives have already been purchased and planted within the park. Too young to label. | 1, 2, 4 |
| We are currently planning with Memphis Parks to develop and acre of old railroad land in the community. We are asking for all native species on one side and fruit and nut trees on the other side. We always would like to have two of each species listed on our map. | 1, 2, 5 |
| We have a wet lands and nature trail on campus and would like to hook these 3 together to provide a nature walk. After that is completed we would like to have a spur off of the walking trail in Tusculum that comes across the campus that would allow walkers the option of walking along our nature trail (that would go through the arboretum, wetlands, and nature walk on campus. | 5 |

**Table E.4 Coding (N = 21):**

1. *Tree Inventory* (n = 4)
2. *Signage* (n = 9)
3. *Undesirable Plant Removal* (n = 4)
4. *Increase Attendance* (n = 2)
5. *Plant Trees* (n = 8)
6. *Maintenance* (n = 12)
7. *Continuing Education* (n = 1)
8. *Increase Program Offerings* (n = 2)
9. *Strategic Planning* (n = 4)
10. *Plant Garden* (n = 10)
11. *Improve Communication with Visitors* (n = 5)
12. *Improve Facilities* (n = 2)

| Short-Term Goals | Codes |
|---|---|
| Add QR Codes to Signage Digitize all documents Continue to identify qualifying species to increase count over 100. | 1, 2, 9 |
| better number and labeling system, eliminate invasive or non-native species | 1, 3, 9 |
| complete annual weeding improve tree tags | 2, 3 |
| Continue to encourage members to invite others to a guided tour or self-guided tour of the arboretum | 4, 11 |

| Short-Term Goals | Codes |
|---|---|
| Continued biannual maintenance inspections with tree tag replacement as needed; removal of dead and dying trees, brush, etc; replacement plantings | 2, 3, 5, 6 |
| continued maintenance and education | 6, 7 |
| Create Master Plan and Habitat Management Plan Drive visitor attendance and program enrollment | 4, 8, 9 |
| Expand native trees in open areas and better tracking and map system. | 1, 5, 9 |
| Keep labeled and unlabeled trees free from 'weeds' and labels clear. Tree tags have one moth or butterfly species that tree supports mentioned. Will do the same for next batch of trees as they become old enough to label. Continue to remove invasives Continue to plant natives No mowing | 3, 5, 6 |
| Maintain existing arboretum trees and add a few species every year | 5, 6 |
| Maintaining existing trees and establishing a camellia garden | 6, 10 |
| Make sure our website is up to date and all of our tree tags are correct!!! | 1, 2, 11 |
| Make sure trees are healthy and being watered in the drought times. Check for disease regularly. | 6 |
| Plant diverse trees and keep the current trees in the arboretum alive and replace trees that have died. | 5, 6 |
| Plant new oak trees Create visitor guide for arboretum | 5, 11 |
| Plant new tree species. | 5 |
| Properly manage the arboretum trees, maintain signage. | 2, 6 |
| Prune and care for all trees on campus Water all trees during periods of drought Label all new trees that were added in 2021-2022 school year | 2, 6 |
| Revise/upgrade signage of trees, lighting, mapping | 2, 6, 11, 12 |
| signage, trails, and bridges | 2, 6, 12 |
| To continue to add diversity to the arboretum. To install new signage at each tree with QR codes for visitors to learn more. To do a better job managing lawn care damage impact on trees. To have more workshops on tree care and importance. | 2, 5, 6, 8, 11 |

**Table E.5 Encoding (N = 12):**

1. *Outdoor Environment Was More Accessible Than Restricted Areas* (n =7)
2. *Restrictions Reduced Audience* (n = 6)

