ABSTRACT

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Climate change will impact the suburban forest and the ecosystem services it provides. Diversifying and increasing the amount of canopy cover are considered fundamental strategies for mitigating impacts of climate change on the suburban forest. However, little is known about communities most at-risk to adverse effects of climate change, especially in communities where private homeowners manage trees. To understand which subdivisions are most at-risk, applied historical ecology was used to provide a frame of reference for assessing the vulnerabilities of suburban forests (n=76) throughout Fayetteville, North Carolina. Then I evaluated the socio-economic characteristics and, using a Likert-scaled survey, the adaptive capacity of the homeowners (n=76) within those subdivisions to mitigate and adapt the suburban forest. The most at-risk subdivisions were evaluated for potential risk factors that could be more broadly applicable for identifying at-risk subdivisions. The majority of trees in the study area had low to moderately low vulnerability, with higher vulnerability species being at the southern or eastern-most edge of their habitat range. Approximately half of the samples currently above 30% canopy cover are predicted to fall below 30% due to the impacts of climate change on vulnerable species. Evidence suggests that the modern-day presence of vulnerable species is related to (1) subdivision age, (2) changes in the land cover that occurred during early settlement, and (3) land use changes that occurred during the Great Depression and World War II. The strongest evidence suggests that land abandonment and the rise of ruderal species following the Great Depression is correlated with greater proportions of higher vulnerability species, indicating a possible land use trend. The capability, willingness and knowledge of homeowners to mitigate or adapt their forest to climate change was moderately correlated to income ($r = 0.46$, $p <$

0.0001), while inversely correlated to the proportion of minorities ($r = -0.25$, $p = 0.03$). The total number of land use changes occurring between pre-European contact and today was found to significantly improve the model for adaptive capacity from an adjusted R^2 of 0.20, for income alone, to an adjusted R^2 of 0.31. Within the sample, eight subdivisions were found to be at-risk to the adverse effects of climate change, none of which were high minority or low-income communities. Two possible risk factors were found: (1) the number of land use changes that occurred following the Great Depression and World War II and (2) the total number of land use changes that occurred between pre-settlement and today; however, the results from Monte Carlo simulations and Mantel-Haenzel testing were inconclusive. The results highlight the importance of including the historical perspective to increase effectiveness of management by identifying trends that may lead to greater risk, inform managers of possible outcomes for particular land management practices, and help to guide or constrain management actions in the future. Moreover, the historical perspective adds explanatory power to understanding of the current suburban forest and its vulnerabilities, which can improve predictive models, thereby reducing potential missteps. Additionally, the results are a cautionary tale against strictly relying on socio-economics, as the most at-risk subdivisions were not highest minority or lowest income communities. Nor should decision-makers neglect to consider future climatic conditions when considering canopy cover improvement goals. Integrating historical, socio-economic, and ecological factors into assessment, planning, decision-making, and management tools for suburban forests is needed. While the complexity and dynamic nature of suburban landscapes and tree vulnerability make identifying vulnerable subdivisions challenging, such understanding is of vital importance for sustaining the ecosystem services that suburban forests can provide for generations to come.

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Not in my Backyard: Suburban Forests and Climate Change

by
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DEDICATION

I dedicate this thesis to my little research assistants, Abigail and Grant Karp, who offered assistance in the field, many distractions, and more patience than can be asked of young children. I also dedicate this to my husband, Oliver Karp, for encouraging me, even during the most difficult times. I want to thank my aunt, Therese O'Toole, for her academic discussions, guidance, and inspiration. I also want to thank my uncles, Jimmy O'Toole and Jim King, for helping me at a crucial moment in my research. Lastly, I want to thank my father-in-law, Richard Karp, whose dedication to our family is unwavering.

BIOGRAPHY

My interests in people and the landscape began when I was a geography undergraduate in 2001 at the United States Military Academy at West Point, New York. After graduation, I was commissioned as an officer in the United States Army and began training in human resource management. After completing my training, I began a journey around the world, serving in a variety of job positions. My diverse experiences lend to my understanding of the interface between the human and natural environments. My interests include urban and suburban ecology, land transitions, and conservation in the built environment. The coursework I have pursued has sought to understand how various fields view the intersection of the suburban typology, the forest contained within it, and climate change.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Gary Blank, who helped me to navigate my way through this research. Thank you for letting me fall when I needed to fall, for keeping me from trying to solve the world's issues, and for helping to coalesce this paper.

I would like to thank Dr. Consuelo Arellano and Chandni Malhotra for their assistance with the statistical analysis. I learned more about statistics and statistical analysis in our discussions than a semester's worth of statistics class. Chandni, you have a knack for explaining statistical results with clarity.

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CHAPTER 1

INTRODUCTION

Suburban forests provide many social, economic, and environmental benefits. In the eastern part of the United States, for every dollar a city spends on street trees it will realize $3.25 (Raciti, 2006). Often the benefits trees provide go unnoticed until their decline begins to impact these benefits. A perfect example of this is illustrated in the Baltimore-Washington,D.C. area between 1973 and 1997. The canopy had declined approximately 15%, causing stormwater runoff to increase by 19% at a cost of $1.08 billion, in addition to $24 million per year to remove air pollutants (Cappiella et. al, 2005). This example also demonstrates the potential issues for people living in the suburbs that could arise as a consequence of climate change. With nearly half of the US population living in the suburbs and receiving ecosystem services the suburban forest provides, understanding the vulnerabilities and adaptive capacity of suburban forests is critical so that governments, subdivisions, and homeowners can plan for the future and act to lessen the impact of climate change (Frey, 2012).

To understand how climate change my impact the suburban forest, both the caretakers of the forest and the forest itself need to be considered (Dale, 1997). The research on suburban forests, especially with respect to climate change, is relatively limited (Wilby and Perry, 2006). The impacts that climate change will have on the suburban forest is just beginning to be understood, with studies completed for several metropolitan suburbs to include Chicago, Illinois; Atlanta, Georgia; Washington D.C., and Philadelphia, Pennsylvania (Brandt et. al, 2016; Lanza and Stone, 2016; Brandt et. al, n.d.). However, these studies focus on only one form of the suburban landscape where public trees make up a large portion of the canopy. These studies do

not consider suburbs where privately managed trees dominate, suggesting that the definition of a suburb is problematic.

In suburbs, where privately managed trees dominate the forest, the socio-economics of the individuals within the suburb need to be understood to evaluate the management capabilities. Much of the literature that evaluates the relationship between the suburban forest and its caretakers has centered on the quantity of the forest, such as the amount of canopy (Heynen and Lindsey, 2003; Danford et. al, 2014). However, little is understood about the relationship between the quality of the suburban forest, especially with respect to climate change, and the socio-economics of its caretakers.

While climate change will affect the current suburban forest in the future, a need to understand relationships between historical legacies and current conditions exists. Past dynamics not only form current conditions, but also inhibit future responses (Foster et. al, 2003). It is well understood that historical land legacies influence both the ecosystem structure and function on long temporal scales and may even be potentially irreversible (Christensen, 1989; Foster, 1992; Goodale and Aber, 2001; Dupouey et. al, 2002; Foster et. al, 2003; Janowiak, 2017). This knowledge of historical land legacies adds explanatory weight to our understanding of current conditions of suburban forests. More importantly, such knowledge reduces missteps in planning and managing the suburban forest for future climatic conditions (Foster et. al, 2003). More importantly, historical legacies have been found to greatly improve climate feedback models (Caspersen et. al, 2002). Despite the importance of including historical land legacies, no research has focused on the relationship between historical land legacies and the presence of species vulnerable to climate change in the suburban forest. This information is needed to assist

policy makers and homeowners in planning for and enacting mitigative and adaptive strategies to lessen impacts to the suburban forest (Dale, 1997).

Therefore, considering predicted climate change, I conducted an assessment of vulnerability and adaptive capacity focused on a suburban forest. My research uses Fayetteville, NC as a model for representing southeastern US suburban forests. Fayetteville is centrally located in Cumberland County and is predominately suburban. Fayetteville has a wide range of developments of various ages and socio-economic configurations. Additionally, Fayetteville has well over a century of documented historical changes to the landscape. To assess the vulnerability and adaptive capacity of suburban Fayetteville to predicted climatic conditions, I used a dynamic framework outlined by Ramalho and Hobbs (2012). Their dynamic framework evaluates the urban ecosystem on varied spatial-temporal scales, such as socio-economic land use, urbanization age, past vegetative remnant configurations, and land use legacies. Ultimately, this data will be used to evaluate where and who is at risk to ecosystem services degradation given predicted climatic conditions (Allen et. al, 2010).

Many definitions of risk, vulnerability and adaptive capacity exist (Brooks, 2003). In general, risk is a function of exposure and vulnerability (Cardona et. al, 2012; Brooks, 2003). To further complicate the issue, there are two aspects of vulnerability: exposure and ability to cope (Chambers, 1989). It is important to differentiate the social vulnerability from the biophysical vulnerability, where adaptive capacity is a determinant of vulnerability (Brooks, 2003). As such, risk is defined as a degradation of ecosystem services as a function of biophysical vulnerabilities of tree species to climate change and the adaptive capacity of people living within a subdivision.

Biophysical vulnerability results from forest composition and structure. The average canopy cover in the United States in urban and metropolitan areas is 27 and 33 percent,

respectively (Dwyer and Nowak, 2000). Theory suggests that species are more sensitive to changes in the habitat when remaining habitats are below 30%, which was confirmed by Banks-Leite et. al (2014), who found that both phylogenetic integrity and endemism declined when the canopy cover was below 30%. Additionally, the results of empirical studies looking at habitat changes and ecosystem function have suggested a threshold of 30 percent woodland cover (Huggett, 2005). As such, the minimum threshold for tree vulnerability is 30 percent canopy cover or if the canopy cover is already below 30% and declines.

