ABSTRACT

DHALIWAL, KAUR AMANDEEP. Factors Affecting Seedling Regeneration in Raleigh's Urban Greenways. (Under the direction of Dr. Meredith Martin and Dr. Leah Rathbun).

Urbanization brings with it environmental challenges, notably the loss of forest cover, highlighting the importance of urban forests and greenways in mitigating these effects. Urban forests, comprising all city trees, offer vital ecosystem services such as air noise pollution reduction, control of runoff, and sequestration of carbon. Greenways enhance both sustainability of the environmental and urban living conditions. Raliegh, Norh Carolina, which had a population of 123, 000 in teh1970s and over 469,000 in 2020, is a prime example of the urban expansion narrative. Urban planning was ahead of its time in tackling environmental degradation when it proposed a greenway network in the city's 1969 capital improvement plan. The greenways are crucial for conserving urban forests, encouraging natural regeneration, and establishing connections between habitats in addition to serving as recreational spaces. Urban forest areas, however, are at risk from human activities that compromise the diversity of native vegetation and health of the forest, such as the introduction of invasive species. Our study explores the factors that affect seedling regeneration in urban environments, emphasizing the significance of environmental factors such as trail proximity, aspect, slope, and light availability. The also consider the social aspects of urban forestry by examining the potential impact of socioeconomic status differences on the outcomes of forest regeneration inside the urban greenway system. To mitigate the adverse impacts of urbanization, enhance living conditions in cities, and encourage biodiversity, it is imperative to prioritize crucial requirements of urban planning and community engagement in the upkeep of urban forests. The example of Raleigh's greenway system shows how connected green paces can be used to accomplish social justice and ecological resilience in urban development. The study concludes with a detailed understanding of the benefits and problems associated with forest regeneration in urban settings.

Factors Affecting Seedling Regeneration in Raleigh's Urban Greenways

by

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DEDICATION

I dedicate my project to my parents, who gave me so much love and support, and to the Almighty God, for their care and nurturing throughout my life.

BIOGRAPHY

Amandeep Kaur Dhaliwal has a strong background in botany and is an enthusiastic explorer of the flora. She completed her master's degree in plant physiology after completing her bachelor's degree in botany, and her master's thesis was accepted for publication in the South African Journal of Botany. She made the decision to continue her education in the US at North Carolina State University. There, she pursued a second Master of Science in forestry with a minor in geographic Information Systems (GIS) under the esteemed guidance of Drs. Meredith Martin and Leah Rathbun. Her continuing interest in plants, which she studied extensively while attending NCSU, has influenced her academic career. Her natural interest and will to learn have led her to investigate the application of this knowledge in the subject of urban forestry, even though she only has a foundation in botany. She enjoys playing badminton and going on walks to explore the outdoors. As she continues her academic journey, she is expanding on her understanding of plant sciences and her experience is testament of the value of lifelong learning and pursuing interests outside of the classroom.

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CHAPTER 1: Literature Review

1.1 Introduction

The trend of urbanization worldwide is striking with 55% of the world's population in 2018 living in urban areas, up significantly from 30% in 1950 (Parris, 2016; United Nations, 2018). According to the United Nations (2018), there will be five billion people in the urban cities by 2028, and six billion by 2041. Urban green spaces are becoming more and more important to conserve as cities grow rapidly, resulting in what is frequently referred to as "urban sprawl" (Chiesura, 2004; Landers & Nahlik, 2013; Walmsley, 2006). In addition to providing recreational opportunities for residents that have a positive effect on their physical and mental health as well as socioeconomic status (Larson, Jennings, & Cloutier, 2016; Tzoulas et al., 2007), these urban green spaces are essential for promoting the environment.

As the Eastern U.S. continues to become more densely populated and urbanized, understanding how to incorporate urban forestry into city design is critical (Phillips et al., 2019, Massetti et al., 2019, Nowak, 2020). Among these, greenways stand out as linear parks that have drawn an increasing amount of interest within urban planning (Ahern, 1995; Fabos; Akpinar, 2016). By the 19th century, American communities had started implementing greenways as extended open spaces. According to Ahern (2002), greenways are purposely created land networks that serve a variety of goals, including ecological, recreational, and cultural ones. These goals are in line with the notions of sustainable land use; and greenways frequently have special qualities that make travel within urban areas easier (EJSCREEN 2020 report).

Urban trees provide numerous advantages. They primarily produce oxygen and simultaneously take up carbon dioxide and other airborne contaminants. According to research, urban trees in the United States are expected to help remove 75,000 tons of air pollutants annually (www.nps.gov, 2022). Trees reduce the effects of heavy rain by promoting ground absorption, which in turn lowers the likelihood of flooding and erosion and stops pollutants from contaminating water sources. Trees naturally cool the air by absorbing heat and producing water vapor, thus their shade serves uses beyond simple amusement (www.epa.gov, 2018). According to U.S. Forest Service research, trees reduce the amount of energy needed for cooling homes by over 7% in the United States. Increasing the quantity and quality of green areas has the potential to eliminate short- lived climate pollutants that have a significant impact on global warming and cause more than 7 million premature deaths yearly due to air pollution (Gordon,1986).

Urban greenways create natural vegetative trails that improve urban environments. According to De Groot et al. (2010) and Shafer et al. (2000), such greenways sustain wildlife habitat, improve air, and water quality, and perform critical flood control among other urban regulatory activities. Urban trails have proliferated across the world's cities, in part because of their ability to benefit the ecology of the built environment. Habitat loss, degradation, and fragmentation are only a few of the many ecological impacts of urbanization (Qian et al. 2018). However, evidence on the structure and function of greenways themselves is limited. Despite their potential to promote habitat connectivity by bridging the gaps between remnant patches throughout urbanized zones, greenways themselves are attractive. Undeveloped landscapes and unmanaged greenspaces are sometimes thought of as homogeneous "biological wastelands," despite research showing that they are best described as diversified landscape patches that provide animals with a diverse variety of possible habitats and transit pathways (Ignatieva et al. 2011, Kupfer et al. 2006, Pirnat 2000).

In addition to their ecological advantages, greenways anchor a plethora of socio-cultural advantages. By encouraging outdoor activities and creating links between different urban spaces, they improve the quality of life. These connections can boost well-being (Chiesura, 2004), encourage community engagement (Kazmierczak, 2013), and support a sustainable coexistence between humans and nature (Chon and Shafer 2009; Gobster 1995). By lowering the urban heat island effect and controlling temperature extremes, green spaces can also improve climate in urban areas. Air pollution causes heat wave occurrences and temperature increases and has been linked to an increase in the occurrence of heart attacks and stroke due to heat stress (Glen et al. 2010). Each tree that is specifically planted to provide shade could directly result in a 10 kg decrease in carbon emissions from power plants by lowering the requirement for air conditioning (Akbari et al 2002). According to the United Nations, air pollution alone costs Europe between $356 billion and $1,015 billion per year and results in 400,000 premature deaths (www.un.org).

Recognizing these benefits, urban centres are progressively investing in prominent green spaces or "hotspots" to spur economic development (Gould and Lewis, 2017) and serve as countermeasures to climate challenges (Oliveira, Andrade, and Vaz 201). Urban trees provide numerous advantages. They primarily produce oxygen and simultaneously take up carbon dioxide (CO2) and other airborne contaminants. According to research, urban trees in the United States are expected to help remove 75,000 tons of air pollutants annually (www.nps.gov, 2022). Trees reduce the effects of heavy rain by promoting ground absorption, which in turn lowers the likelihood of flooding and erosion and stops pollutants from contaminating water sources. Trees naturally cool the air by absorbing heat and producing water vapor, thus their shade serves uses beyond simple amusement (www.epa.gov). According to U.S. Forest Service research, trees reduce the amount of energy needed for cooling homes by over 7% in the United States. Increasing the quantity and quality of green areas has the potential to eliminate short-lived climate pollutants that have a significant impact on global warming and cause more than 7 million premature deaths yearly due to air pollution (Gordon, 1986).

1.2 Urban Forest Succession and Management

As natural forest ecosystems develop, a few consensus-driven changes are seen at the community level. At the beginning, species that grow quickly and are less shade-tolerant dominate ecosystems. These pioneers eventually give way to species that develop more slowly and can tolerate shade (Brown & Lugo, 1990; Chazdon, 2012). This change represents the natural succession process of the forest. Along with greater taxonomic and functional richness, this succession is characterized by increased structural complexity, including enhanced basal area and stratification under the forest canopy (Guariguata & Ostertag, 2001; Chazdon, 2012). Human disturbance, especially in urban areas, can cause secondary forest development to follow a variety of unpredictable paths that deviate from traditional succession models (Gardner et al., 2009; Chazdon, 2012; Arroyo Rodriguez et al., 2017).

The current disturbances to the forest regeneration layer may influence the composition of the canopy in the future as trees in the overstory may die and be replaced, resulting in long term changes in the community dynamics (Franklin et al, 2009). There is a noticeable gap in comprehensive ecological data to guide planning processes (Beier and Noss, 1998; Shwartz et al., 2014; Viles and Rosier, 2001).

Understanding the various types of urban forests is essential to developing goals and strategies for efficient management. Urban arborists stick to strict guidelines set by recognized certification programs such as those provided by the International Society of Arboriculture, which prioritize ecological sustainability and public safety. There is a lack in best practices for these regions because, despite these well-established procedures for caring for urban trees, there are no standardized standards for managing more natural urban forest environments (Piana et al., 2021). In contrast to their rural equivalents, urban environments place distinct demands on plant life cycles, from seed germination to maturation, affecting the composition and growth patterns of plant communities. (Piana et al., 2019). As a result, non-native plant species proliferate in urban forests more frequently,

and the canopy and seedling layers' compositions diverge, changing the ecosystem's trajectory (Pregitzer et al., 2019a; Piana et al., 2021).