| Reasons for Attendance Changes due to COVID-19 Pandemic | Codes |
|---|---|

| | |
|---|---|
| All classes were online during the 2020-2021 school year. None of the 2000+ students/faculty or staff were on campus on a daily basis to use the arboretum for research, study, or recreational purposes. | 2 |
| Fewer people were using other resources at our park, such as the playground, walking trails, and other recreation facilities. | 2 |
| It is self guided and outdoors. People were limited in their options for activity. It is also part of our most popular walking trail. | 1 |
| It was a great way to get outside. | 1 |
| More people got outside and discovered their accessible city parks... | 1 |
| More people outdoors in general. Our arboretum is a city park-like area open to the public 24/7 and we have no indoor facilities. The large open lawn area in the center of the arboretum area has been used for years for organized soccer games, which were suspended during 2020. But this was not related to the arboretum. | 1, 2 |
| Our arboretum is community wide. At school yards, businesses, our park, and front yards of homes. People riding bikes and walking notice our signs. | 1 |
| people in the neighborhood were at home more, and walked around | 1 |
| People wanted to get outside | 1 |
| Public self imposed isolation | 2 |
| Reduction of students on campus | 2 |
| We are a wedding venue, so attendance was down at weddings, as well as in planning for events. | 2 |

**Table E.6: Encoding (N = 9):**

1. *Desire to Increase Visitor Educational Offerings* (n = 2)
2. *Desire to Improve Facilities* (n = 2)
3. *Desire to Improve Technology* (n = 3)
4. *COVID-19 Pandemic Comment* (n = 2)
5. *Ease of Certification Process* (n = 2)
6. *Difficulty with Certification Process* (n = 2)
7. *Desire for Better TUFC Communications* (n = 1)
8. *Visitor Restrictions* (n = 1)
9. *Satisfaction with TUFC* (n = 3)
10. *Financial Hardship* (n = 1)
11. *Satisfaction with TAEP Grant* (n = 1)

| **Final Thoughts** | **Codes** |
|---|---|

| | |
|---|---|
| Our arboretum is behind an elementary school in a rural part of the county. It rests in a 37 acre mostly forested park maintained by the county. We are sole managers of the planting, labeling, and management of the chosen trees. We are merely a committee of the local county Extension Master Gardeners. We fund it at about $800 per year out of Master Gardener raised money. Tours are conducted by Master Gardeners or by TUFC volunteers. We want to increase our educational component by adding QR codes to signs linking to both Facebook and our web site, where we can either provide data or link to .edu horticultural sites related to our trees and wildflowers. Linking to articles related to Arb. benefits would also work | 1, 2, 3 |
| Our arboretum is in park which has no fencing or gated so public can roam grounds at any time 24 hours. During pandemic more food trash was scattered on property as more children and adults were not in school snd working and more were hanging out at the park | 4 |
| Our arboretum is part of our campus and is a self-guided tour unless we are asked by groups for guided tours. There are no changes to the visitation due to Covid. The certification process is easy enough to follow. | 4, 5 |
| Reorganization of TUFC made it difficult to get recertifications; specifications for certifications should have been clearer. | 6 |
| See previous comment about lack of responsiveness by TUFC staff. Overall, the arboretum certification program is extremely worthwhile. | 7, 9 |
| Since the […] is on private property it is different than most. The owners love to have visitors and are open to events/school field trips, etc., but it has not been a priority. Everything must be scheduled with the owners directly since it is not available to the public. | 8 |
| The certification process was relatively easy and I received a good bit of helpful advice. | 5, 9 |
| The recertification price is too high. I can see the charge on the front end when certifying, but recertifying every three years for the same price will have a majority of groups dropping out soon and going to Arbnet for free. It is hard to purchase new trees, keep trees mulched and healthy with that high of a price. | 6, 10 |
| […] is very proud of the Arboretum. The certification has encouraged donors of new trees and improved educational opportunities for all on campus. The desire to increase to a level 2 and create more of a peaceful arboretum setting on campus is felt by administration, faculty, staff, students, parents, and surrounding community members. We are thankful for the grant we received from the TN Dept of agriculture TAEP grant that helped us reach the Level 1 and hope that we might also receive additional grant funding to increase our status to Level 2. The school is an urban environment that would greatly benefit from the addition of more native trees. | 1, 2, 9, 11 |