The threshold for adaptive capacity using a Likert-scaled survey is the bottom 20th percentile or lowest quintile. Quintiles are commonly used by the US Census Bureau for comparing income groups (Donovan, 2015). As such, adaptive capacity scores were grouped in the same manner. Subdivisions that fall below both canopy cover and adaptive capacity score thresholds are deemed at risk to ecosystem service degradation. This study assumes that the absence of action to address ecosystems with vulnerable trees will result in ecosystem service degradation given climate change (Murphy et. al, 2015). Thus, subdivisions with low mitigative and adaptive capacity coupled with high numbers of vulnerable tree species are at the greatest risk of ecosystem service degradation.

Tree vulnerability is defined as the degree of susceptibility of a tree species to climate change and its ability to adapt to climate change (Glick et. al, 2011, Mach and Mastrandrea, 2014, Brandt et. al, 2016). I developed a tree species vulnerability matrix based on this definition was created by using the suitability of the future habitat for a given tree species and its ability to adapt. Similar matrices have been developed for forested habitats, but are based on abundance data (Janowiak et. al, 2017; Iverson et. al, 2011). In urban areas, approximately 30-50% of trees are forestland species, but the densities of these trees is half of their forestland

counterparts (Woodall, et. al 2010). Abundance data of forest tree species for urban and suburban applications, therefore, may not be as relevant (Janowiak et. al, 2017). I used ForeCASTS (Potter and Hargrove, 2013) to determine the suitability in lieu of the US Forest Service (USFS) Climate Change Tree Atlas (Prasad et. al, 2007) because suburban trees can be maintained in habitats that are outside of Importance Value Ranges used by the USFS. Within the USFS Climate Change Tree Atlas, however, MODFACs provides readily available information about the adaptability of tree species based on a multitude of factors to include life history, disease, and pests (Matthews et. al, 2011). MODFACs was used in conjunction with ForeCASTS to determine the vulnerability of a species. The species vulnerability was combined with the adaptive capacity of suburban communities to determine the risk of ecosystem service degradation.

To define the adaptive capacity of suburban communities, this study uses the Intergovernmental Panel on Climate Change (IPCC) definition of adaptive capacity, which is defined as "the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change" (McCarthy, 2011). Expanding on this, adaptive capacity is a function of the willingness, knowledge, and abilities of communities to mitigate or adapt their environment to climate change stimuli or their effects or impacts (Murphy et. al, 2015; Eakin and Luers, 2006). Thus, subdivisions with low adaptive capacity are viewed as those that lack action or capacity to employ adaptive or mitigative strategies (Murphy et. al, 2015). Adaptive and mitigative strategies are complementary strategies to address climate change. Mitigation strategies focus on the *causes* of climate change, while adaptation strategies center on *responding* to the effects of climate change. Neither strategy alone is thought to be effective (Millar et. al, 2007). While a variety of strategies exist, the efficacies are situationally

dependent. This study does not seek to determine the efficacies of any particular strategy nor to determine the drivers of adaptive capacity, but rather uses common strategies as an indicator of the mitigative and adaptive capacity (Smit and Wandel, 2006).

Adaptive capacity in this study was estimated using a survey based on common mitigative and adaptive strategies presented by Brandt et. al (2016). The strategies from the Brandt et. al (2016) study include resisting change, enhancing resiliency, and facilitating transitions. These strategies include retaining biological legacies, maintaining and enhancing native species, increasing biodiversity, and promoting diverse age structures. Strategies to facilitate transitions include selecting tree species adapted to current and future site conditions, introducing southerly species that are expected to adapt, and incorporating disease and insect-resistant species (Brandt et. al, 2016). These strategies formed the basis for the questions used in the survey.

The management and thereby, the capacity for adaptation, of the suburban forest is a social endeavor (Wilby and Perry, 2006; Ordóñez and Duinker, 2014). Since, the suburban forest has an inherent social component, adaptive capacity and the management of the suburban forest is related to socio-economic factors. The quantity of canopy cover is commonly used to predict the relationship between the management of the suburban forest and socio-economic factors. Numerous quantitative canopy cover studies have found that higher levels of canopy cover are correlated to higher income, neighborhood age, and inversely correlated to the proportion of the total population made up by minority populations (Heynen and Lindsey, 2003; Danford et. al, 2014). This study, however, seeks to understand the role socio-economics plays in the managing the *composition*, particularly the vulnerability to climate change, rather than the *quantity*, of the canopy cover. Adaptive capacity plays a role in forest management in

subdivisions, so two factors known to be related to the quantitative management of the suburban forest, income level and minority populations, were explored as possible determinants of adaptive capacity. While adaptive capacity seeks to understand the potential future implications of managing and adapting the suburban forest, it is also important to understand the historical factors that have led to the current composition.

There is a long debate among cultural geographers about how to look at the landscape, to include the suburban landscape. Two schools of thought on how to look at the arrangement of the landscape exist: as a chronological series of layers of landscape changes or as a temporal process, whereby, a multitude of dynamic processes are occurring on varying temporal scales (Crang, 1998; Heatherington et. al, 2017). The temporal process allows for one to view the spatial dispersion of change, which was the approach taken in this study. The changes of interest for this study are historical land use and land cover because of their impacts on forests (Christensen, 1989; Foster, 1992; Goodale and Aber, 2001; Janowiak, 2017). Several methods exist for determining historical land uses and land cover, some more quantitative and others more qualitative. One promising quantitative approach is a back-cast approach, which has been used in a few, relatively recent studies (Tayyebi et. al, 2015). The back-cast approach to modeling land use and land cover changes is an alternative to forecasting. Back-casting begins with defining desirable futures and working backwards to the current conditions. It is used to identify pathways leading to desirable states. However, for historical land use and land cover reconstruction applications, the direction is reversed. Reconstruction begins with defining the oldest historical point and working forwards to current conditions. One recent study reconstructed the historical land uses of the Ohio River Basin, where two reference land use maps were used, oldest to newest, in combination with historical data from agricultural and US

population censuses (Tayyebi et. al, 2015). However, this approach may lack the ability to capture some of the more nuanced land use changes that can occur on a local level, depending on the length of time under consideration, the accuracy and availability of historical data, and the questions being asked (Christensen, 1989). A qualitative approach, alternatively, can capture land use processes at a regional and local level that more generalized, quantitative approaches cannot (Gragson and Bolstad, 2006). For this study a combined quantitative and qualitative approach was used, where a historical narrative was generated for multiple critical time periods and coupled with current land cover and land use datasets, previous research results, and historical documents, such as census data, to reconstruct historical land uses and land covers.

Because land use and land cover are interrelated, these terms are often used interchangeably (Anderson, 1976). Land use describes the human activities on the landscape, along with the decisions about the use of land (Anderson, 1976; Nickerson et. al, 2015). Meanwhile, land cover refers to the vegetative or manmade constructions on the surface of the land (Anderson, 1976; Nickerson et. al, 2015). However, it is important to note that there is not a singular land use or land cover classification system that is ideal and tends to be subjective (Anderson, 1976). The USGS National Gap Analysis Program is a dataset of regionally distinct vegetation based on the national vegetation classification level, suitable for use in reconstructing land cover (GAP, 2011). There are three datasets applicable to the study area that classify land use or are a hybrid classification of land use and land cover: Economic Research Service, Natural Resources Conservation Service, and the US Geological Survey's (USGS) National Land Cover Database (NLCD). The Economic Research Service is a comprehensive land use dataset dating back to 1945 (Nickerson et. al, 2015). While ideal for the topic of this research, the Economic Research Service provides estimates for land uses at the State level only and, therefore, is not

suitable for this study. The Natural Resources Conservation Service and the NLCD use a hybrid classification system of both land use and land cover. The focus of the Natural Resources Conservation Service database is agricultural, while the NLCD is focused on ecosystems, biodiversity, climate change, and land management policies. The NLCD is based on the Anderson Land Cover Classification System, which takes into special consideration the definitions used by other agencies to categorize land uses, permits the use of vegetation as surrogates for certain land use activities, and was designed for land use planning and management activities (Anderson, 1976). Therefore, the NLCD is the best candidate for using to reconstruct historical land uses in this study area. Differentiating between land use and land cover is important in terms of modelling, where land cover is needed for physical environmental models, while land use tends to be used for policy, planning, and management purposes (Comber, 2008). Furthermore, the characteristics of land cover differ from land use in important ways. Land cover classification the record of the vegetation on the surface of the earth tends to be static, while land use is complex, where many simultaneous land uses can occur at any given location (Comber, 2008). This study looks at both the physical and management aspects of the suburban forest, hence the importance for differentiating land use and land cover.

There are three questions guiding my research. The first question looks at possible historical factors that might result in higher portions of species of trees vulnerable to climate change. Are there land use or land-cover legacy pathways or eras of development that are correlated to the proportion of the number of species of trees vulnerable to climate change? The second question seeks to understand the socio-economic factors that could limit a subdivision from applying adaptive or mitigative strategies. Does income or the proportion of minorities correlate to low adaptive capacity scores? Lastly, are the at-risk subdivisions, for each factor

considered, different than subdivisions not at risk in the sample or from the subdivisions in the study area?

Hypotheses:

1. There is a positive correlation between the percent of vulnerable tree species and subdivision age, with mid-century subdivisions having the highest proportion of vulnerable tree species.
2. There is a positive correlation between the percent of vulnerable tree species and frequency of land use and land cover change.
3. There is a positive correlation between the percent of vulnerable tree species and land use change and land cover pathways.
4. Adaptive capacity scores are positively correlated to income and negatively correlated to the percent of minorities in a subdivision.
5. The mean of each factor for subdivisions identified as at-risk will be statistically different than subdivisions not at-risk.