Urban forest projects in North America usually aim to increase the urban tree canopy cover, species diversity, and different size of trees (Ordo´n˜ ez and Duinker 2013). These objectives highlight the ecosystem benefits that the urban forest canopy provides. The total number of acres of forests managed and maintained, as well as the expansion of UTC cover, may be the key goals and objectives for forest managers. Municipal plans frequently include social themes related to relating to community partnerships and education are also common in municipal plans. For instance, creating minimal distances to urban green spaces for all residents has become a municipal priority, and public access to greenspace—rather than only natural areas—has become an environmental justice problem (Mekala and Hatton MacDonald 2018).

There has not been a lot of research on succession in urban environments, especially when it comes to abandoned land (Rebele, 1992; Rebele, 2008). Most of the research has been done on European cities. The dynamics of vegetation in these urban environments are greatly influenced by non-native species, particularly in undeveloped areas, which causes a noticeable decrease in the richness of native species (Kuhn et al., 2004; McKinney, 2006). Because urban land is altered, different environmental circumstances arise, requiring species to adapt to survive and develop in these new environments.

1.3 Impacts to Regeneration

Urban forests have an important role, although research on their natural regeneration is still scarce (Lehvävirta and Rita, 2002, Massad et al., 2019, Piana et al., 2021). According to research, planted native species in urban forests frequently do not recruit or only rarely recruit their own progeny; instead, they primarily recruit from neighboring ex-situ trees (Robinson and Handel, 2000). Meanwhile, invasive, or undesired non-native species—which are more prevalent in urban areas— provide the majority of the local seed sources. Urban settings generally exhibit a consistent trend of introduced tree species predominating over native ones (Alvey, 2006, Toledo-Garibaldi et al., 2023, Jim and Liu, 2001, Muthulingam and Thangavel, 2012).

Urban activities play a major role in the spread of plants, as human activity and transportation networks facilitate the distribution of seeds. The seeds, or diaspores, of both domestic and foreign plants frequently wind up on clothing and vehicles, taking advantage of the network of roads, train lines, and walkways as efficient means of dispersal (Nemec et al 2011, Kostrakiewicz-Gierałt et al 2021, Gmyrek, and Pliszko 2022). On the other hand, because urban regions are avoided by many wild animals or limit their movement within urban ecosystems, urbanization may have a negative impact on the spread of zoochorous plants (Gelmi-Candusso et al 2019). The soil characteristics and species composition of the areas near the trails are considerably impacted by the creation of spontaneous routes by travellers, runners, and cyclists.

Researchers are becoming more interested in the effects that spontaneous use of trails may have on the soil characteristics and/or plants in patches near trails in urban forests. Foot traffic from humans influences natural places that goes beyond diminishing the amount of vegetation, plant height, and species variety. Visitors' constant walking on top of and trampling on the soil cause compaction, which in turn impacts the soil's structure by lowering its porosity, retaining less moisture, and having less organic matter in it (Kuss, 1986; Jim, 1993; Grieve, 2001; Kutiel & Zhevelev, 2001; Andre´s-Abella´n et al., 2005). Moreover, the physical and chemical characteristics of the soil as well as the composition of the herbaceous layer might be impacted by the deposition of food remnants and ashes by visitors (Sarah & Zhevelev, 2007; Zhevelev & Sarah, 2008). Studies in the past have mostly focused on the effects of official and informal trails on the forest strata (Referowska-Chodak, 2019, Sikorski et al,2008; Ballantyne et al 2015, McWilliam et al 2010, Sarah et al 2015), the properties of the soil (Ballantyne et al 2015, McWilliam et al 2010), and the impact of spontaneous pathways on habitat fragmentation (Kostrakiewicz-Gierałt et al 2021).

According to other studies, trails have a significant impact on ecosystems. High-use trails typically result in a decrease in plant cover near the trail (Cole 1995a, 2004; Hamberg et al. 2010; Mason et al. 2015; Parikesit et al. 1995; Sun and Liddle 1993; Wolf and Croft 2014), particularly for woody species (Cole 1995b; Cole and Monz 2002; Cole and Trull 1992; Pescott and Stewart 2014; Sun and Liddle 1993). However, in certain cases, the presence of trails either increased plant life and species variety or had no impact on it (Are´valo et al. 2008; Bright 1986; Hall and Kuss 1989; Queiroz et al. 2014).

Humans have introduced alien plant species all over the world, and many of them have become invasive. According to Vila et al. (2010) and Vila and Hulme (2017), they have altered ecosystems for millennia with significant negative repercussions on the environment and human well-being. Agriculture, forestry, and industry have all contributed to an incline in the number of invasive species, which has not yet reached saturation (Seebens et al., 2017; van Kleunen et al., 2015; Pyek et al., 2017). Urbanization, as is well known, encourages the influx of invasive plant species.

In metropolitan environments, a variety of environmental conditions and human activities influence the abundance, diversity, and dispersion of alien plant species (Kostrakiewicz-Gierałt et al 2021). Invasive plants often have a negative impact on ecological integrity and the availability of ecosystem services (Ehrenfeld 2010; Liebhold et al. 2017), particularly when they influence native species composition, species richness and abundance, and forest regeneration (Hejda, Pyek, and Jarok 2009). Worldwide, numerous invasive species have taken over sizable portions of numerous forested ecosystems (Bradley, Early, and Sorte 2015). River and alluvial soils, woods and related rusty soils, and locations of intense human activity, including areas of urbisols and industriosols, are the most significant variables for the distribution of invasive alien species in urban settings.

For example, the invasive species Ligustrum sinense, known as Chinese privet, has successfully spread across one million hectares of forest undergrowth in the southeastern parts of the United States (Miller, Chambliss, & Oswalt, 2008). During the 19th century, L. sinense was brought from Southeast Asia as an attractive shrub. However, because it was spread by animals like birds and mammals, it eventually escaped into the wild. Chinese privet has taken advantage of accessible ecological niches by spreading its seeds widely through animal digestive systems, making efforts to monitor and prevent its expansion more difficult. With very little restrictions, it has spread from Massachusetts across Florida and Texas and down to Florida. Once established, Chinese privet drives away native plants from the once-open forest canopy close to disturbed regions, resulting in a monoculture. By shading out and outcompeting the native plants, it inhibits the establishment of native plant seedlings, leading to a fall in the population of native plants (Greene & Blossey, 2012). Due to Chinese privet's tendency to prevent other species from germinating, the diversity of native flora may significantly reduce, thereby turning once-diverse ecosystems into monocultures dominated by this one plant (Hart & Holmes, 2013). This invasive shrub can quickly take over wooded areas regions in the absence of new plant seedlings. Due to their dynamic nature, which includes frequent flooding events that typically support a high variety of species, riparian zones—ecosystems that are adjacent to rivers and streams—are particularly vulnerable to such invasions (Hood & Naiman, 2000; Hulme & Bremner, 2006; Planty-Tabacchi et al., 1996; Pysˇek & Prach, 1993).

The aspect or orientation of a slope affects the number and variety of plant species in an environment. Studies reveal significant differences in species richness and biomass between slopes that receive sunlight directly and those that don't (Badano et al., 2005; Gong et al., 2008). These microenvironmental factors, which include high soil penetration depths and a large amount of cover by herbaceous vegetation, promote higher rates of infiltration of rainfall and improve the soil's ability to hold onto water (Sarah, 2004). These microenvironments were not subject to visitor pressure. Soil moisture levels in these microenvironments were anticipated to be high. The flat, or planar slopes were the only ones with the observed elevated moisture content. On the other hand, a region situated on a south-facing slope with a 5° gradient had more sunlight exposure, which resulted in increased rates of evapotranspiration and decreased soil moisture (Kirkby et al., 1990). According to Sarah (2004), the process of runoff formation on sloping surfaces impedes plant growth by causing the nutrient-rich topsoil layer to erode. The gully formation and the observed decreased vegetation metrics in the exposed, bare soil patches typical of intentionally modified slopes are caused by this mechanism.

Medium-sized gaps caused by disturbances in particular increase the complexity of conditions at the forest floor, supporting a variety of tree species regeneration (Helbach et al 2022). In general, it is still unclear how different disturbance patterns (such gap sizes and gap structures) affect the success of regeneration, especially when considering climate extremes into consideration. Plants frequently interact with other biotic interactions in ways known to have significant effects on light (Odling-Smee et al., 2003; Thakur and Wright, 2017). Examples of these interactions include competition and facilitation. For instance, competition among plants might change the lighting beneath them; consequently, these new lighting circumstances will unavoidably change how the light affects smaller plants. The rivalry between plants with various heights may become more asymmetrical because of these changes in light circumstances (Hautier et al., 2009; Inman-Narahari et al., 2016). To better understand and safeguard the understory plant communities, more reliable research on the filter effect of light is required. Previous evidence of light based on species mix of forest understory plants may have been affected by these confounding factors.

Throughout the growing season, disturbances in forests have a major impact on the microclimate by raising local temperatures, lowering humidity, and enhancing light penetration through canopy gaps (Kova´cs et al., 2020; Thom et al., 2020). The microclimate of the understory is dramatically altered by these tiny openings in the forest canopy, particularly in the vicinity of the forest floor. Seedlings are more fragile because of their increased sensitivity to these environmental changes (Blumroder et al, 2021). There shorter root systems and lower capacity for storage make them more vulnerable to different stresses than mature canopy trees (E Silva et al., 2012; Leuschner, 2020).

A more useful framework for evaluating management outcomes and directing future strategic decisions, however, is provided by using a set of performance-based criteria and indicators which include elements of the vegetation resource, community engagement, and management techniques (Kenny et al., 2011). The loss of important tree species or a shift in the ecosystem's structure from forests to shrublands can have a significant impact on biodiversity and ecosystem services, which makes the incapacity of forests to successfully regenerate a serious concern (Barnosky et al., 2012; Reyer et al., 2015).