## APPENDIX F

## ARBORETUM MANAGER SURVEY CROSSTABULATION RESULTS

| | **Board of Directors (categorical)** | **Size of Arboretum (ordinal)** |
|---|---|---|
| Host educational events (categorical) | $X^2$= 3.475, df =1, p = 0.114 | U = 0.341, p = 0.141 |
| Give guided tours (categorical) | $X^2$ = 0.191, df =1, p = 0.718 | U = 35.000, p = 0.126 |
| Interest in ecosystem services | t = -0.627, df = 24, p = 0.536 | rho = 0.341, p = 0.141 |
| Interest in reporting pests | t = 0.723, df = 24, p = 0.477 | rho = -0.017, p = 0.943 |
| Vegetation maintenance plan (categorical) | $X^2$ = 0.258, df = 1, p = 0.705 | U = 38.500, p = 0.238 |
| Master plan (categorical) | $X^2$ = 0.678, df = 1, p = 0.648 | U = 9.000, p = 0.080 |
| Long term goals (categorical) | $X^2$ = 3.590, df = 1, p = 0.128 | U = 56.500, p = 0.797 |
| Short term goals (categorical) | $X^2$ = 6.190, df = 1, p = 0.039* | U = 22.000, p = 0.765 |
| Budget (ordinal) | U = 63.000, p = 0.649 | rho = 0.606, p = 0.008* |
| Revenue Stream (categorical) | $X^2$ = 1.759, df = 1, p = 0.378 | U = 19.000, p = 0.062 |
| Region (categorical) | $X^2$ = 1.423, df = 1, p = 0.585 | KW = 2.945, df = 2, p = 0.229 |

*Statistical significance

## APPENDIX G

## TENNESSEE URBAN FORESTRY COUNCIL CERTIFIED ARBORETUM LIST

| TUFC Certified Arboretum Name | Address |
|---|---|
| Monteagle Sunday School Assembly | 1 Assembly Ave, Monteagle, TN 37356 |
| Pleasant Run Creek Park | 100 Stevens Road, Bolivar, Tennessee 38008 |
| Ardinna Woods | 101 Britt Dr, Jonesborough, TN 37659 |
| 1st Presbyterian Church | 101 Legends Club Ln, Franklin, TN 37069 |
| Bell Buckle Park | 101-299 Peacock St, Bell Buckle, TN 37020 |
| Louise Pearson Memorial | 104 Green Frog Lane, Alamo, Tennessee 38001 |
| Union University | 1050 Union University Dr, Jackson, TN 38305 |
| Arboretum at Poplar Estates Park | 1130 Poplar Estates Pkwy, Germantown, TN 38138 |
| Glenview Park | 1141 South Barksdale, Memphis, TN 38114 |
| Burchfiel Grove | 120 Gary Wade Blvd, Sevierville, TN 37862 |
| Orion Hill | 12055 Donelson Rd, Arlington, TN 38002 |
| Jacob's Nature Park | 1254-1342 King Springs Rd, Johnson City, TN 37601 |
| Daniel Boone Arboretum | 138 Harrogate Crossing, Harrogate, TN 37752 |
| Marathon Petroleum Nashville 51st Arboretum and Trail | 1409 51st Ave N, Nashville, TN 37209 |
| LaGrange Cemetery | 14115 Lagrange Rd, Moscow, TN 38057 |
| Parris Powers Memorial | 1480 Nashville Pike, Gallatin, TN 37066 |
| Sycamore Shoals State Park | 1651 W Elk Ave, Elizabethton, TN 37643 |
| Columbia State Community College | 1665 Hampshire Pike, Columbia, TN 38401 |
| Okeena Park | 1710 Lake Rd, Dyersburg, TN 38024 |
| Mabry-Hazen House | 1711 Dandridge Ave, Knoxville, TN 37915 |
| McCoy Farms and Gardens | 1715 Anderson Pike, Signal Mountain, TN 37377 |
| Prescott South Middle School | 1859 S Jefferson Ave, Cookeville, TN 38506 |
| Ivan Racheff House and Gardens | 1943 Tennessee Avenue, Knoxville, TN 37921 |
| Chucalissa Tree Trail | 1987 Indian Village Drive, Memphis, TN 38109 |
| Edgehill Arboretum | 2000 Edgehill Ave, Nashville, TN 37212 |
| Rhodes College | 2000 North Pkwy, Memphis, TN 38112 |
| Memphis Zoo and Aquarium | 2000 Prentiss Pl, Memphis, TN 38112 |
| Cane Creek | 201 C C Camp Rd, Cookeville, TN 38501 |
| Old Town Arboretum | 2031 Old Natchez Trace, Franklin, TN 37069 |
| White House Arboretum | 210 Rolling Acres Dr, White House, TN 37188 |
| Cooper-Young Historic District | 2120 Young Ave, Memphis, TN 38104 |
| Interstate Packaging, White Bluff | 2285 TN-47, White Bluff, TN 37187 |
| Northeast State Community College | 2425 TN-75, Blountville, TN 37617 |
| UT Gardens | 2518 Jacob Dr, Knoxville, TN 37996 |