CHAPTER 2

METHODOLOGY

Overall

In this study, I used Fayetteville, NC as a model for US southeastern suburban forests to conduct a vulnerability and adaptive capacity assessment. First, I identified which tree species in the southeastern suburban forest are vulnerable to climate change. Then, I determined the subdivisions, categorized by historical land factors, where the greatest amounts of vulnerable tree species occur. Next, I quantified the adaptive capacity of the different socio-economic subdivisions. Lastly, I evaluated the subdivisions at risk of ecosystem services degradation.

Using the dynamic urban framework outlined by Ramalho and Hobbs (2012), a multi-step process was used for this assessment (Figure 2.1). The initial step was collecting, filtering, and sorting already accessible data, which included average age of homes built, income and demographics from Census data. Simultaneously, historical documentation was collected to develop an historical narrative. The historical narrative was interpreted and, using a backcasting method, the land use and land cover for 5 periods was determined. This was then analyzed to determine the land use and land-cover legacy pathways, to include the frequency of change and the types of changes for each subdivision. The next step was to sample suburban homeowners and their lots throughout Fayetteville, NC to determine the mitigative and adaptive capacities of homeowners and percentage of vulnerable tree species. A survey was used to assess the mitigative and adaptive capacities at each sample site and at the same sample site, trees were identified and quantified for each species. Later, both the survey and tree inventory were tabulated, assigning each sample site a survey score and a percentage of vulnerable tree species. Next, I used statistical analysis to evaluate relationships between the adaptive capacity scores

and the selected socio-economic factors: incomes and percent of minorities. The percentage of vulnerable tree species was analyzed to see if a correlation with subdivision age, land use, or land-cover legacies existed. The last step was to determine subdivisions that are at risk of ecosystem service degradation.

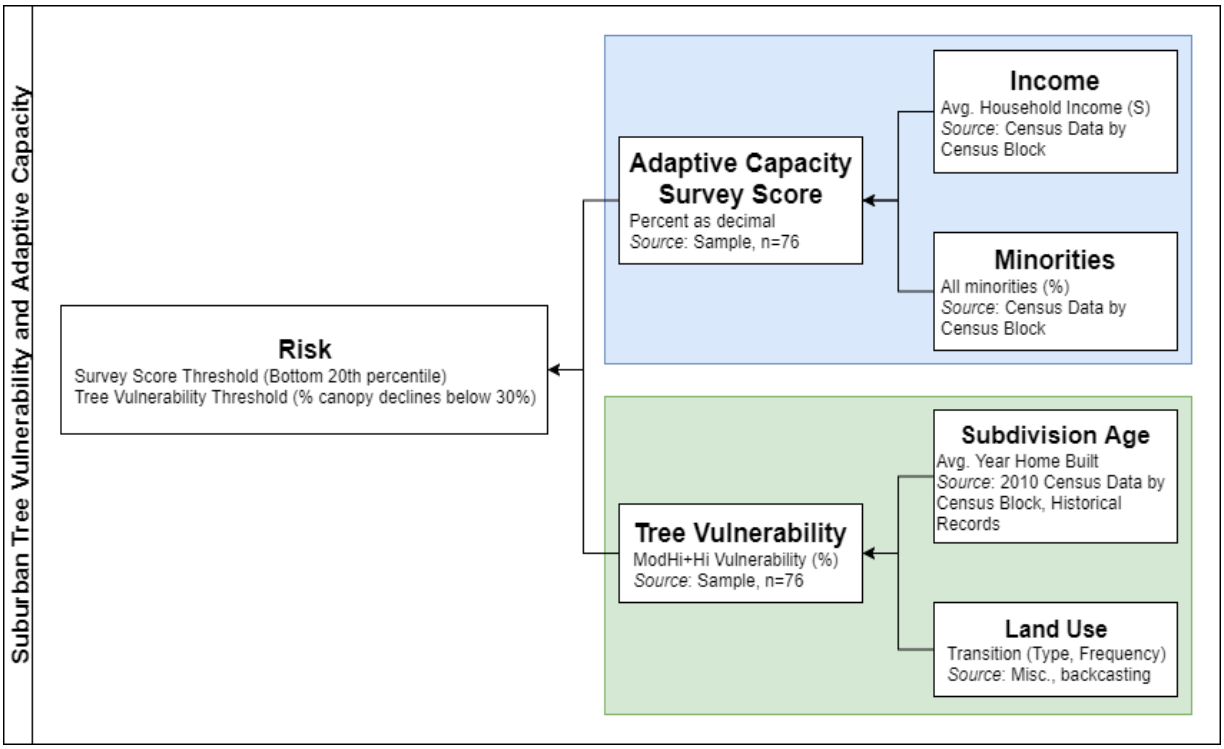


Figure 2.1 Suburban Tree Vulnerability and Adaptive Capacity Assessment Conceptual Diagram.

One important concept to consider is the characterization of the suburban forest. The characterization of what makes an area suburban or not is difficult to discern as there are numerous definitions available (Forsyth, 2012). Gianotti et. al (2016) presented a method that qualitatively characterizes suburbs, making comparisons between different suburbs feasible. Due to time constraints, this method was not used; however, this method may offer a solution for comparing various suburban typologies in the future. As an alternative, Gordon and Shirokoff (2014) characterize suburbs into three types: (1) exurbs or low density rural areas, (2) auto suburbs, where dwellers commute via personal transportation, and (3) transit suburbs or

metropolitan suburbs that use advanced public transit systems (Gordon and Shirokoff, 2014). The study area in this research is an auto suburb, which is different from the Chicago metropolitan suburbs used in the Brandt et. al study (2016). Since the definition of a forest differs from the collective of trees in the suburbs, the urban forest definition from Duinker et. al (2015) was used, which defines the urban forest as including "[a]ny tree found within a city boundary, whether planted or naturally occurring." Trees were defined using the USFS Urban Forest Inventory and Analysis definition: a woody perennial plant with a single well-defined stem, definite crown, and a diameter of 3 inches (USDA Forest Service, 2016).

Census Data

US Census data for Cumberland County was used to determine subdivision age, the percentage of minorities (US Census Bureau, 2010a), and income (US Census Bureau, 2010b) for each census block. Census blocks are statistical areas that are bounded by a variety of visible features, such as streets, streams, and select property lines (US Department of Commerce, 1994). Census blocks are the smallest statistical areas with accessible social-economic data and was found to be generally consistent with politically and socially recognized subdivisions (City of Fayetteville, 2017a). Subsequently, the census block was used as a proxy for subdivisions. Overall, 118 census blocks make up the study area.

The City of Fayetteville has overlapping relationships and responsibilities with outlying communities, including Fort Bragg, Hope Mills and Spring Lake (City of Fayetteville, 2017b). Since these outlying communities are still socially, culturally, and, in some regards, politically unique from Fayetteville, they were not included as part of the study area.

In the census report, the age of the census block is equivalent to the year when the majority of homes were built (U.S. Census Bureau, 2010c). The dataset, however, does not

determine home ages prior to 1950. Using the historical maps collected for the historical land use and land-cover, the census blocks recorded as 1950 in the dataset were re-evaluated to determine what decade the majority of the census block was built; either 1950 or earlier. Census blocks were not dated to earlier than 1900, as only two census blocks cover the area of settlement that occurred between the 1730s and 1900. No census blocks were recorded with dates between 1930 and 1950 for several reasons. First, this period starts with the Depression and was followed by World War II, a period of limited residential development. Furthermore, of the few homes that were built during this period, many of them were built on land cleared for development in the 1920s, thus filling in subdivisions. Lastly, the criterion is based on the majority of homes in a census block. While homes were built during this period, they did not constitute the majority of a census block.

Survey

The suburban forest survey asks 26 questions to determine the awareness, willingness, and ability of an individual to use these mitigation and adaption strategies (see Appendix A). This survey was approved by North Carolina State University's Institutional Review Board for the Protection of Human Subjects in Research (Protocol # 11714). Several questions pertain to financial and physical capabilities that some participants chose not to answer. Non-responses were not included in the overall score. The Likert scale was used, where parametric testing can be used (Sullivan and Artino Jr., 2013). Using the Likert scale, each response was assigned a point value, with higher values assigned to responses that support a mitigative or adaptive strategy. The mean of the responses was the individual's mitigative and adaptive capacity score. Subdivisions with large proportions of tree species vulnerable to climate change and low capacity scores are at the greatest risk of ecosystem service degradation.

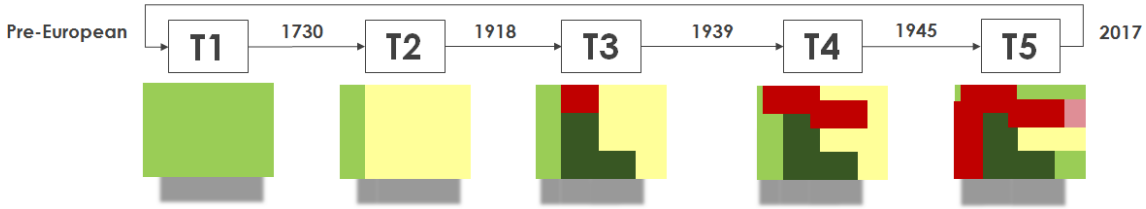
Historical Land Use and Land Cover

The method used for part of this research was a combination of both quantitative and qualitative approaches. First, a historical narrative was generated for five critical time periods. This narrative was then quantitatively interpreted using research, historical maps, records, and census data. Finally, the current land use/land cover quantitative datasets and the quantitative interpretations were back-casted to estimate the historical land use and historical land cover for each time period for each census block. From this data, the frequency of changes and the types of changes and pathways for land use and land cover was determined. To capture possible gardening trends that may have influenced the composition of suburban forests, particularly the presence of vulnerable tree species, the age of the subdivision was determined using census data and historical maps.