1.3 Socioeconomic disparities

There are numerous explanations for the unequal utilization of greenways and other green spaces. White users' opinions of cultural benefits were much lower than those of Hispanic users, probably because Hispanic people place a higher priority on outdoor activities and group socialization (Chavez 2008, Shinew et al 2004). Although these advantages are commonly felt by greenway users, their use may not be uniformly distributed among the population. Users of the Greenway are typically White, have good incomes, and have advanced degrees (Coutts & Miles, 2011, Keith et al 2018, Lindsey 1999, Lindsey, Han, Wilson and Yang 2006, Reed 2014, Wolch et al 2010). There is conflicting evidence about low-income and members of racial and ethnic minorities' access to the availability of greenways, possibly because of the complex characteristics of urban environments. In many cities, there are more parks in white, affluent neighbourhoods (Abercrombie et al 2008, Rigolon 2016, Rigolon, Browning, Lee, and Shin 2018). These results, meanwhile, are not applicable in every situation.

Others have reported that low-income members of racial and ethnic minorities have more access to greenways than do people with greater incomes (Lindsey, Maraj, & Kuan, 2001). However, some have found that neighborhoods with a greater proportion of low-income members of racial and ethnic minorities have smaller, lower-quality parks than their White, wealthy counterparts. There is conflicting evidence regarding the equity of spatial distribution of parks and green spaces (Rigolon 201, Sister, Wolch, and Wilson 2010). According to Byrne and Wolch (2009), there may also be structural limitations, such as a shortage of free time, or a failure to consider the demands of racial and ethnic minority cultures while designing greenways (Crawford and Godbey 1987). Geographical limitations can make it difficult to discover the right physical location for the development of greenways (Miller, Collins, Steiner, and Cook, 1998).

Geng et al. (2021) emphasized the vital role that green spaces played in enhancing resilience during the Covid epidemic, attributing this to their positive effects on people's physical health, psychological well-being, and social cohesion. Previous studies highlight the importance of green spaces for health and well-being, with a focus on the connection between ethnic and racial characteristics and urban park accessibility (2011, 2014). Urban environments that incorporate green spaces and social ties have been shown to significantly improve residents' sense of safety. It

is noteworthy, nevertheless, that a large portion of the study on the psychological advantages of green spaces has been qualitative, often including socioeconomic factors in its analysis (Escobedo et al., 2011). Research on the function of green spaces in the built environment and their effects on health is severely lacking. Furthermore, it has been determined that physical activity in green areas is an essential component in improving mental health. For example, thorough assessments of research conducted in the Netherlands and the UK have shown that green spaces have a favorable impact on several psychological health-related factors (2010, 2009). The potential advantages of green spaces, however, may be jeopardized in some urban areas where drug dealers, criminals, and the homeless predominate, transforming what should be places of leisure and recreation into places that adversely impact locals' daily lives (Jacobs, 1993). The mere existence of vegetation does not ensure favorable outcomes in terms of physical or any kind of social activities. The location and design of urban green spaces are major factors that influence how these spaces are utilized by the community (Putnam & Quinn, 2007).

Therefore, finding new approaches to conserve and enhance the quality of urban greenery is more than just a recreational advantage; it is a critical tactic for tackling environmental issues and social inequality in urban environments. The ecological benefits of green spaces include biodiversity preservation, natural habitat conservation, species propagation, and flora preservation. According to Nowak et al. (2006), green areas have a crucial role in enhancing air circulation and offering shade, which helps to control urban heat and moderate ambient air temperatures. However, the actual worth of these urban green spaces relies on their alignment with the preferences of the local communities, underscoring the importance of community centric planning in urban green space development.

1.4 The Capital Area Greenway System - Raleigh

In Raleigh, North Carolina, which is a portion of the Southern Appalachian Piedmont, mixed oak- hickory-pine forests coexist with grasslands that are prone to fire. Notably, during the time of Native American occupation, the ecosystem of the area has been significantly influenced by land modification (Nature Serve 2015). In recent years, this area—often referred to as the Piedmont "megalopolis"—has experienced a rapid urban sprawl (Terando et al. 2014). Concerns about native biodiversity decline and habitat damage have increased because of this expansive growth in the Southeast US (Lawler et al 2014).

Launched in March 1974, the Capital area greenway system master plan sought to conserve green spaces in the face of Raleigh, North Carolina's rapid urbanization and growth (Lee, 2023). The number of Americans who live within 50 miles of national forests increased by 36% between 1990 and 2010, and this trend is predicted to continue (English et al., 2015).

Trails made possible by this funding fall into two main categories: park trails, which are located inside a single park area, and connector trails, which are essential for connecting parks and other recreational places. Due to this distinction, a large network with multiple access points dispersed around the region can be established (Lee, 2023). The development of the greenway system took place between 2010 and 2015 with the aim of showcasing the diverse ways that greenways are utilized and appreciated. Many kinds of greenways were created; some connected neighborhoods to the downtown region or additional commercial areas, while others were more isolated.

According to Raleighnc.gov (2012), this expansion has greatly improved accessibility to Raleigh's parks, enabling a larger portion of the population to participate in outdoor activities and establish connections with the natural environment. Furthermore, numerous sections of the Capital Area Greenway System are essential for controlling stormwater runoff and assisting with efforts to manage floodplains, both of which increase the city's resilience to natural catastrophes (raleighnc.gov, 2012). Numerous native, late-successional riverside trees are still thriving despite the massive construction surrounding the greenway, demonstrating that natural vegetation may survive even in isolated city regions (Chin et al. 2020). It's interesting that the areas of the greenway with sparse tree cover were mostly found in areas that were in agricultural zones, which provided little support for woody species. Meanwhile, disturbed forests, marshes, and urban areas all contained portions with reduced canopy but increased impervious surfaces. A slight increase in species variety was caused by this diversity. According to many studies (Booth et al. 2003, Flory and Clay 2009, Kupfer and Runkle 2003, LaPaix et al. 2003), places with denser tree populations, greater diversity, and richer species compositions were typically found farther from roadways, closer to water bodies and floodplains, and under wide canopies (Booth et al 2003, Flory and Clay 2009, Kupfer and Runkle 2003, LaPaix et al 2012).

Managing greenway trails for succession of tree species involve a multifaceted approach, addressing not only the promotion of native vegetation but also the control of invasive plant species, such as Ligustrum sinense (Chinese privet), which poses significant threats to local ecosystems. To maintain the sustainability and well-being of these important green areas, management plans for greenways in the United States frequently combine community involvement with ecological restoration concepts. Invasive species must be eliminated or controlled as part of this management to support the healthy development of native plant ecosystems (U.S. Forest Service, 2021).

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CHAPTER 2: Factors affecting seedling regeneration in capital area greenway system

2.1 Introduction

In 2018, approximately 88% of the U.S. population, or 281 million people, resided in one of the 383 metropolitan areas (US Census Bureau, 2018). Between 2010 and 2018, these metro areas witnessed an average population growth of just over thirteen percent which is six percent greater than national average (Carolina Demography, 2020). The largest growth increases were seen in Austin (26.3% growth), Orlando, (25%), Raleigh (20.5%), Houston (18.2%), and San Antonio 17.5%. By 2018, Raleigh had gained 232,000 residents when compared to 2010.

The loss of forest cover is a significant environmental impact of increasing urban populations (Heimlich and Anderson, 2001; Hall et al., 2002). For example, in Rhode Island, where the population has increased approximately twelve percent from 1972 to 2006, urban expansion resulted in a 10% loss of forestland over the same timeframe (Butler et al., 2008). Deforestation has had a particularly negative impact on ecoregions such as the Piedmont, the Southern Coastal Plain, and the Northeastern Highlands. Due to distinct types of development, the Piedmont region, a plateau region located in the east which stretches from New York to central Alabama, has lost a sizable amount of forest cover, including over 530,000 hectares to residential and commercial development and approximately 225,000 hectares to mechanical disturbances (White and Lloyed, 1998). These changes in land use have resulted in conservation strategies receiving more attention. More privately held lands are being protected through local, state, and regional land trusts prompted by the interface between growing urban areas and remaining forests (Theobald, 2004).

Urban areas tend to be epicenters of poverty and health problems, and the ability of trees to provide ecosystem services can be a key factor in reducing these concerns. According to Theodore (2018), the term "urban forest" refers to all trees that may be encountered inside a city, including those on the streets, in parks, and in other green areas like rooftops and nurseries. Networks of connected green spaces are extremely beneficial to metropolitan communities. They provide recreational opportunities, raise living standards, and supports environmental sustainability. According to Zong et al. (2010), these networks serve as habitats routes for animals, which contribute to the conservation of biodiversity. Moreover, studies show that different types of biological processes, including distributed seed and diminished edge impacts, can promote forest regeneration using these greenways (Beier et al., 2017). Raleigh is currently one of the fastest growing metropolitan cities in the United States.

Interestingly, City of Raleigh greenways are permitted to function as tree conservation zones provided that primary tree conservation areas are established, and a 25-foot width multiplied by the length of the route is excluded during development. Urban forests face challenges as they are frequently impacted by human activity (Picektt et al., 2001). A rise in invasive species has been associated with elements like canopy gaps and proximity to green way trails (Charbonneu & Fahrig, 2004; Burton et al., 2014; Daneils & Larson, 2020). There are various mechanisms which drive the invasion of non-native species, including the spread of ornamental plants from adjacent landscapes (Reichard & White, 2001; McKinney, 2008; Lehan et aal; 2013), historical land -use patterns (Picektt & Cadenasso, 2009; Ziter et al.; 2017; Trammell et al., 2020), and specific disturbances affecting stand continuity and canopy formation (Ehrenfeld et al., 2001; Mavimbela et al., 2018; Dyderski & Jagoodzinski, 2019).
The tiny seedlings are the principal barriers of regeneration plant species and are vital to maintain the stability of the growth of urban forest communities (Liu et al, 2017). The land use history and the changes it has undergone over time are the factors which are influencing the rate and extent of ecological succession. In addition, resource competition with understory vegetation, and proximity to seed sources are additional biotic factors that may inhibit natural regeneration (Ponge et al., 1998; Go mez-Aparicio et al., 2008; Milakovsky et al., 2011; Bose et al., 2016). Greenway trails are the major defense against some of the negative consequences of urbanization, but their capacity to promote urban forest regeneration depends on planning and considering both biotic and abiotic factors.