| TUFC Certified Arboretum Name | Address |
|---|---|
| Drummonds Park | 261 Tate Rd, Drummonds, TN 38023 |
| St. Jude Hospital | 262 Danny Thomas Pl, Memphis, TN 38105 |
| New Hope Christian Academy | 3000 University St, Memphis, TN 38127 |
| Christ the King Church & School Arboretum | 3105 Belmont Blvd, Nashville, TN 37212 |
| Tennessee Residence | 312 Rosa L. Parks Avenue, Nashville, TN 37243 |
| Trevecca Nazarene University | 333 Murfreesboro Pike, Nashville, TN 37210 |
| Cleveland State Community College | 3535 Adkisson Dr, Cleveland, TN 37312 |
| Ridgetop Station Park | 37152, 1954 Woodruff Ave, Ridgetop, TN 37073 |
| Dyersburg Middle School | 400 Frank Maynard Blvd, Dyersburg, TN 38024 |
| Reflection Riding Arboretum and Nature Center | 400 Garden Rd, Chattanooga, TN 37419 |
| Oaklands Park | 427 Roberts Street, Murfreesboro, Tennessee 37130 |
| Ghertner & Company Arboretum | 50 Vantage Way #100, Nashville, TN 37228 |
| Gresham Middle School Arboretum | 500 Gresham Rd, Knoxville, TN 37918 |
| Belle Meade Plantation | 5025 Harding Pike, Nashville, TN 37205 |
| The Mulch Company | 511 Agri Park Dr., Murfreesboro, TN 37129 |
| White Station High School Arboretum | 514 S Perkins Rd, Memphis, TN 38117 |
| Owl's Hill Nature Sanctuary Arboretum | 545 Beech Creek Rd S, Brentwood, TN 37027 |
| Tusculum University | 60 Shiloh Rd, Tusculum, TN 37745 |
| Austin Peay Arboretum | 601 College St, Clarksville, TN 37044 |
| Linda T. Collins Arboretum | 615 McCallie Ave, Chattanooga, TN 37403 |
| Milan City Park | 7001 Ellington Dr, Milan, TN 38358 |
| Riverdale Elementary School | 7391 Neshoba Rd, Germantown, TN 38138 |
| Moss-Wright Park Arboretum | 745 Caldwell Dr, Goodlettsville, TN 37072 |
| Memphis Botanic Garden | 750 Cherry Rd, Memphis, TN 38117 |
| Cleveland/Bradley County Greenway | 775 Raider Drive, Cleveland, TN 37312 |
| Oaklawn Garden | 7831 Poplar Pike, Germantown, TN 38138 |
| John P. Holt Library, Brentwood | 8109 Concord Rd, Brentwood, TN 37027 |
| Bearden High School | 8352 Kingston Pike, Knoxville, TN 37919 |
| Cordova Library | 8457 Trinity Rd, Cordova, TN 38018 |
| UT Arboretum | 901 S Illinois Ave, Oak Ridge, TN 37830 |
| East Park | 908 Country Club Dr, Tullahoma, TN 37388 |
| Carnes Garden | 912 J W Williams Ln, Memphis, TN 38105 |
| Memphis-Shelby County Humane Society | 935 Farm Rd, Memphis, TN 38134 |
| Baddour Parkway Arboretum | 945 E Baddour Pkwy, Lebanon, TN 37087 |
| City Lake, Cookeville | Bridgeway Drive, Cookeville, TN 38506 |