The temporal frame for constructing the historical land use and land cover begins prior to European contact and ends in 2017. The temporal frame is divided into five periods. Each period remains relatively constant in terms of development during a given period. The periods are demarcated by significant events, such as a new technology or war, that result in dramatic changes in the landscape. These periods include: pre-European contact to 1730s (T1), with an influx of European settlers; 1730s to 1918 (T2), marked by the new railroad line, industrialization, and natural resource exploitation; 1918 to 1939 (T3), when Fort Bragg was permanently established and the automobile became commonplace; 1939 to 1945 (T4), when incoming troops and returning troops begin to settle in Fayetteville; and the post-war period, from 1945 to 2017 (T5), with the conception and continuation of suburbia.

The decennial census reports from 1880 to 2010 for Cumberland County from the National Historical GIS database were used to evaluate changes in farmland, including pasture

land and woodlands (Manson et. al, 2017). The census block age, as discussed earlier, was also used to evaluate when land became urbanized. The census data, coupled with historical research reports, historical maps, and modern research, especially longleaf pine research, were used to develop a historical narrative. The historical narrative was used to interpret the land use and land cover for each period. The interpretation provided quantitative guidelines for calculating the land use and land cover for each period. The current or baseline maps were used to develop the land use and land cover for the first period, pre-European contact (T1), which has the fewest land use and land cover categories, primarily due to the lack of more detailed data. The second period, T2: settlement and natural resources exploitation, was based off the first map, where elements were added or removed in accordance with the interpretation of the historical map. However, the changes for the period of settlement and natural resources exploitation period (T2) were checked to ensure that they made sense with the baseline map. Subsequent periods were based on the previous period and the current period (Figure 2.2).



Land Use (ac)	T1	T1:T2 (# of LUC, LUC Types)	T2	T2:T3	T3	T3:T4	T4	T4:T5	T5
Developed	0	0	0		10		25		45
Crop	0	0	80	2	45	1	40	2	25
				AO		A		AJ	
Forest (Managed)	100	1	20		20	1	15	1	10
		F				B		B	
Forest (Unmanaged)	0	0	0		25	1	20		20
						C			
Barren	0	0	0		0		0		0
# of Land Use Changes		1		2		3		3	
Land Use Pathways		F		AO		ABC		ABJ	

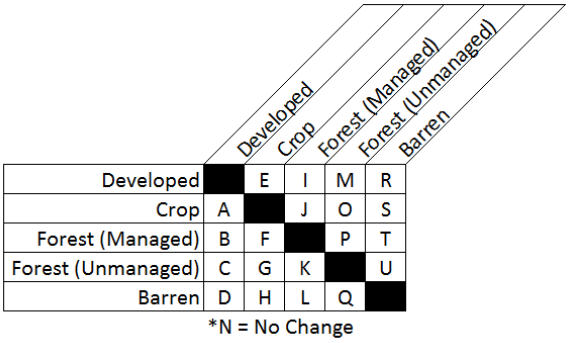


Figure 2.2 Determining the Number of Land Use Changes and the Types of Land Use Changes. After each period is estimated, the number of changes is recorded based on the amount of acres *to* a category. For example, between the settlement and natural resources exploitation period *(*T2) and the T3: rise of the automobile period, the land transitioned *from* Crops *to* Developed and Unmanaged Forest; therefore, the number of land use changes is 2. Using the table, each transition type is recorded in alphabetical order by the letter represented on the table, where the vertical categories are the *from* and the horizontal categories are the *to*. Using the previous example, the transition *from* Crops *to* Developed and Unmanaged Forest is recorded as AO. Then all of the changes are added to determine the overall number of changes; for the example above, there are 9 total land use changes. The overall land use change pathway is recorded by separating the transitions with an underscore. In the above example, the overall land use pathway is recorded as F_AO_ABC_ABJ. The method is the same for land cover changes. Note that many land use changes can occur within the same census block between any given period.

I generated a baseline map for the land cover using data from the USGS National Gap Analysis Program (GAP) from 2011. The baseline land cover map displays the macro group national vegetation classification level, which features regionally distinct vegetation (GAP, 2011). The baseline map for the land use was generated using data from the USGS National Land Cover Database (NLCD) from 2011. Both maps are raster, but slight variations in cell size exist, so caution should be exercised when selecting baseline maps. While the baseline maps offer relatively accurate resolution to approximately 1 acre (GAP, 2011), it is important to note that resulting representational historical data derived from these baseline maps are not intended to provide the same resolution. Rather, this data provides a coarse resolution, approximating the land-cover and land use based on available research and historical maps. It is assumed that this coarse resolution should hold true down to the census block level, where the average census block is 473.6 acres and the smallest census block is approximately 101 acres. Additionally, it is important to evaluate the applicability of this method to other cases. The Census Bureau's criteria for a census block establishes a minimum of 30,000 square feet, which is approximately 0.69 acres (US Department of Commerce, 1994). While not applicable to this case, the method employed may not be applicable to regions where census block areas do not correlate with representational historical maps or historical data. See Appendix B for procedures for historical land use and land cover reconstruction.

Tree Inventory and Rating

Tree data was collected based on standard sampling and inventory protocols used by i-Tree (Nowak et. al, 2008). Samples were determined using a randomized grid (Blood et. al, 2016). An 18 x 15 square (470 acres/square) grid was applied to the study area using fishnet in ArcGIS version 10.4.1 software was used (ESRI, 2018). A point was placed in the center of

each grid cell. The nearest residential intersection to this point was selected as a sample site. Any grid cells that did not have a point inside of the study area was not included. Additionally, 6 grid cells with a point inside the study area lacked any residential intersections and were excluded. Mobile home parks were excluded as they are land renters, while mobile homes on land owned by the same person were included in the study. Condominiums and townhouses were included, as well. Lastly, the absence of trees did not preclude a homeowner from participating. The total number of potential sample sites was 119, from which 76 samples were obtained. Maps produced in ArcGIS, however, show 61 census blocks, as some census blocks had multiple samples and were averaged.

A similar sampling method employed by Nitoslawki and Duinker (2016) to evaluate tree diversity in suburban developments was used. Starting clockwise at the nearest intersection, homeowners were asked to participate in the study. Homeowners must have been above the age of 18. If the homeowner did not wish to participate, the homeowner to the left of the original randomly selected home was asked, and so on until a homeowner chose to participate in the study. When a homeowner opted to participate, they were provided a written survey (Appendix A) to complete and all trees on the property were identified, quantified, and recorded.

In the field, a variety of field guides were used to verify tree species. The main resource was Katherine Kirkman's *Native Trees of the Southeast* (2007). Trees that were unfamiliar and not identifiable in field guides were photographed and subsequently researched. Most of the photographed trees were exotic species that are available in local nurseries. Tree species were recorded and counted for each property. Trees were then evaluated using the tree vulnerability matrix (Table 2.1) to determine their vulnerability to climate change.

The tree vulnerability matrix evaluates both the habitat suitability and the adaptability of a species based on a multitude of factors to include life history, disease, and pests. The habitat suitability model used was ForeCASTs. From ForeCASTS, the "Present and Future Ranges" maps were used for the matrix and are based on the Hadley climate model, lower emissions scenario (B1) to the year 2050 (Potter and Hargrove, 2013). On these maps, green represents new habitat in 2050, red represents areas that are currently suitable, but expected to be unsuitable in the future, yellow represents areas that are both currently and projected to be suitable in the future, and white represents areas beyond the habitat range. It is important to note that all species distribution models, such as the USFS Climate Change Tree Atlas and ForeCASTS, have limitations. These limitations include grid cell size, number of cells needed, and assumptions about biotic interactions, to include human interactions (Iverson and Hargrove, 2014). In ForeCASTS, a grid cell is 4 square kilometers and the study area is approximately, 230 square kilometers or approximately 57 grid cells. To overcome uncertainties associated with the limited number of grid cells for the study area, a regional approach, which is more robust, was used (Littell et. al, 2011). Because more than one category of suitability can be found within a region, the tree vulnerability matrix categorizes the suitability based on both the dominant category on the ForeCASTs map and the second most dominant category. (First color is the dominant color, 2nd is minor compared to dominant). Green represents future suitability. Green-Yellow represents future suitability, although limited areas might be suitable now and in future. Yellow-Green represents both current and future suitability, but some areas might only be suitable in the future. Yellow represents both current and future suitability. Yellow-red represents both current and future suitability, but some areas might be unsuitable in the future. Red-Yellow represents mostly unsuitable future habitat, although limited areas might be suitable now and in future. Red

represents habitats expected to be unsuitable in the future. White represents areas not currently or predicted to be suitable in the future. Because the habitat suitability model does not take into account biological and disturbance factors, MODFACs was used to evaluate adaptability of species. MODFACs is a score system based on current literature that evaluates 9 biological and 12 disturbance factors. These factors can modify the interpretations of the future habitat suitability model. For example, if the future habitat of a species currently present is predicted to be unsuitable, then extirpation is likely. However, if the species is highly adaptable, then the species could do better than the habitat suitability model suggests. Species with a MODFACs of greater than 0 (+), are more adaptable and may do better than modelled, while species with a MODFACs score of less than 0 (-) are less adaptable and may do worse than modelled (Table 2.1).