Our study is investigating how environmental factors affect seedling regeneration in urban greenway systems. We examine the relationship between different environmental factors and social factors that impact the seedling composition and decide whether emergent vegetation can thrive in urban environments. Our research concentrates on how light availability functions, as this is a vital factor in determining the ability of tiny seedlings to get involved in photosynthetic actions. Moreover, we are understanding other factors such as slope, aspect, edaphic factors etc. to understand their influence on seedling regeneration in urban forests.

2.2 Study area

The study was carried out within the greenway system of Raleigh, North Carolina. There are currently about 3,803 acres of greenway open spaces in the city as of 2014 (City of Raleigh, 2017). The 1976 original draft of the Capital Area Greenway (CAG) master plan was last updated in 1989 (City of Raleigh, 2017). Boasting 117 miles of trails and 371 miles of interconnected corridors, the CAG System connects communities across Raleigh, earning it a reputation as a premier greenway network. According to Little (1990), Raleigh is regarded as a pioneering city in the United States in the adoption and advancement of contemporary greenway systems. The study area has a diverse greenway trail throughout the city including Rocky Branch Trail Extension, Crabtree Creek Trail, and Neuse River Trail.

The current greenway trails weave through different sections of the city, with a few going through downtown and others found in more remote areas along rivers and creeks (City of Raleigh, 2017). There are more than 30,000 acres within a quarter mile of the greenway system, and each trail experienced different changes between 2001 and 2016. A few trails are also a part of the East Coast Greenway and the Mountains to Sea Trail, including the Neuse River Greenway. Struggling to keep up with the rapid development, Raleigh began to experience significant environmental and flooding problems that needed to be addressed. City managers and the US Army Corps of Engineers worked together to develop a flood control program, which originally proposed the construction of 25 different flood retention structures, including Lake Crabtree (City of Raleigh, 2017). These different flood control structures could also serve as recreational spaces, which is why many of them have greenways or parks around or near them. Greenways are located along the watercourses within Raleigh and protect the floodways along these corridors. The greenway is a corridor typically 50 to 150 feet in width, extending from the top of the stream bank (CAG Master Plan, 2021). This corridor may or may not be developed to provide access. If access is provided, the greenway trail may be natural surface, boardwalk, or a hardened surface such as concrete or asphalt.

The city of Raleigh experiences hot and muggy summers, short and cold winters, and a consistent pattern of partial cloudiness and precipitation year-round. Temperatures typically range from

33°F to 89°F, with possible minimum temperatures below 20°F and maximum temperatures above 95°F (NOAA, 2016). The growing seasons vary from year to year with spring beginning from March 1st to May 15th and fall beginning between September 1st and November 30th.

Annual rainfall fluctuates between 30 and 36 inches, (NOAA, 2016). According to the Natural Resources Conservation Service (NRCS), Cecil soil is the most common type of soil in North Carolina, covering over 1.6 million acres. The area of Raleigh has firm gravelly sandy loam soil (NRCS, 2016). The study area features various topographical elements (Table 1) including slopes ranging from 2 to 22 degrees, and aspects ranging from 12 to 353 degrees. The slope and aspect were calculated utilizing tools such as surface toolset (slope and aspect) ArcGIS pro for the study.

Social vulnerability is an important narrative of our study. Community's social vulnerability is described as the degree to which a community exhibits certain social conditions, including high poverty, low percentage of vehicle access, or crowded households, may affect that community's ability to prevent human sufferings and financial loss in event of disaster (CDC SVI, 2018). SVI leverages 16 U.S. census variables to calculate the relative vulnerability of every U.S. Census tract, ranking these tracts based on 15 social factors across four thematic areas: socioeconomic status, household composition and disability, minority status and language, housing type and transportation. In this context our study utilized the data gathered from American Community Survey (ACS), 2014-2018 (5 year) data in form of shapefile for estimating the overall vulnerability which included all four themes (Figure 1).

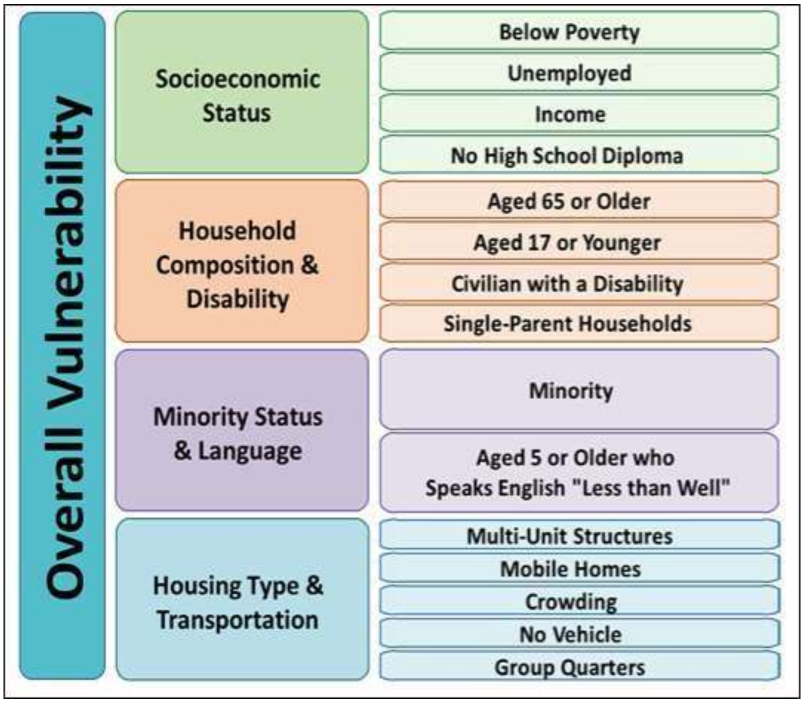

Figure 1: The variables used in our study (ACS, 2014-2018 (5 year) data for the above estimates.

The polygons were created based on percentile ranking values range from 0 to 1, with higher values indicating vulnerability (CDC SVI, 2018). Tracts in the top 10%, i.e., at the 90th percentile of values, are given a value of 1 to indicate high vulnerability. Tracts below the 90th percentile are given a value of 0. The SVI indices were ranked as: 0-0.17, 0.17-0.29, 0.29-0.67, 0.67-0.98. Based on this the SVI indices were classified as Low, Medium Low, Medium High, and High (Figure 2). The High SVI represents high vulnerability, which depicts low socioeconomic status in that area.

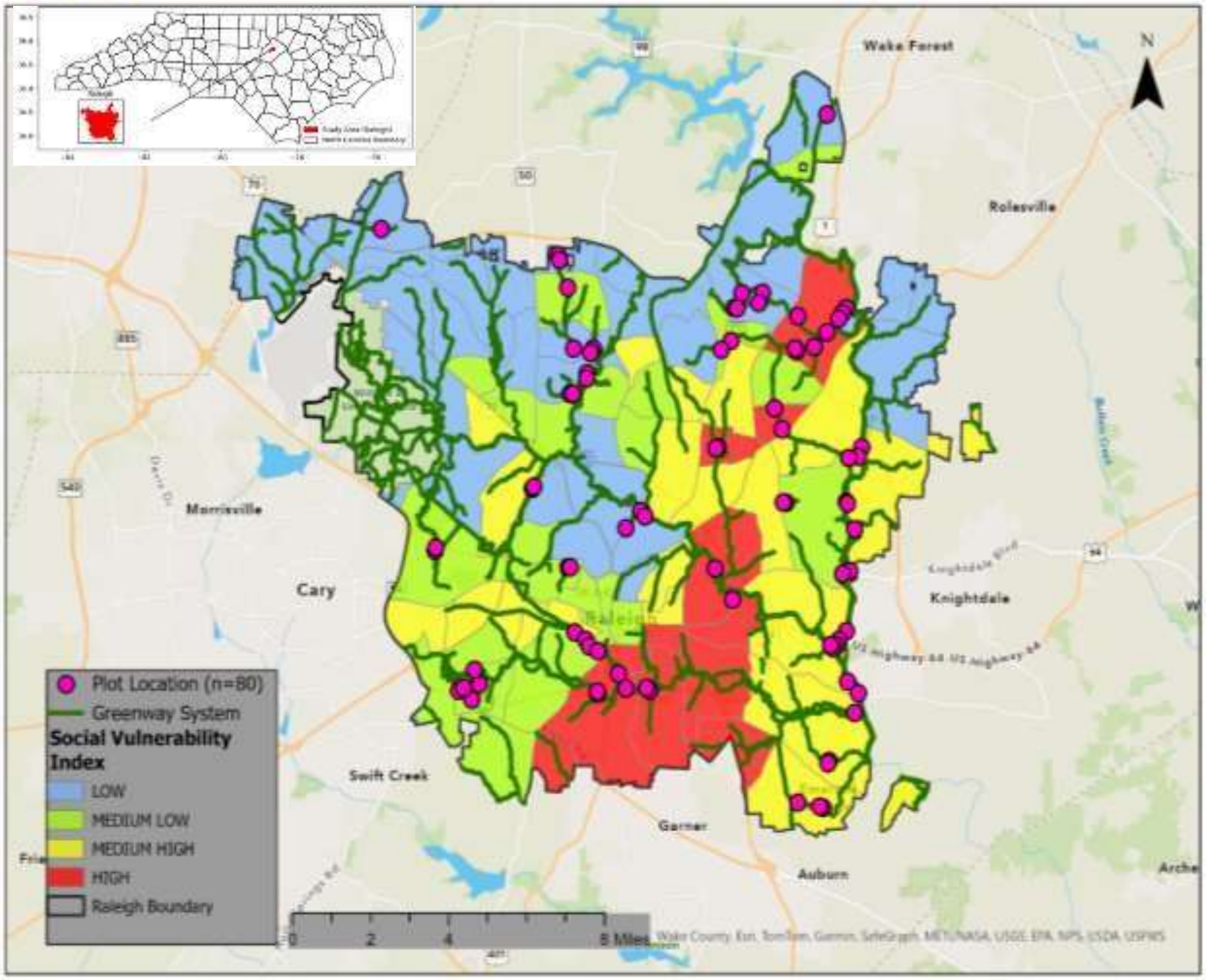

Figure 2: Socioeconomic Disparities and Greenway Trails in Raleigh, North Carolina, USA. (n= total number of plots)