## APPENDIX H

## TUFCCA ACCESSIBILITY OPPORTUNITY COMMUNITIES

| **Tennessee Communities whose Center Point is located greater than 30 minutes proximity to a Tennessee Urban Forestry Council certified arboretum.** | | | |
|---|---|---|---|
| Adamsville | Englewood | Loudon | Rogersville |
| Allardt | Enville | Lynnville | Rutherford |
| Altamont | Erin | Madisonville | Rutledge |
| Ardmore | Etowah | Martin | Sale Creek |
| Baneberry | Eva | McEwen | Saltillo |
| Bean Station | Fairfield | McMinnville | Samburg |
| Beersheba Springs | Fairfield Glade | Michie | Sardis |
| Bethel Springs | Fayetteville | Midtown | Savannah |
| Big Sandy | Fincastle | Milledgeville | Scotts Hill |
| Bowman | Finger | Minor Hill | Selmer |
| Bruceton | Flat Top Mountain | Mooresburg | Sharon |
| Bulls Gap | Flintville | Morrison | Slayden |
| Byrdstown | Gleason | Morristown | Smithville |
| Camden | Graysville | Mount Carmel | Sneedville |
| Celina | Greenback | Mountain City | South Fulton |
| Centertown | Grimsley | New Johnsonville | Spencer |
| Centerville | Guys | New Market | Spring City |
| Chapel Hill | Harriman | Newport | St. Joseph |
| Chesterfield | Helenwood | Niota | Stantonville |
| Church Hill | Henderson | Oakdale | Sunbright |
| Clarkrange | Henning | Olivet | Surgoinsville |
| Clarksburg | Henry | Oneida | Sweetwater |
| Clifton | Hohenwald | Orme | Tellico Plains |
| Collinwood | Hollow Rock | Palmer | Tellico Village |
| Copperhill | Hornbeak | Paris | Tennessee Ridge |
| Cornersville | Huntingdon | Park City | Tiptonville |
| Cottage Grove | Huntland | Parker's Crossroads | Townsend |
| Crab Orchard | Huntsville | Parrottsville | Union City |
| Crossville | Iron City | Parsons | Viola |
| Crump | Jamestown | Petersburg | Vonore |
| Cumberland City | Jefferson City | Philadelphia | Walland |
| Darden | Jellico | Pikeville | Walnut Grove |

| **Tennessee Communities whose Center Point is located greater than 30 minutes proximity to a Tennessee Urban Forestry Council certified arboretum.** | | | |
|---|---|---|---|
| Dayton | Kenton | Pleasant Hill | Wartburg |
| Decatur | La Follette | Powells Crossroads | Waverly |
| Decaturville | Lafayette | Pulaski | Waynesboro |
| Dover | Lake Tansi | Puryear | Westmoreland |
| Dowelltown | Lawrenceburg | Ramer | White Pine |
| Dresden | Lewisburg | Red Boiling Springs | Whitwell |
| Ducktown | Lexington | Ripley | Winfield |
| Eastview | Linden | Rives | Woodland Mills |
| Elgin | Lobelville | Robbins | Wrigley |
| Elkton | Loretto | Rockwood | |