Table 2.1 Tree Vulnerability Matrix

ForeCASTS: Decreasing in Habitat Suitability	MODFACS: Decreasing in Species Adaptability						
	VHi+	***Hi+***	***Lo+***	***Minimal***	***Lo-***	***Hi-***	***VHi-***
Green	Low	Low	Low	Low	Low	Low	Low
Green-Yellow	Low	Low	Low	Low	Low	Low	Low
Yellow-Green	Low	Low	Low	Low	Low	Low	Low
Yellow	Low	Low	Low	Low	Low	Low	Low
Yellow-Red	ModLo	ModLo	ModLo	Mod	Mod	Mod	Mod
Red-Yellow	Mod	Mod	Mod	ModHi	ModHi	ModHi	High
Red	ModHi	ModHi	ModHi	High	High	High	High
White	ModHi	ModHi	ModHi	High	High	High	High

Notes: In ForeCASTS, the category was determined by the dominant category for the region. If more than one category was present in the region, the dominant category is listed first, followed by the secondary category. When creating the matrix, it was assumed that if a tree species was projected to remain within its habitat, then the need to adapt (MODFACS) would not impact its overall vulnerability.

For species not identified in the ForeCASTS model or MODFACs database, a literature review was conducted. Pests, pathogens, climate-related disturbances, and hardiness zones were used as proxies for both habitat suitability and adaptability (Hunter, 2011). Species similar to forest species used in ForeCASTS and MODFACs, were categorized the same, unless the literature review suggested a higher or lower categorization. Species were categorized using the same categories as the tree vulnerability matrix: low, moderately low, moderate, moderately high, and high vulnerability.

The total species for each sample were tabulated, indicating the species richness for each sample. Using the tree vulnerability matrix, species categorized with high and moderately high vulnerability were summed together to determine the total species vulnerable. The proportion of tree species vulnerable equals the sum of species categorized with high and moderately high vulnerability in the sample divided by the total species in the sample. For example, a site has four species, one of which is categorized as high vulnerability and two categorized as moderately high vulnerability. The total vulnerable species is three and the proportion of species vulnerable to climate change is three divided by four total species or 75%. Subdivisions with higher proportions of tree species vulnerable to climate change along with low adaptive capacity scores are at the greatest risk of ecosystem service degradation.

CHAPTER 3

ANALYSIS

SAS® software v 9.4.1 (SAS Institute Inc., 2016) was used for all analyses. The procedures used for the descriptive statistics for all variables were MEANS, CORR, REG, UNIVARIATE, FREQ, and SGPLOT. Income was transformed using a log transformation to use for linear regression analysis. The percent of tree species vulnerable to climate change was transformed using a square root transformation to address the skewness and for regression analysis.

Socio-economic factors that could inhibit a subdivision from applying adaptive or mitigative strategies were evaluated using Pearson's correlation. A linear regression model was fit for adaptive capacity scores, the dependent variable, to further explore the relationship. Low adaptive capacity was defined as the lower 20^{th} percentile of adaptive capacity scores and was calculated using R version 3.4.3 software (R Core Team, 2017). See Appendix C for code.

Possible historical factors (land use legacies, land-cover legacies, and development ages) that might result in higher portions of tree species vulnerable to climate change were explored. Pearson's correlation and partial correlation were used to assess the relationship between the percent of tree species vulnerable to climate change and historical factors. A multiple linear regression analysis was conducted between historical land factors and the percent of vulnerable species.

The National Land Cover Database 2011 USFS Tree Canopy (Cartographic) was used for determining the current canopy cover of each census block (Homer et. al, 2015). To estimate the proportion of the canopy cover that is vulnerable, species richness was used as a proxy (Conway and Bourne, 2013). The current canopy cover for each census block was multiplied by the

proportion of species vulnerable to climate change found from the sample within that census block (Eqn 1). For example, a sample in a census block with 50% total canopy cover, four total species inventoried, and one species vulnerable to climate change, the proportion of the total canopy cover that is vulnerable is 12.5%. When calculating the canopy cover under future climatic conditions, the worst-case scenario was used: extirpation of all vulnerable species. The canopy cover under future climatic conditions is the current canopy cover less the proportion of the canopy that is vulnerable (Eqn 1). Using the previous example, the predicted canopy cover would be 37.5%.

$$Canopy\ Cover_{future} = Canopy\ Cover_{current} - (Vulnerable\ Species\ Ratio * Canopy\ Cover_{current}) \quad \textbf{(Eqn 1)}$$

If the future canopy is predicted to decrease below 30% or if the current canopy cover is already below 30% and is predicted to decline further, then the census block was deemed to be at risk of ecosystem service degradation.

Subdivisions at risk of ecosystem degradation due to the impact of climate change on trees was defined by having low adaptive capacity scores (20^{th} percentile and below) and canopies predicted to decrease below 30% or if currently below 30%, then any further decline. Socio-economic and historical land factors showing a possible relationship with at-risk subdivisions were tested for association using a Monte Carlo randomized Exact Fisher Test and Mantel-Haenzel nonzero correlation test.

CHAPTER 4

RESULTS

Between February and March 2018, I worked with a statistical consulting team. Dr. Consuelo Arellano and graduate student, Chandni Malhotra were responsible for all the statistical analyses that were conducted for this study. Everything in this section, with the exception of all the figures and the land use and land cover pathway results, are from the statistical consulting report prepared by Dr. Arellano and Chandni Malhotra (Arellano and Malhotra, 2018).

The Suburban Forest

The tree tree inventory occurred at 76 random plots, corresponding with homeowners who respondeded to the adaptive capacity survey. The plots varied in size, depending on the homeowner's lot size. Plots were varied in subdivision age, dating from 1914 to 2010. The suburban forest of Fayetteville, NC can be broadly characterized as a temperate forest with a mix of hardwood and softwood tree species. Oak-pine is the dominant forest type, accounting for 44% (416) of the total trees inventoried (947). The remaining forest is a hodge-podge of species, most of which are common in the local nurseries. Overall, the 947 trees are comprised of sixty different species. Of the total number of trees, three species made up approximately 50% (475) of the trees: Flowering Dogwood, Longleaf Pine, and Loblolly Pine, in descending order. Twenty-two percent of the trees were the Flowering Dogwood, a popular native ornamental tree. Two species identified in the study area are characterized as invasive: Callery Pear and Mimosa (EDDMapS, 2018). The average number of trees per sample site was 12 trees. Two sample sites, however, accounted for approximately 15% of the trees (78 and 62 trees) in the sample.

Sixty (6.3%) of the trees were categorized as having a moderately-high vulnerability to climate change and none were categorized as high vulnerability.

The percent of tree species categorized as moderately high and high vulnerability to climate change within each sample (n = 76), ranged from 0% to 100% with a mean of 18.42%. The average number of species per sample site is 4 species. There were 60 species identified in the study area, of which 30% (18) were categorized with moderately high vulnerability to climate change (Appendix D). None were categorized with high vulnerability to climate change. Eight of the 18 vulnerable species (44%) are at the southern or eastern edge of their habitat ranges. Just under half (42%) of the samples had no species vulnerable to climate change, causing the distribution to be heavily skewed (Figure 4.1).

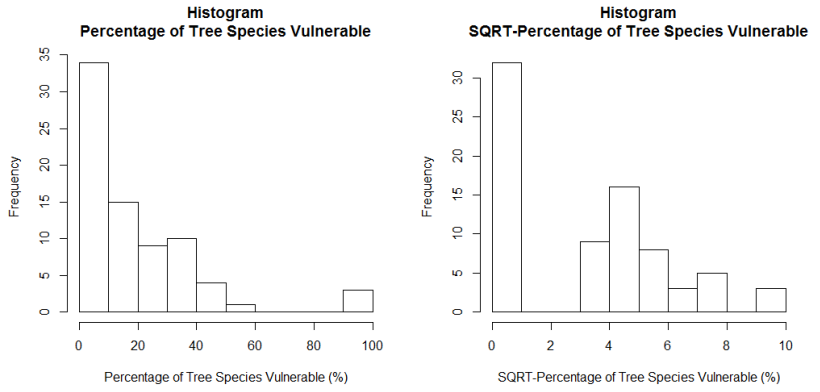


Figure 4.1 Histogram of the Percentage of Tree Species Vulnerable to Climate Change. The histogram is heavily skewed (left). After a square root transformation, the distribution is approximately normal (right); however, robust methods are needed.

Tree species richness vulnerability was used as a proxy for canopy cover vulnerability (Conway and Bourne, 2013). Canopy cover under future climatic conditions is the current canopy cover less the species richness vulnerability (Eqn 1). Spatially, there is a small cluster of subdivisions exhibiting canopy risk that is located approximately five miles west of the historic city center. These subdivisions vary in the proportion of vulnerable species and the current

amount of canopy cover (Figure 4.2). The current canopy cover for the study area covers approximately 21,140 acres out of approximately 55,885 acres.