2.3 Data Collection

Eighty plots were distributed across four distinct socioeconomic neighborhoods based on four social vulnerability indices (SVI); low, medium low, medium high, and high (CDC SVI, 2018). Each socioeconomic strata contained twenty plots. Plot locations were determined randomly along greenway trails and open corridors using ArcGIS Pro. A 122-meter buffer was created using buffer tools on both sides of greenway trails and open-space corridors within the greenway system that contained at least ten percent of tree cover. Plot centers were randomly located within the tree cover buffered areas on each SVI strata and placed at least 30-meter apart from one another (Figure 3).

Figure 3: The map depicts the tree cover buffer along the greenway system on the study area. The selected plots (yellow color) meet the criteria (Map Author: Alejandra Betancourt)

A nested plot design was used to collect the data (Figure 4). A fixed, 10-meter radius plot located at plot center was used to measure all trees, defined as individual stems, both single- and multi- stemmed having a diameter at breast height (DBH, measured at 4.5 feet from the ground) greater than 10cm. For each tree the following was measured or recorded: species, status (live or dead), DBH, total tree height measured from the ground to the tip in meters.

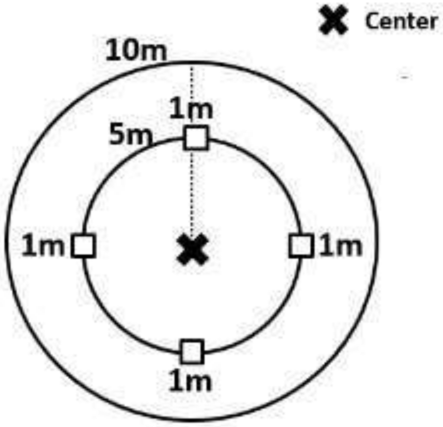

Figure 4: Nested plot design.

Saplings and midstory trees, defined as stems with a DBH between 2.5 and 10 cm, were measured on a fixed, 5-meter radius plot also located at plot center. For each sapling the following was measured or recorded: species, status (live or dead), DBH, total tree height measured from the ground to the tip in meters.

Four, 1 square-meter quadrant plots were established 5 meters from plot center along the cardinal directions (north, south, east, and west). On each quadrant seedlings, defined as stems greater than 20 cm in height were identified. Seedlings within all quadrants were counted, species were identified, and they were categorized as either native or invasive. *Carya* seedlings were identified only to the genus level; all other species were identified to species level. Seedling was classified into four groups which represent different growth stages: <20 cm, 20-50 cm, 50- 100 cm, and >100 cm.

An assessment of tree health was conducted by considering various parameters, including the presence or absence of climbers, the extent of dieback exhibited by each tree, and the count of tree stumps.

For the assessment of light availability, canopy closure was quantified using three methods: Densiometer, Go Pro Fusion, and ocular estimation. All three methods were applied within each quadrant. A convex spherical crown densiometer was used to identify percent canopy closure by measuring the number of obstructed dots within each engraved square on the device (USDA, 2018). Go Pro Fusion cameras were positioned at a height of 1 meter at the right corner of each quadrant. Various software tools, including Gap Light Analyzer, Canopy Cover Analyzer, and Forest Crowns, were harnessed to gauge the transparency percentage of forest crowns. Among these forest crowns was utilized for the final analysis that calculated the forest canopy transparency (light transmittance) using ground-based digital photographs taken with hemispherical camera lens at four carinal directions (Mathew et al 2016). The last method was the ocular measure used in the comparison, carried out by same observer in all sampling plots to estimate the canopy cover by eyesight for each plot from all four carinal directions (Silva 2006). The USDA FS provided sampling of polygons were used to classify the range (5 – 95%) of canopy cover (FIA field manual version 3.0). For each method, the average value was calculated on each plot.

Using ocular method, further quadrant evaluation encompassed the calculation of percent vegetation cover and percent invasive cover, with four delineated classes: <5%, 6-25%, 26-50% and 76-100%.

2.4 Data Analysis

In our analysis of plant community composition across different growth stages – namely trees, saplings, and seedlings, we employed species abundance curves derived from density per hectare measurement. Within each plot, the number of trees, saplings, and seedlings were counted to get these measurements. In our investigation, we employed Python 3.11 and the matplotlib tool to create species abundance curves based on ranks that illustrate the compositions of native and non-native vegetation. We were able to compare community structures graphically across different stages (Python Software Foundation, 2022).

We used Analysis of Variance (ANOVA) to look more closely at the correlation between species composition and Social Vulnerability Index (SVI). Furthermore, we used nonparametric multivariate techniques to investigate the relationship between environmental variables (e.g., slope, canopy cover %, soil pH, nitrogen and carbon content in the soil, and organic matter

percentage) and the seedling species composition. We specifically used Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson, 2001) and Non-metric Multidimensional Scaling (NMDS; Kruskal, 1964), all of which were carried out in the R statistical environment (R Core Team, 2013). We used the 'vegan' package in R for our multivariate analyses, with the ordination method 'metaMDS' for NMDS and 'adonis' for PERMANOVA. The Bray-Curtis dissimilarity was used as the distance measure method on a two-dimensional approach (k=2). To make sure that our test results were effective, we ran 999 permutations in our PERMANOVA. Additionally, we used Pillai's trace test in addition to MANOVA (Multivariate Analysis of Variance) with the "manova" function to evaluate the correlations between environmental variables and species composition to determine the significance of environmental variables on species composition.

2.5 Results

The study area features various topographical elements, including slopes ranging from 2 to 22 degrees, and aspects ranging from 12 to 353 degrees (Table 1).

Table 1: Summary of Environmental Factors at study area (n=80 plots)

Environmental Factors	**Mean**	**Range**
Slope (Degrees)	7	2-22
Distance from trail (Feet)	1727	7-14,251
Aspect (Degrees)	157	12-353

2.5.1 Species diversity and stand structure of urban greenway.

In total, our study revealed 64 distinct species across various strata, including canopy, midstory, and regeneration layers. Specifically, we documented 55 unique species of canopy trees, and there are, on average, 431 trees/ hectare (Table 2). As an illustration of a higher density of midstory, saplings exhibit a total of 42 species and a higher average density of 699 saplings/ha. With 33 different species and a noticeably higher mean density of 7,693 seedlings/ha, the data on seedlings.

Table 2: Number of species and stem density by category as means with standard deviation and total range for the 80 plots.

Category	**Total Species**	**Mean/ha**	**Range**
Trees/ha	55	431 ± 187	127 - 1,146
Midstory/ha	42	699 ± 622	0 - 2,928
Seedlings/ha	33	7,693 ± 13,140	0 - 101,115

Table 3 depicts the key structural characteristics of the urban forest, distinguishing between trees and saplings based on diameter at breast height (DBH).

Table 3: General characteristics of the forest inventory at measurement plot level

Variable	Mean	Range
Basal area (m^2ha^{-1})	38	3-91
Canopy Cover (%)	71%	24-91%
Trees Height (m)	18	0-72m
Saplings Height (m)	7	0-18m
Trees DBH (cm)	27	0-109cm
Saplings DBH (cm)	5	0-10cm

2.5.2 Species composition and successional trajectory

The abundance of several species was examined at three important growth stages—trees, saplings, and seedlings in our analysis. Among trees, the most abundant species per hectare was found to be *Liquidambar styraciflua*, with an average number of 63 trees/ha. This was closely followed by *Pinus taeda* and *Acer rubrum*, with average number of 53 trees/ha and 38 trees/ha respectively (Figure 5).

At the sapling stage, *A. rubrum* emerged as the most prevalent, with an average density of 91 saplings /ha. *L. styraciflua* also showed a significant presence in this category with 84 saplings/ha, while *Carpinus caroliniana* (muscle wood) had an average density of 60/ha (Figure 6). The

seedlings plots ($1m^2$) were dominated by the invasive *Ligustrum sinense*, which showed a remarkably high average of 14,125 per hectare. Other notable species included *A. rubrum* and *Quercus alba*, with mean density of 2,406 and 1,250 seedlings/ ha respectively (Figure 7).