## APPENDIX I

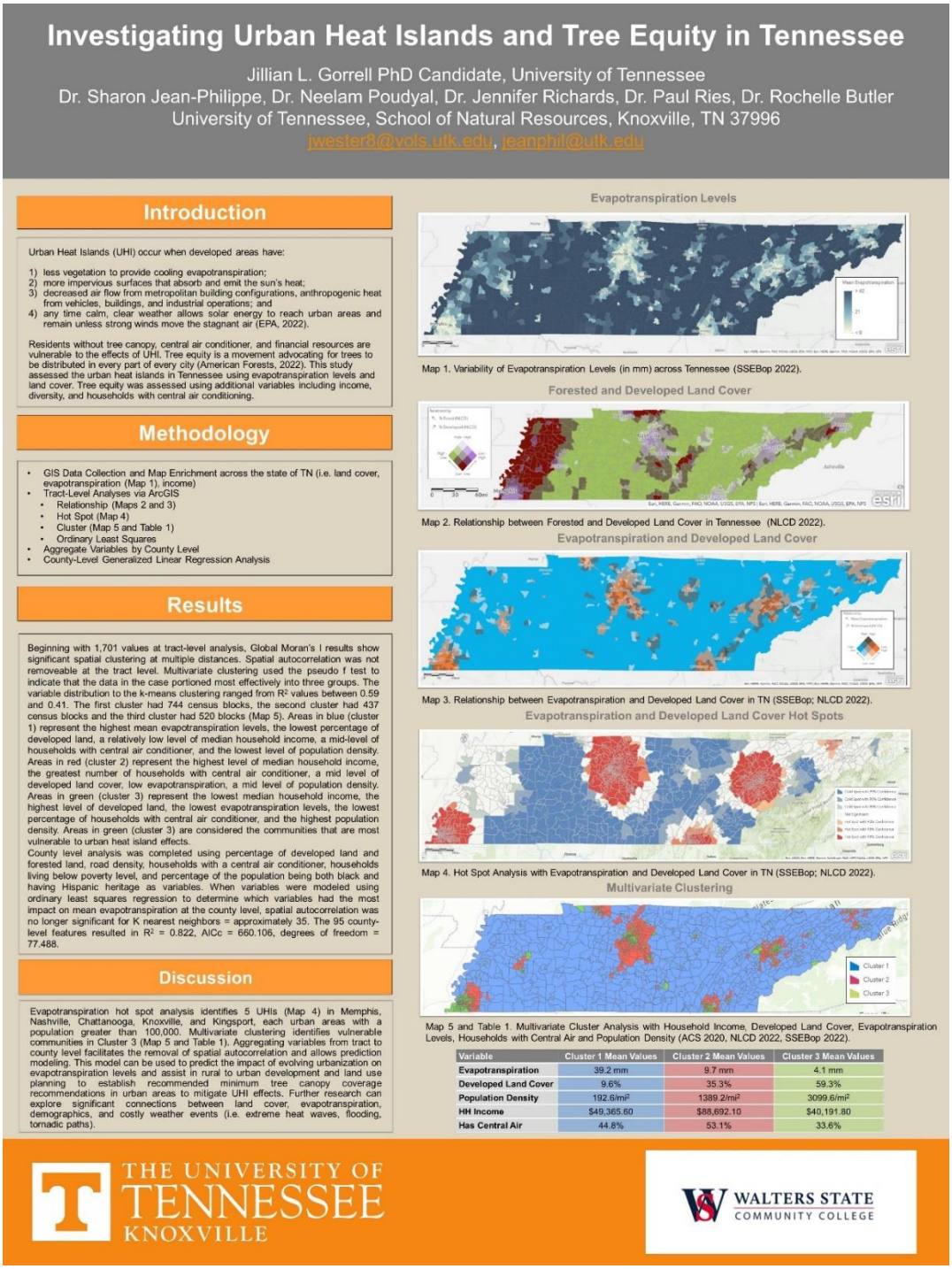



*Figure I. Investigating Urban Heat Islands and Tree Equity in Tennessee Poster.*

## APPENDIX J

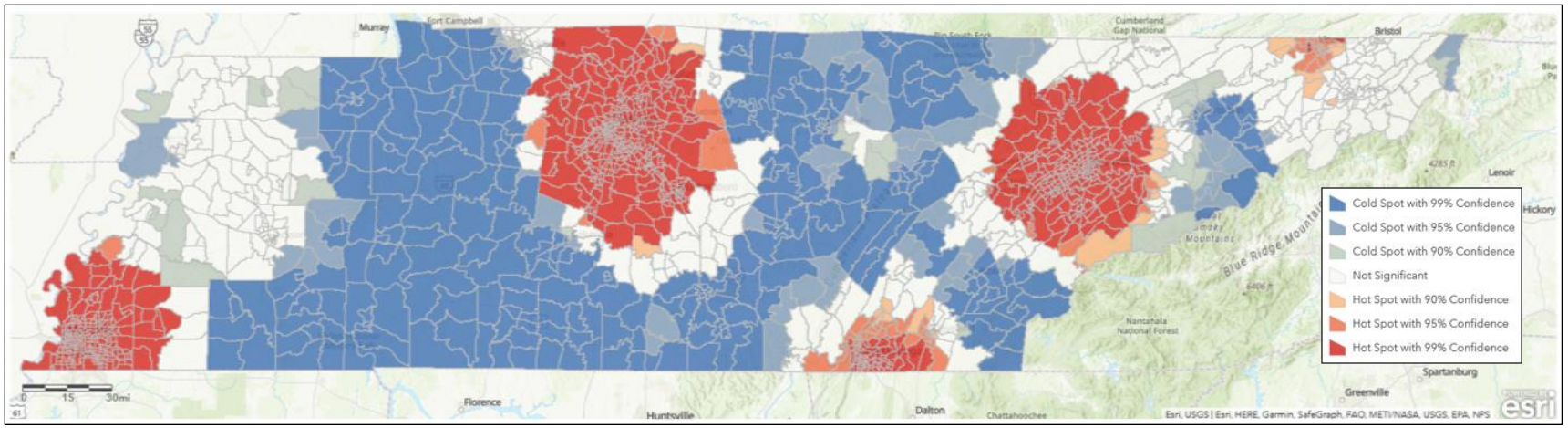



*Figure J. Hot Spot Analysis of Evapotranspiration and Developed Land Cover in Tennessee (SSEBop, 2022; NLCD, 2022).*