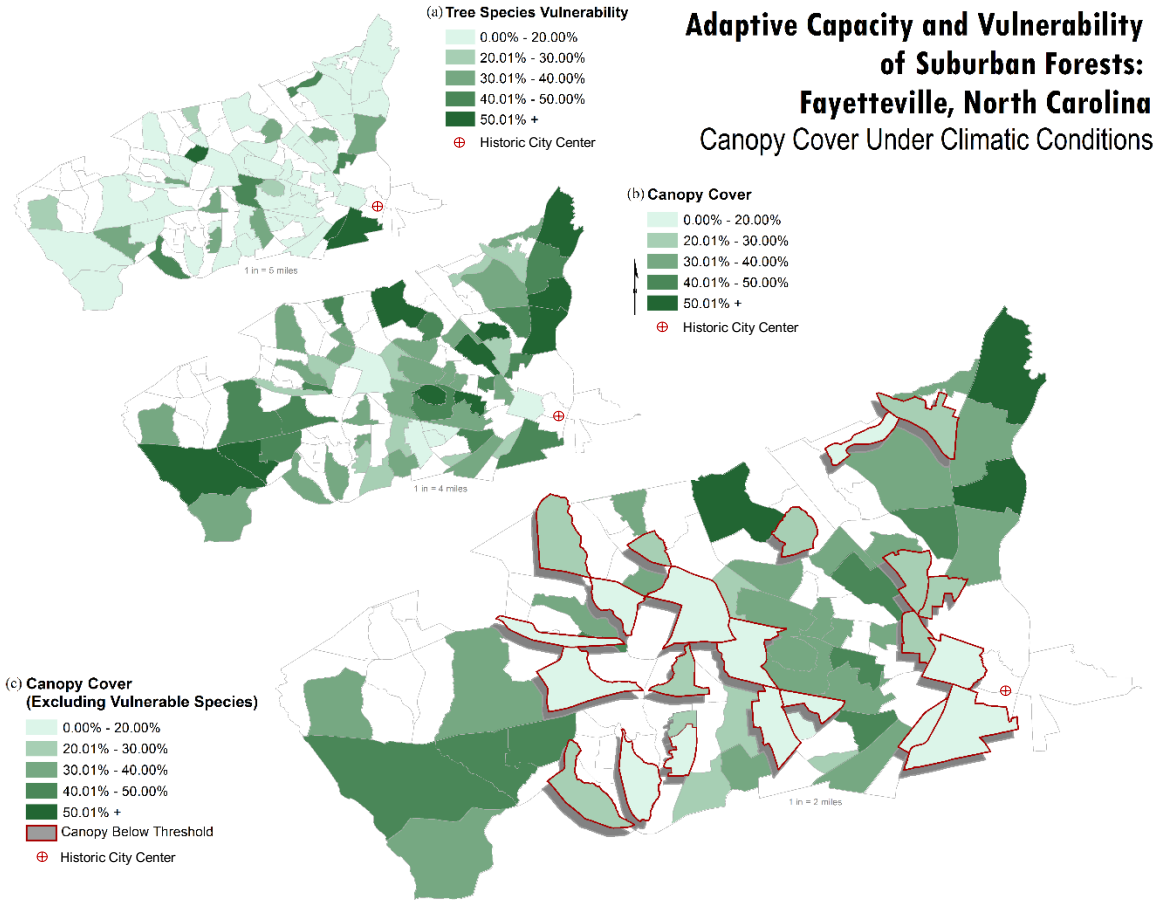


Figure 4.2 Canopy Cover: Current, Expected Decline, and Expected Under Climatic Conditions. Figure (a) shows the proportion of species vulnerable to climate change (n=76). Figure (b) shows the current canopy cover. Figure (c) illustrates the canopy cover under climatic conditions, where the current canopy declines by the percent of vulnerable species. There appears to be a cluster of subdivisions exhibiting canopy risk, located approximately five miles west of the historic city center.

A total of 25 samples (33% of observations) had canopy covers that were expected to decline below 30% or are currently below 30% and are expected to decline due to climate change (table 4.1). Of the 18 samples currently below 30% canopy cover, 39% (7) were not expected to decline further due to climate change. Approximately, one quarter of the subdivisions with canopy covers above 30% were expected to decline below the threshold. More than half of the

subdivisions with canopies expected to decline below the 30% threshold were subdivisions that are currently above the threshold.

Table 4.1 Canopy Cover Summary Table

Current Canopy Cover	*Canopy Cover Excluding Vulnerable Species*	*Total*	*Risk*
> 30%	Decrease, but remain > 30%	19	No
> 30%	< 30%	14	Yes
> 30%	No Change	25	No
< 30%	Decrease	11	Yes
< 30%	No Change	7	No

Notes: One third of the samples are at-risk due to declines in canopy cover. Since risk is defined as a decline in ecosystem services, subdivisions with pre-existing degraded systems due to low canopy cover were not identified at-risk if there is no expected decline in canopy cover due to tree species vulnerable to climate change. However, those subdivisions that experienced any amount of decline were considered at-risk.

Tree Species Vulnerability and Historical Land Factors

Several historical factors might result in higher proportions of tree species vulnerable to climate change. Subdivision age, the frequencies of land use and land cover changes, and the types of land use and land cover changes were analyzed to see if they are factors that indicate high proportions of tree species vulnerable to climate change. Land use and land cover changes were reported over five periods. The year subdivisions were built ranged from 1914 to 2010. Approximately 50% of the samples date from 1978 or later (Figure 4.3). Both the frequency of land use changes and land cover changes between each of the five periods is reported in discrete values. The average total number of land use changes per subdivision is five (n=76), while the

most frequent number of land cover changes is eight. In general, the values have a relatively small range and tendency for observations to concentrate around one or two values (Figure 4.3).

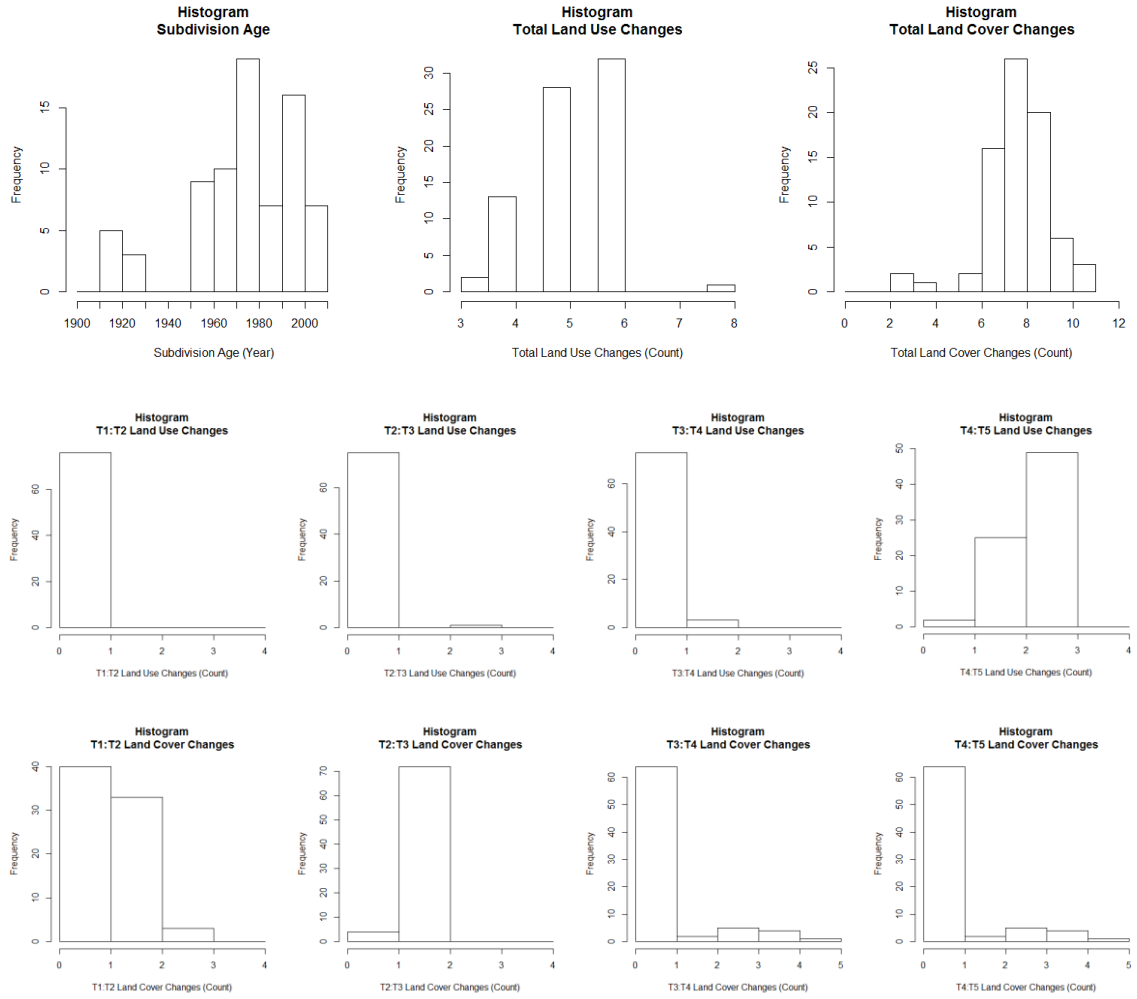


Figure 4.3 Histograms of Historical Land Factors. The histogram of total land use and land cover changes and subdivision age are approximately normal. The histograms clearly show that the changes between the five periods have small ranges with many of the samples concentrated around one or two values. The small sample size for the percent of trees vulnerable to climate change and the limitations of historical land factors may result in not being able to detect any relational evidence.

Historical studies of forests have found that forest changes occur in predictable ways. In general, a large decline in forest cover occurs when societies undergo economic development and industrialization. After that, the trend reverses and forest cover increases slowly. This occurs simultaneously with increasing urbanization (Mather, 1990; Walker, 1993; Mather and Needle, 1998; Rudel, 1998; Rudel et. al, 2005). However, this overall trend occurs on various scales, may

vary from one place to another, and is not inevitable (Rudel et. al, 2005). In this study, this general trend of canopy decline followed by a slow increase in canopy corresponds with the land use and land cover changes across the entire study area. This study also produces evidence that land use and land cover changes varied among subdivisions. Subdivisions closer to the historical town center underwent this trend earlier than other subdivisions (as indicated in the blue line in Figure 4.4). While at-risk subdivisions followed the same general trend, it was when these subdivisions transitioned to urbanization that is notable.