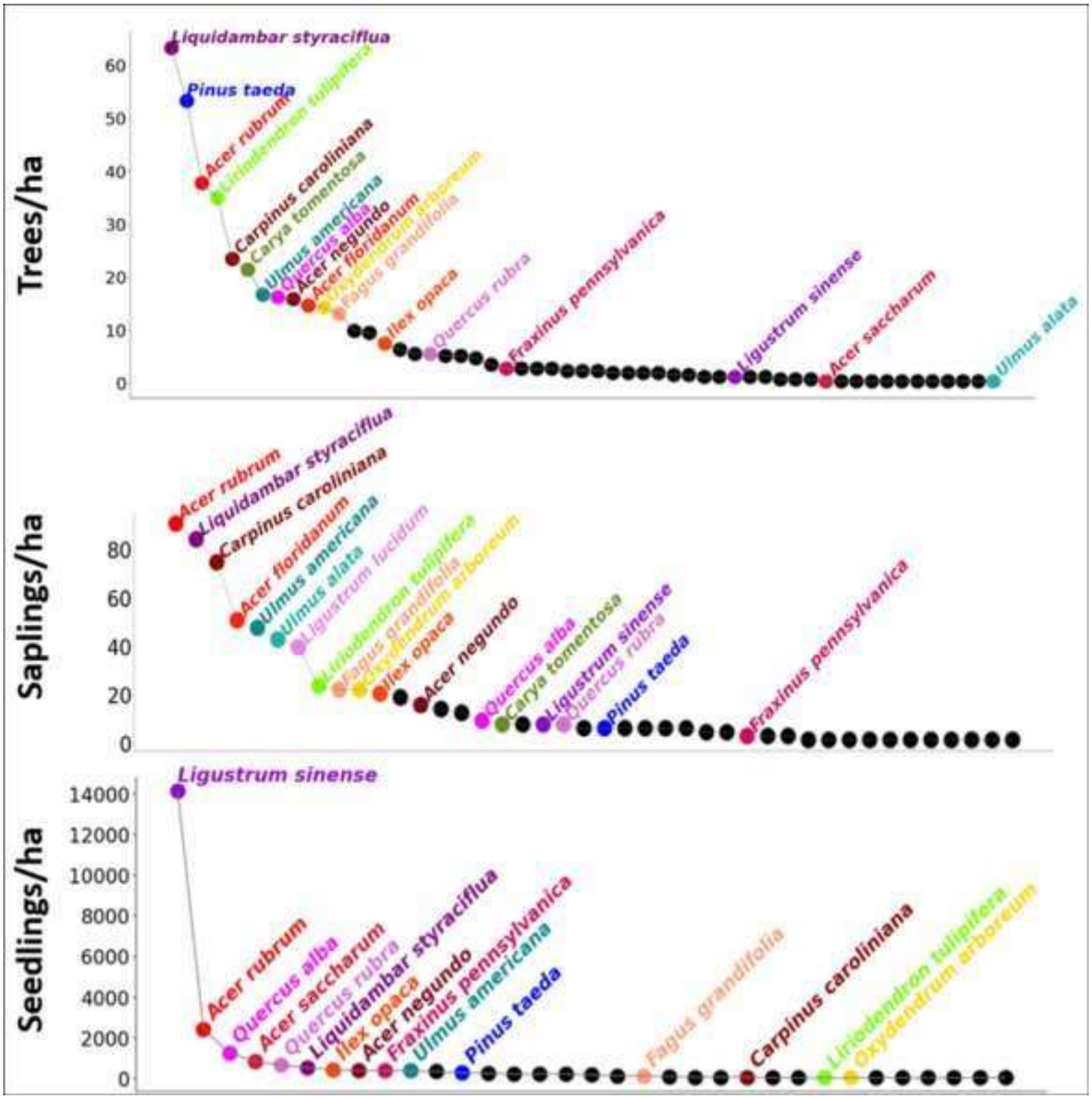

Figure 5: The rank abundance curve depicting the presence of seedlings with the dominance of Invasive species (Ligustrum sinense).

Overall, we observed the trajectory of Genus abundance across three stages: trees, midstory, and seedlings. It demonstrates *Acer* as the most prevalent genus among trees (69/ha) and midstory (157/ha), followed by Pinus (67/ha) among trees and Ulmus (97/ha) in the midstory. Liquidambar, commonly known as sweet gum also appears within the top three for both trees (63/ha) and midstory (84/ha). For seedlings, *Ligustrum* is most abundant (14125/ha), with Acer (3,635/ha) and Quercus (2/ha) also showing significant presence. Our findings indicated the abundance of plant family in the urban forest setting, marking the predominance of the Sapindaceae (Maple) family with density of 68 trees/ha among trees, the Sapindaceae (Maple Family) with 157 saplings/ha in the midstory, the Oleaceae (Olive Family) family with the maximum of 14,531 seedlings/ha. Following the leading families are Pinaceae (Pine Family) and Hamamelidaceae (Witch-hazel Family) which only constitutes sweet gum with 67 trees/ha and 63 trees/ha respectively. The Elm Family called Ulmaceae constitutes 105 saplings/ha, while Sapindaceae and Fagaceae (Beech) have seedlings with density of 3,625/ha and 2,281/ha respectively.

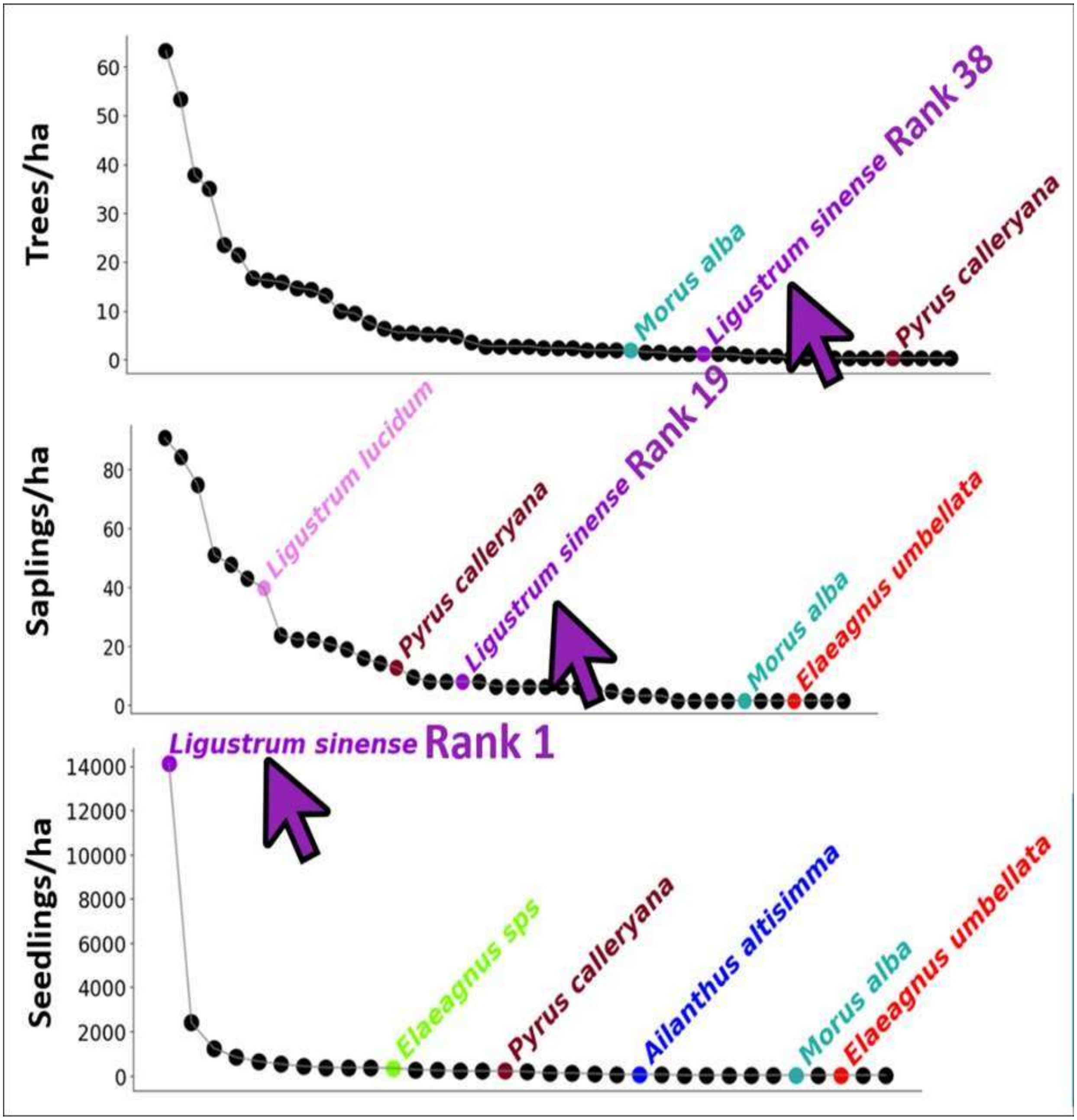

Figure 6: The species abundance curve highlights only the presence of invasive species in our study area. The invasive species are color coded based on ranks among trees, saplings, and seedlings. The plot highlights the rankings of Ligustrum sinense as its the species of concern found as most prevalent species in our study area.

2.5.3 Variability among socioeconomic strata affecting seedlings regeneration in urban greenway.

We conducted one way ANOVA to understand the relationship between seedling density and Socioeconomic disparities in urban areas. Our study showed that the important variable in our study, which is social vulnerability index does not have statistically significant (ANOVA; p-value= 0.273) effect on seedling density in urban greenways.