## APPENDIX K

**GWR OUTPUT – WHERE DOES THE SPATIAL AUTOCORRELATION NO LONGER BECOME SIGNIFICANT**

**Manual Interval Results**

| Number of Neighbors | AICc |
|---|---|
| 20 | 662.0649 |
| 25 | 660.9137 |
| 30 | 660.2995 |
| 35 | 660.1063 |
| 40 | 660.3177 |
| 45 | 660.4262 |
| 50 | 660.4984 |
| 55 | 660.5103 |
| 60 | 660.6056 |
| 65 | 660.8480 |
| 70 | 660.9414 |
| 75 | 661.1857 |
| 80 | 661.2475 |
| 85 | 661.4241 |
| 90 | 661.5774 |

**GLR Details**

| | |
|---|---|
| Number of Features | 95 |
| Dependent Variable | EVAPOTRANSPIRATION |
| Explanatory Variables | DEVELOPED_LAND_COVER |
| | FORESTED_LAND_COVER |
| | ROAD_DENSITY |
| | HOUSEHOLDS_WITH_CENTRAL_AIR |
| | HOUSEHOLDS_BELOW_POVERTY_LEVEL |
| | BLACK_AND_HISPANIC_ORIGIN |
| Number of Neighbors | 35 |

**Model Diagnostics**

| | |
|---|---|
| R2 | 0.8222 |
| AdjR2 | 0.7815 |
| AICc | 660.1063 |
| Sigma-Squared | 51.3349 |
| Sigma-Squared MLE | 41.8721 |
| Effective Degrees of Freedom | 77.4882 |
| Adjusted Critical Value of Pseudo-t Statistics | 2.2743 |

*Figure K. County Level Geographically Weighted Regression Model Output*

# VITA

Jillian L. Gorrell was born at her family's home in Milford, Michigan as Jillian Lee Moss. Her family soon returned to her maternal ancestral farmland in the foothills of English Mountain in East Tennessee. She spent a significant amount of time in nature, admiring plants, animals, the landscape and enjoying the peace and joy of being in the natural environment of the Appalachian Mountains. She was schooled locally and graduated from Jefferson County High School. She earned a Bachelor of Arts degree in Chemistry from Carson-Newman University (back when it was still a 'College').

After her firstborn son turned 18 months old, Jillian began a career at Walters State Community College as the Biology Laboratory Learning Center Specialist at the campus in Sevierville. Within her first month, her graduate school career began at the University of Tennessee's Agricultural Leadership, Communications and Education Master of Science program. Her capstone project was the Proposed Master Plan for the Great Smoky Mountain Arboretum at Walters State Community College Sevier Campus. She took graduate coursework in Geospatial Information Science from Tennessee State University.

Her heart was pulled to research concentrating in the urban forest. This dissertation satisfies her requirement to earn a Doctorate of Philosophy in Natural Resources from the School of Natural Resources in the Herbert College of Agriculture at the University of Tennessee in Knoxville. She completes this task as a wife and mother of three boys aged 10, 8, and 2 years old. Jillian maintained full time employment, self-published four children's books, cowrote a college-level plant science textbook for the Tennessee Board of Reagents Statewide Dual Credit program, sat as a board member and secretary for Cocke County's Board of Sanitation, volunteered as a mentor for TNAchieves high school and undergraduate students, volunteered as a Cloverbud 4H leader, worked as an undergraduate research coach at UTK, volunteered with countless other public, private, and nonprofit organizations, purchased a home, and enjoyed time with family and friends, all while maintaining a 4.0 during her entire graduate academic career. This was only possible with all the loving support from her family, mentors, friends, colleagues, students, and community members.

Jillian encourages her students to keep learning, follow your passion, do your best work, and find your people.