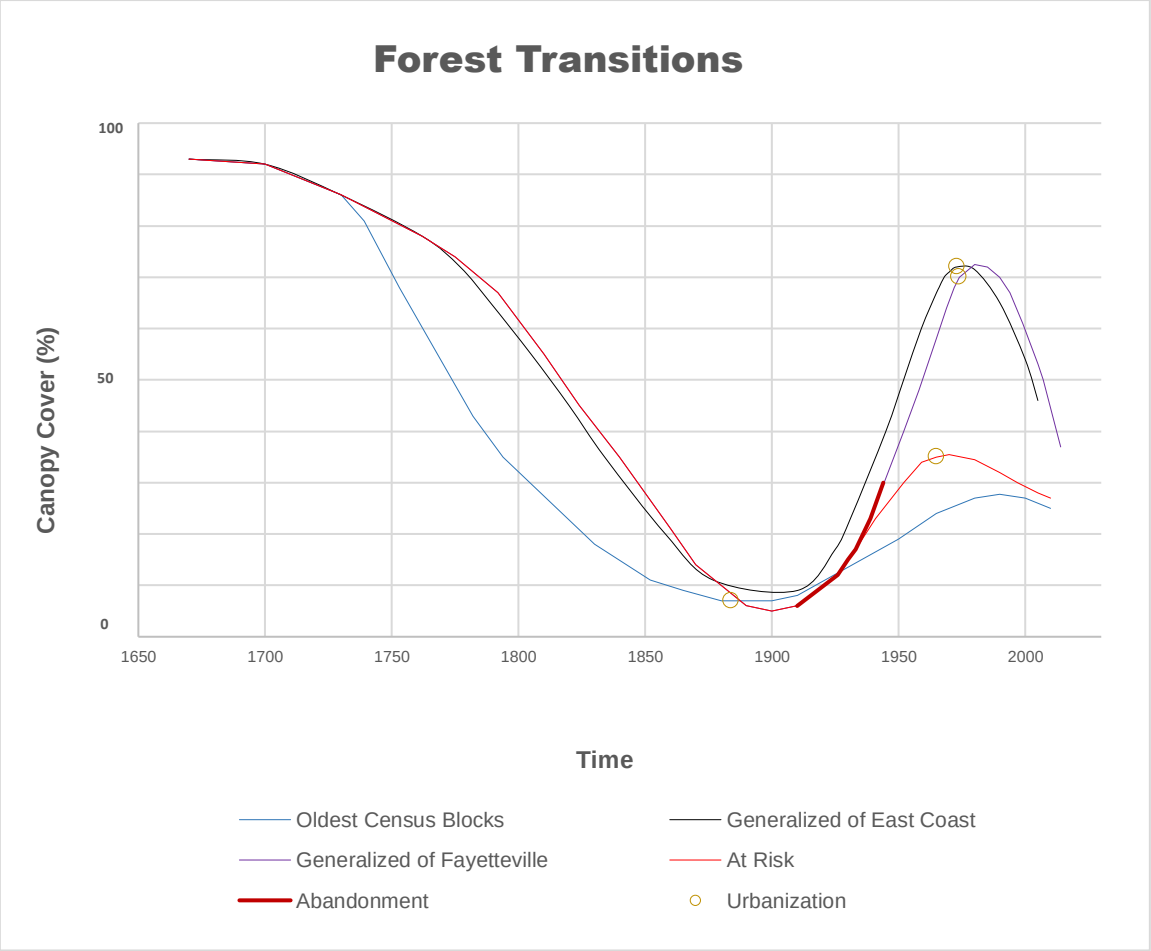


Figure 4.4 Forest Transitions of Fayetteville, North Carolina. Fayetteville, like the forests on the eastern coast of the United States follows a general trend of deforestation, followed by a slow increase in canopy until multiple land use pressures begin to change the canopy again (Drummond and Loveland, 2010; Houghton and Hackler, 2000). Fayetteville, however, reaches its minimum earlier and reaches its maximum later. Early in the 20th century, a trend of abandonment of farm land and field succession persisted (Manson et. al, 2017). This trend had not fully reversed until after 1940. At-risk subdivisions begin heavy urbanization directly following this period. Final canopy cover estimates were from Nowak and Greenfield, 2010.

The most common pathway of land use changes follows the general downward trend of canopy cover resulting from industrialization, intensive natural resource exploitation, railroads, and movement towards agricultural land uses. However, the pathway departs from the expected trend of a slow increase in canopy cover between T3: rise of the automobile and T4, following the Great Depression and the onset of World War II. This departure from the general canopy cover trend in the eastern United States and Fayetteville, in general, is due to the abandonment of agricultural lands, leading to a rise in ruderal species (Manson et. al, 2017). Any gains in canopy cover were minimal before urbanization occurred. This particular pathway of land use changes, FP_P_JO_ABC, accounts for 36% of the land use change pathways that occurred in the study area. Nearly half of the subdivisions with this pathway showed canopy risk. Six of the eight (75%) at-risk subdivisions followed this land use change pathway (Figure 4.5).

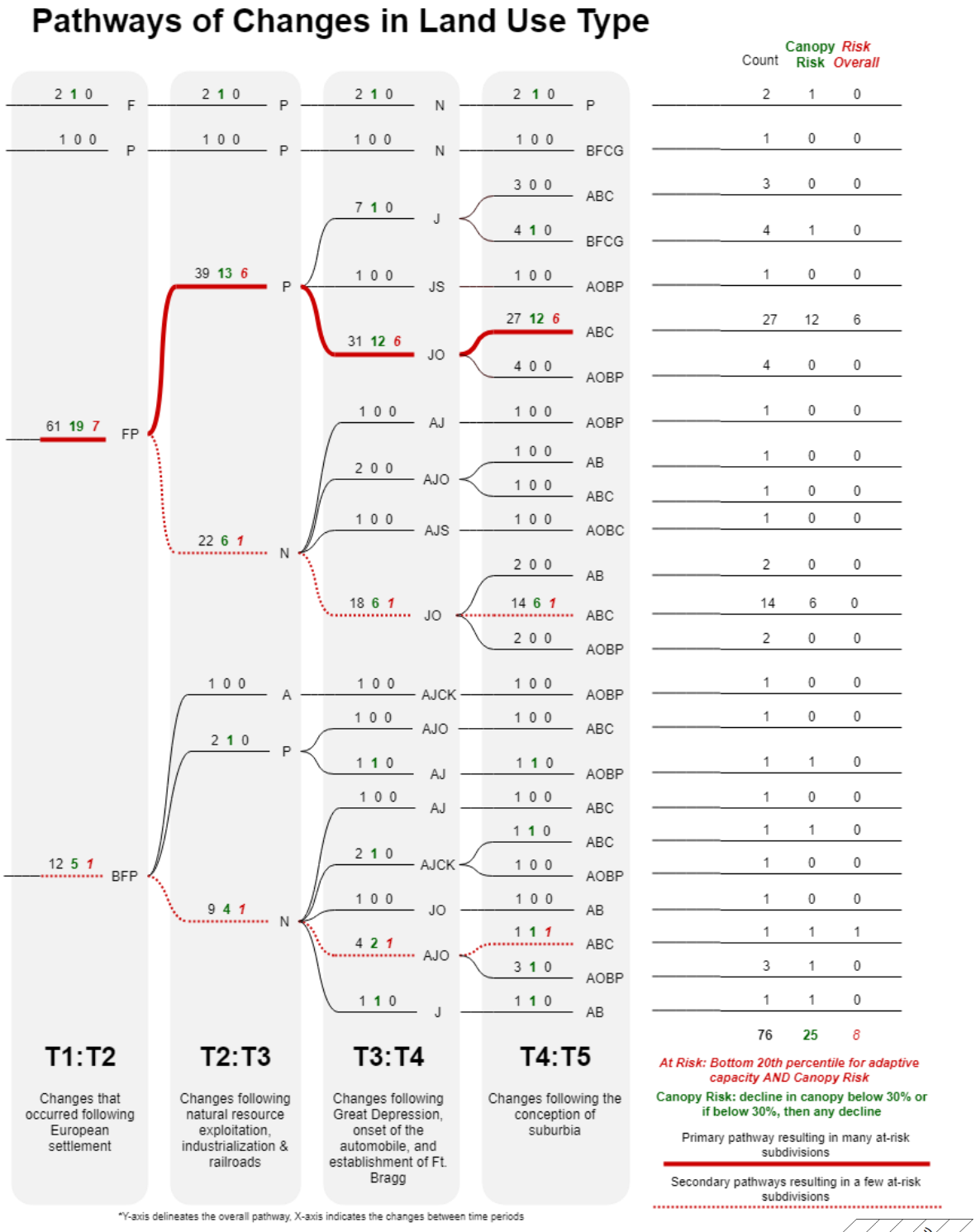


Figure 4.5 Pathways of Changes in Land Use Type. Approximately 1/3 of the samples had the same land use change pathway, FP_P_JO_ABC. Seventy-five percent of at-risk samples were from this same pathway. The remaining at-risk samples followed similar pathways: FP_N_JO_ABC and BFP_N_AJO_ABC. While the sample size was not large enough to detect a relationship between tree vulnerability and historical land factors, these pathways combined with the other results hint at the role that historical land factors play in determining the vulnerability and adaptive capacity of suburban forests to climate change.