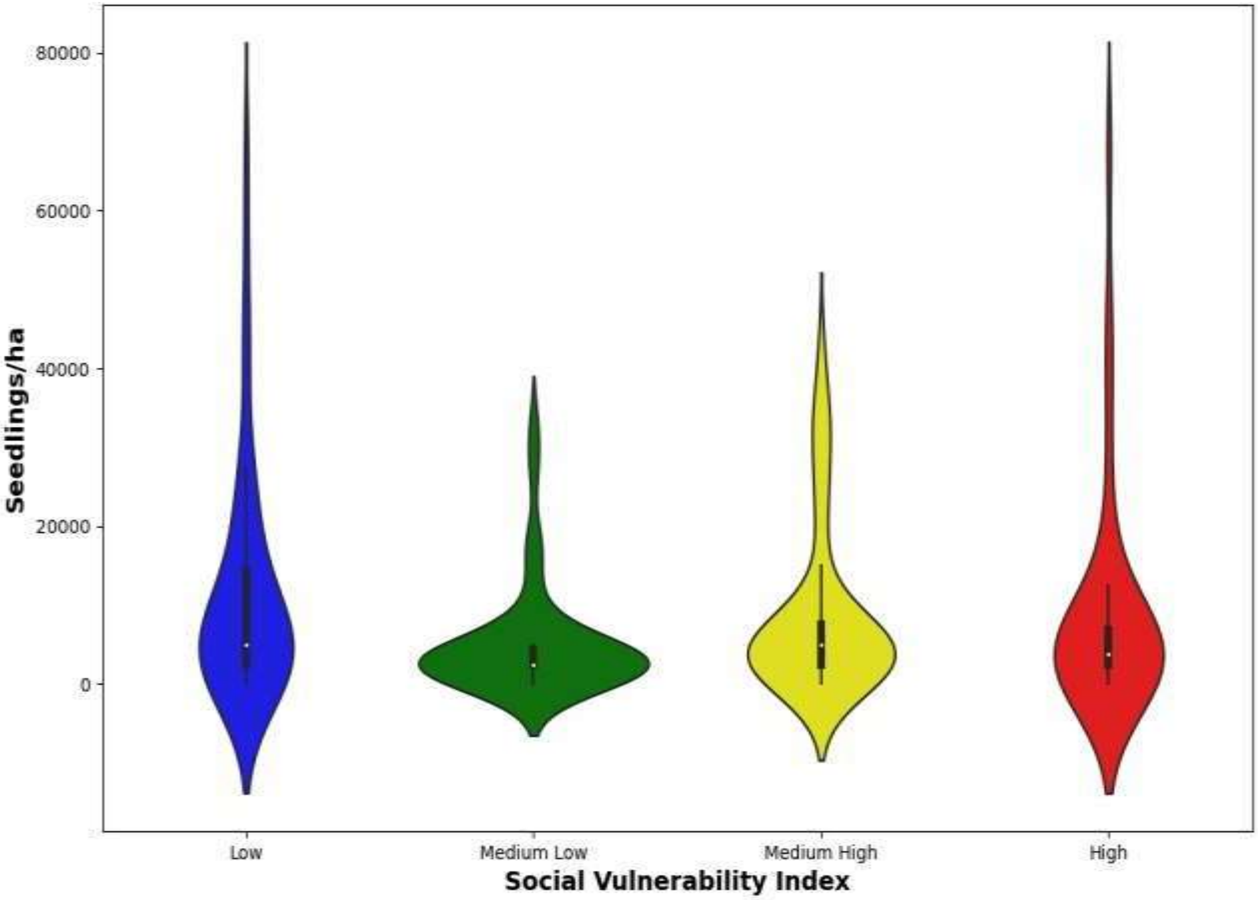

Figure 7: Socioeconomic disparities and seedling density (ha^{-1}) of urban greenways in Raleigh.

Our results showed a significant difference in seedling density/ha when comparing native with non-native species. We performed pair-wise Tukey test for which the results depicted that the mean difference is 8,372 seedlings/ha with a p -value of 0.0001, which is significant. Therefore, our results depicted that there's a significant difference between native and non-native species.

As the L. sinense (Chinese privet) is important part of our story we further studied the presence of Chinese privet in different socioeconomic categories.

Table 4: Ligustrum sinense presence in different socioeconomic categories in Raleigh's greenways. The ligustrum sinense was found in total 41 plots.

SVI	Mean	S.D.	Range
Low	26,667	21,034	5,000-67,500
Medium Low	9,500	7,583	2,500-17,500
Medium high	10,962	13,484	2,500-42,500
High	19,772	21,836	2,500-67,500

Our study revealed that Chinese privet mainly covers most of the study area irrespective of its presence in different socioeconomic strata. The Chinese privet species covered twelve and five plots among low and medium low socioeconomic strata respectively. While the maximum plots (n= 13) were covered by the species in medium high socioeconomic strata. In the high vulnerability index, about eleven plots were found with dominance of this invasive species.

2.5.4 Factors influencing the change in species composition in urban greenways.

To understand the relationship between change in species composition with environmental factors we performed non-multidimensional scaling (NMDS) analysis. In NMDS analysis (Table 5), we evaluated the associations between environmental factors and spatial distribution of seedlings. The SVI index was not statistically significant (p=0.900), which indicates a weak association with species distribution. Slope showed the most significant relationship to species (R^2 = 0.091, p=0.022*). Percent canopy cover showed a significant positive association (R^2=0.091, p=0.025*) indicating that areas with higher canopy cover are characterized by specific set of species. Distance from the trail was not a significant factor suggesting it does not play any role in explaining species distribution.

Table 5: Environmental factors affecting species distribution: NMDS coordinates and statistical significance.

Factors	**NMDS1**	**NMDS2**	**R Squared**	**Pr(>r)**
SVI	0.904	0.428	0.002	0.900
Aspect	0.736	-0.674	0.013	0.598
Slope	0.462	-0.887	0.091	**0.022***
Percent Canopy Cover	0.537	0.844	0.091	**0.025***
Distance from Trail (m)	0.034	0.999	0.009	0.698
Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Number of permutations: 999				

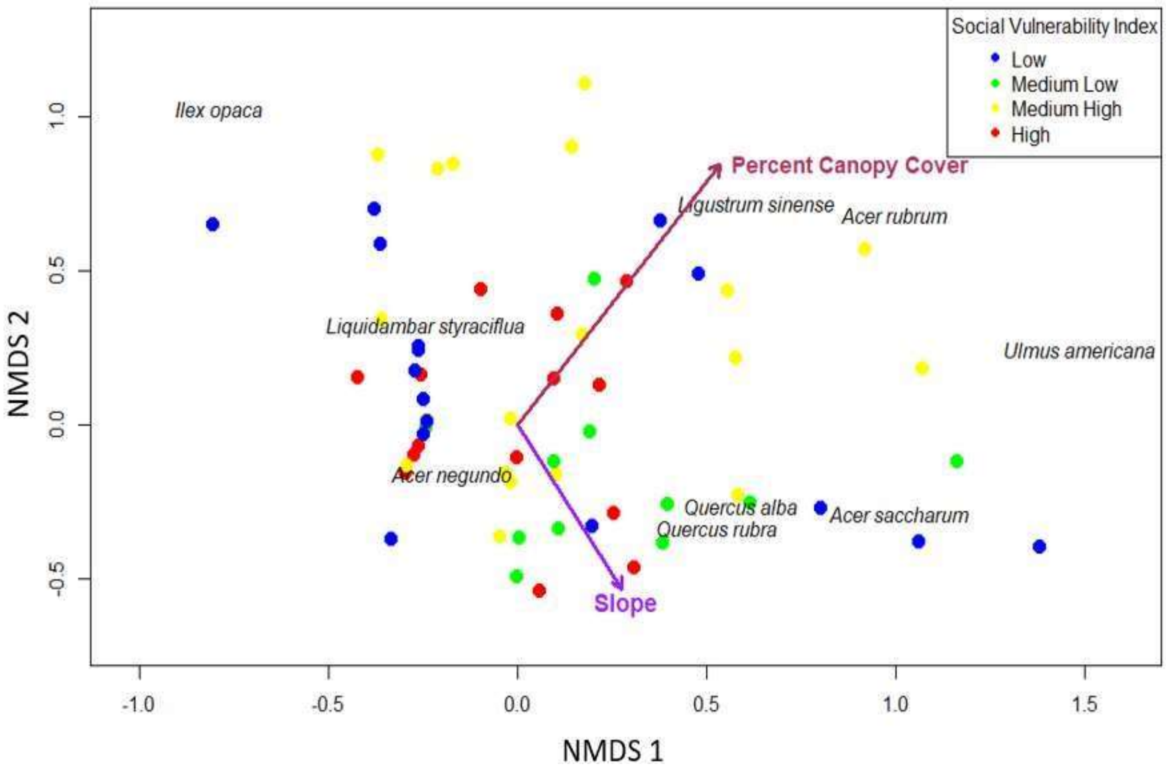

Figure 8: NMDS Ordination of species distribution by environmental gradients.

Non-metric Multidimensional scaling analysis was utilized to distill the complex environmental factors influencing species distribution within our study area. The NMDS ordination plot reveals a clear gradient of percent canopy cover, with shade tolerant species, such as L. sinense and A. rubrum, predominantly occupying areas with denser canopies. Conversely, Quercus (Oak) species exhibit a correlation with steeper slopes. In our results, the NMDS plot shows that species distribution is influenced more significantly by environmental factors such as slope and canopy cover rather than by the social vulnerability index (SVI).

Our statistical analysis (Table 5) corroborates these visual findings, highlighting slope (R^2 = 0.091, Pr(>r) = 0.022*), and percent canopy cover (R^2 =0.091, Pr(<r) = 0.025*) as significant factors in species distribution. Notably, the social vulnerability index (SVI) did not show a significant correlation with species distribution patterns (R^2=0.002, Pr(>r) = 0.900).

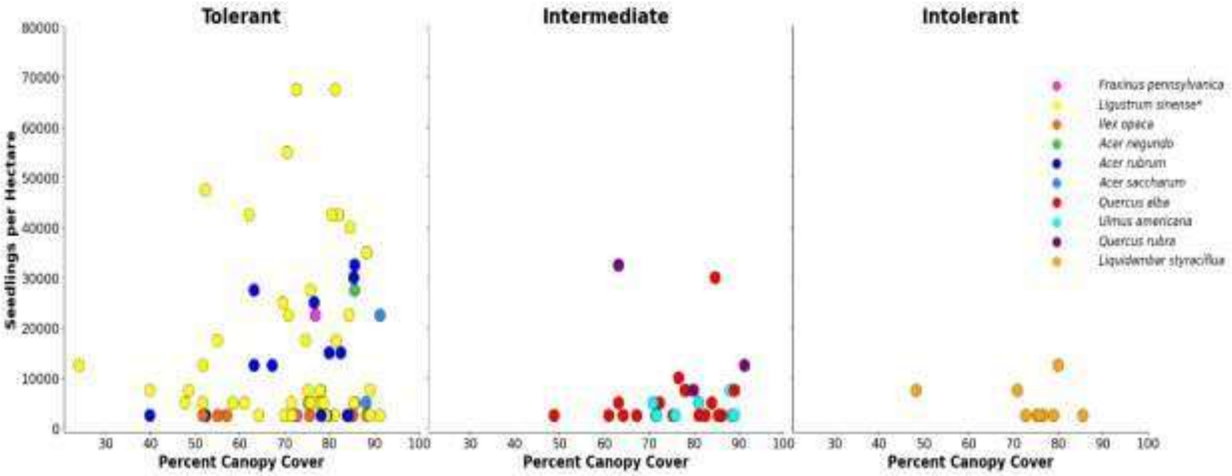

Figure 9: The Relationship between percent canopy cover and seedling density/hectare, categorized by shade tolerance levels: Tolerant, Intermediate, and Intolerant. The top species are selected on the basis of their presence in at least eight plots.

In our study area, a significant observation (Figure 10) is the high average canopy cover, which is approximately 70%. We have also found that most of the species in regeneration layer are identified as shade tolerant and native. Among these predominantly native species, *Ligustrum sinense* stands out as an invasive species, which is an integral part of our narrative. Interestingly, in plots where L. sinense is present, it tends to dominate, exhibiting higher seedlings per hectare compared to other species.

Furthermore, Sweetgum (*L. styraciflua*), is the only shade intolerant species among the top categories. It aligns with the observed trend of shade-tolerant species regeneration.

2.6 Discussion

Our work has revealed the relationship between species composition and environmental conditions in the exploration of forest regeneration within our urban greenway system. The composition of the forest has significantly shifted toward late-successional species, which is indicative of a natural developmental progression. However, this shift coincides with a concerning decrease in the diversity of plants in the understory or regeneration layer, which may have an impact on the long-term resilience and functionality of the ecosystem. Interestingly, the data shows no significant association with the Social Vulnerability Index (SVI), suggesting that in the city of Raleigh, social variables could not be the main determinants of seedling regeneration. A striking aspect of our findings is the regeneration of native species despite the prevalence of invasive ones, such as Ligustrum sinense, highlighting the inherent resilience of our forest ecosystems. The rising number of invasive species is a major problem too and focused on the immediate need for management initiatives aimed at protecting biodiversity.

2.6.1 Understanding seedling regeneration and socioeconomic disparities in greenway system

The real-world relationship between different social issues and urban forestry has acquired significant intention, showing complex relationships that impact ecological outcomes in the urban settings. There is an extensive number of studies which shows that income and urban forest cover are positively corelated, affluent neighborhoods typically benefit from higher percentage of tree canopy cover and the ecological services that it provides (Schwarz et al., 2015). Historical policies like redlining have had a substantial impact on the distribution of urban green spaces and tree cover, resulting in ongoing disparities in access to ecosystem services. Studies have related the current distribution of urban heat islands and tree cover to these practices; neighborhoods that were considered "undesirable" due to their socioeconomic, racial, ethnic, and religious makeup now have less tree cover and are more susceptible to heat (Hoffman, 2020; Locke et al., 2021; Nowak et al., 2022). Ecological injustices have been made worse by the legacy of redlining, which has encouraged systematic neglecting of minority communities, especially those in older, denser urban cores (Aaronson et al., 2021; Locke et al., 2021).

Our work clearly analyses potential socioeconomic disparities in seedling regeneration within urban greenway systems, which sets it apart from another existing research. Interestingly, there is not a correlation between seedling regeneration and socioeconomic position according to the results of our study. This might indicate that the City of Raleigh is using effective management strategies across a range of neighborhoods, deviating from the historical pattern in which ecological outcomes were determined by socioeconomic level. Redlining's historical background highlights a continuing issue, though: communities with a history of lack of investment have less tree cover and, because of their high levels of impervious surfaces, less space for future tree planting (Nowak et al., 2022).

Urban forestry can support more equitable green spaces by implementing tree planting programs in places that have historically been subject to redlining or have extensive impermeable surfaces. This could help eradicate environmental injustices. (Nowak and others, 2022). Along with enhancing urban ecosystems, these initiatives aim at addressing past injustices. As cities develop and change, it becomes increasingly important to implement management strategies that overcome barriers to tree growth and quickly address historical social injustices. Further research on the impact of these measures on seedling growth in urban greenways is necessary to establish resilient and equitable urban forests.

2.6.2 Ecological Progressions and Challenges: From Family to Species in Urban Forest Regeneration

Our study of urban forests reveals a rich ecological variety where the dynamics of regeneration are evident at all levels, from a range of familial variation to the individual species. Among seedlings, the Oleaceae and Sapindaceae are still prominent at the family level, indicating a steady future for the understory (Hanberry et al., 2018b). However, even though they are relatively uncommon in older forest layers, the Fagaceae family, which includes beeches and oaks, exhibits a strong dominance in seedlings (Abrams, 2003), suggesting that these species may eventually become more common as the forest ages.

On the other hand, Pinus—which was previously a prominent genus—shows a concerning decline, leading us to reevaluate its place in the urban forest landscape (USDA, 2022). This is especially true of Pinus taeda in North Carolina.

At the species level, the narrative becomes more specific and, in some ways, more urgent. Acer rubrum, known for its prolific seeding and growth under diverse conditions (Abrams, 1998), emerges as a symbol of ecological resilience. However, the story takes a different turn with Ligustrum sinense. This non-native species not only thrives in the seedling stage but exhibits a concerning dominance (Wenger, 1953), which could alter the forest composition in different ways. The success of Ligustrum spps. serves as an example for the threat of invasive species to urban forests, where rapid colonization may disrupt the native diversity.

2.6.3 Impact of invasive species on seedling regeneration

The remarkable average count of seedlings per hectare in our research area indicates that L. sinense has effectively established itself in the forest understory, partly because it was introduced for ornamental purposes in the past. According to triangle land conservancy's 2008 broad reach and urge for proactive control to slow its growth, this has implications for native biodiversity. Chinese privet was introduced to the United States in 1852 as an ornamental shrub and has now expanded over thousands of acres of hardwood bottomlands in North Carolina nearly 200 years later (Triangle Land Conservancy, 2008). It was preferred in landscaping because it could grow into dense, fast-growing thickets that were perfect for hedgerows and fencerows.

Among these predominantly native species, L. sinense stands out as an invasive species, which is an integral part of our narrative. Interestingly, in plots where L. sinense is present, it tends to dominate, exhibiting higher seedlings per hectare compared to other species. Although, L. sinense is ubiquitous in the seedling plots and implies an invasive potential that could change the composition of future forests, this dominance—especially that of L. sinense—corresponds with findings regarding the potential of species for quick colonization by aggressive sprouting.

2.6.4 Influence of environmental factors on seedling regeneration in urban greenway

Our research has demonstrated the strong influence of environmental conditions on the abundance of different types of seedlings in urban environments. After considering several variables, slope and the percentage of canopy cover were shown to be very significant, supporting the theory that the dynamics of plant communities are significantly influenced by the availability of light. We have also observed a dominance of dense canopy cover and few shade- tolerant species in the urban greenways. According to some research with comparable findings, understory vegetation is significantly impacted by canopy density, which probably prevents the proliferation of species that cannot withstand shade and encourages the shift of species to a community that is more suited to lower light levels.

A notable case within our study is that of *L. sinense*, which exhibits exceptional adaptability and regenerative capacity across a spectrum of canopy cover conditions. Its prevalence and dominance in numerous plots, particularly where the seedling densities are highest, are indicative of its competitive edge. This observation is underpinned by other studies which document the invasive spread of Chinese privet. Once established, it can create a dense understory monoculture by outcompeting and displacing native plant species, particularly in areas adjacent to disturbance (Greene & Blossey, 2012; Hart & Holmes, 2013).

One of the biggest issues deteriorating urban soils is compaction, which is frequently avoidable with proper maintenance operation management and advance planning (Patterson, 1976). It is caused by shear and stress forces applied to the soil by foot and vehicle traffic. We investigated correlations between soil properties and understory vegetation in urban greenways next to water streams to determine if soil conditions affect patterns in the composition of seedling species. The soil conditions of forest soils near metropolitan interstates are influenced by various factors, such as pollution originating from vehicles and surrounding land use, as highlighted by Trammell et al. (2011). Broader urban-scale effects (such as proximity to the city centre or industrial pollution sources) and historical legacies (such as disturbance from road construction) may have an impact on the distribution of soil characteristics. Numerous investigations have demonstrated relationships between soil's organic matter content, carbon content, and the quantity of heavy metals absorbed therein (Li et al 2006). We have found significant influence of soil organic matter and Percent carbon on species composition.

2.7 Conclusion

The study has found no significant correlation with the Social Vulnerability Index (SVI), reveals a meaningful correlation with environmental variables (Percent Canopy cover and

Slope). The regeneration layer’s composition is particularly telling of the ecosystem’s trajectory; it is currently dominated by late successional species, which suggest a resilience and progression towards a mature ecological state. The presence of native regeneration is a positive indicator, demonstrating an inherent canopy for recovery and resilience. Nonetheless, the current state of the study area presents a complex tapestry of dense and diverse canopy layers, mix with both native and invasive species. However, this hopeful sign is tempered by the pervasive presence of invasive species, especially Ligustrum sinense. This invasive species poses substantial threat to the ecological balance due to its aggressive nature, raising concerns about the potential future monoculture within the understory, which could diminish the future plant species diversity and alter the ecosystem functions. To ensure the health and sustainability of greenways, further research is essential to develop a deeper comprehension of myriad factors influencing urban forest regeneration. This includes implications of management decisions, which should be informed by adaptive management practices aimed at conserving and enhancing urban species diversity for the benefit of both environment and the socioeconomic fabric of human communities.

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