Forty-seven unique land cover change pathways occurred between pre-European contact (T1) and the post-war period (T5). The most common land cover change pathway (70% of pathways) mirrors the most common pathway for land use changes, where a rise in ruderal species occurs between T3: the rise of automobile and T4: World War II due to field abandonment. Of the 53 samples that followed this general land cover pattern to the beginning of T4: World War II, over 70% were converted to suburbs. Those samples that converted to suburbs following the rise of ruderal species between T3: the rise of the automobile and T4: World War II account for 76% of the subdivisions with canopy risk and 88% of the at-risk subdivisions.

Subdivision age, the frequency of land use changes, and the frequency of land cover changes were explored to see if they are factors that might result in the presence of tree species vulnerable to climate change. Both the scatterplots and spatial mapping of the percent of tree species vulnerable to climate change and historical factors do not appear to show any strong relationships (Figure 4.6 and 4.7, respectively).

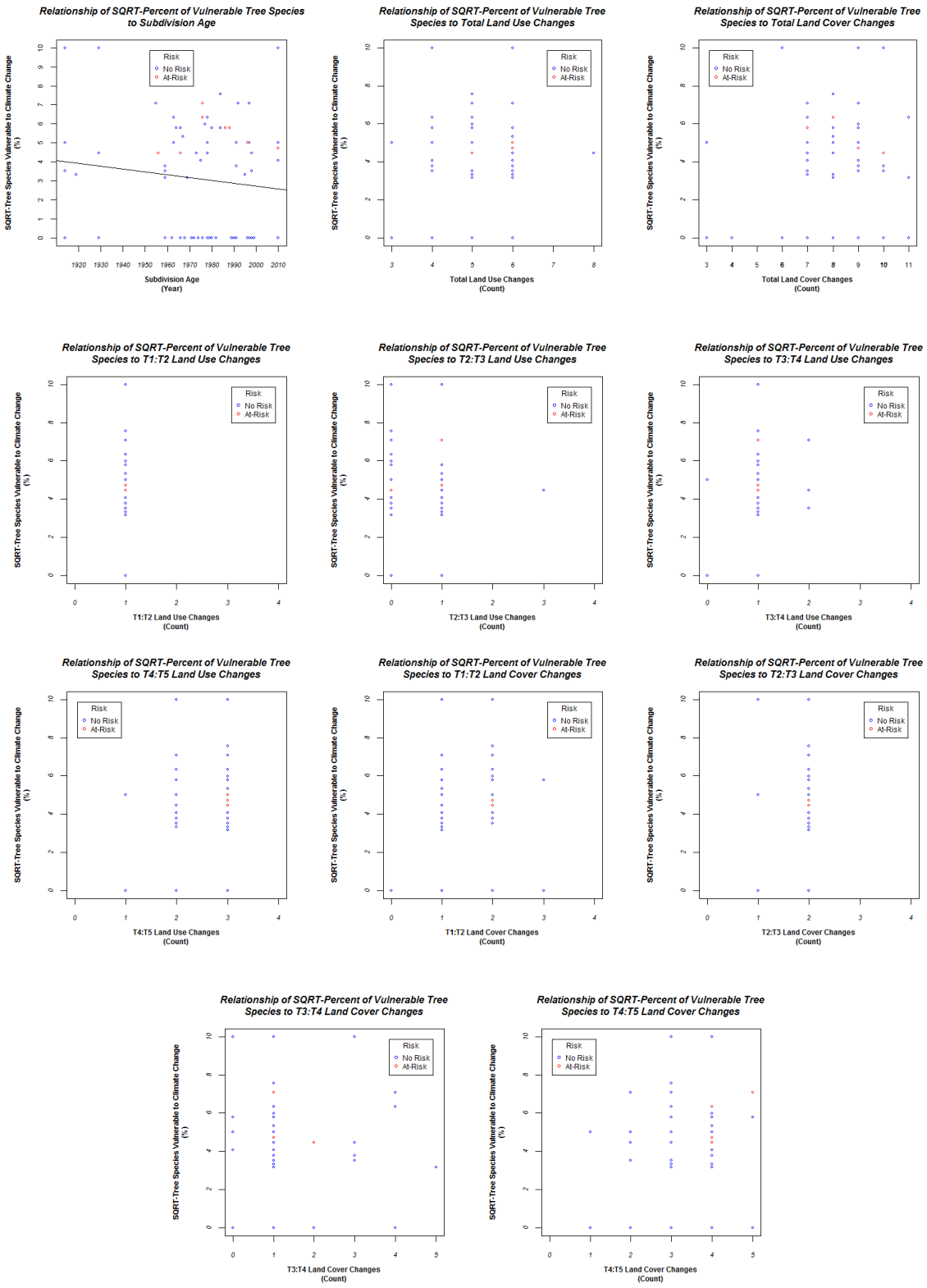


Figure 4.6 Plots of The Percent of Vulnerable Tree Species and Historical Land Factors. Because land cover and land use changes between the five periods have small ranges with many of the samples concentrated around one or two values, it is difficult to detect any linear relationship with the percent of tree species vulnerable to climate change. The plot of subdivision age to the percent of tree species vulnerable to climate change clearly indicates two of the limitations: (1) nearly half of the samples have no tree species vulnerable to climate change and (2) the small sample size may not detect any relational evidence.

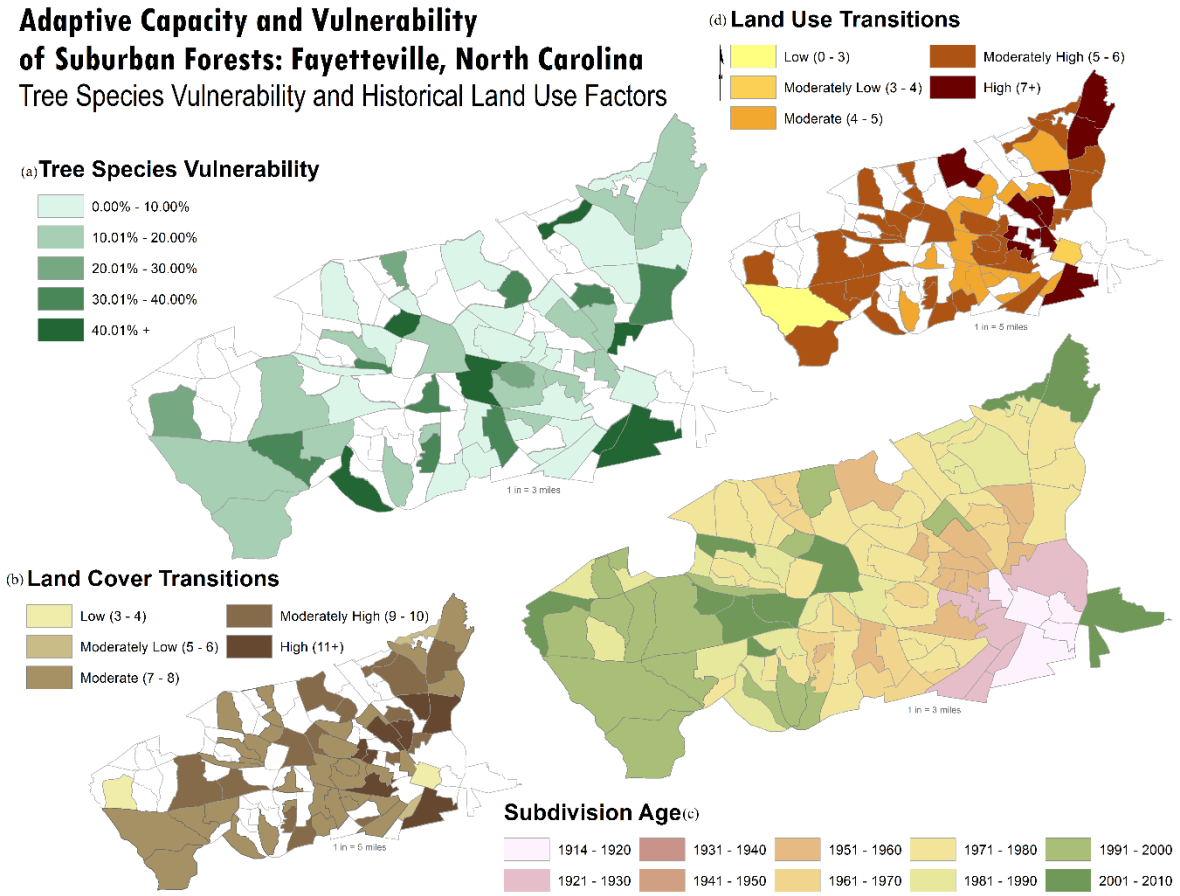


Figure 4.7 Spatial Relationship Between Tree Species Vulnerability and Historical Land Factors. Figure (a) shows the percent of species vulnerable to climate change (n=76). Figures (b) through (d) show historical land use factors that may have a relationship to the percent of species vulnerable to climate change. Figures (b) and (d) show the frequency of land use and land cover transitions. Figure (c) shows the average subdivision year for each census block. In general, there is a radiating pattern from older subdivisions to newer subdivisions on the periphery of the study area. Interestingly, the spatial extent of land cover transitions appears to mirror that of subdivision age. The percent of species vulnerable to climate change (a) does not appear to correlate with any land use factors.

Pearson's correlation coefficient was used to test for relationships between the percent of trees vulnerable to climate change and historical land factors. Only three historical land factors had a correlation with the percent of tree species vulnerable to climate change: the number of land cover changes between T2: settlement and natural resources exploitation and T3: rise of the automobile, the number of land use changes occurring between T3: the rise of the automobile and World War II (T4), and subdivision age. However, all are weak, non-significant, correlations ($r_{partial}$ = -0.20, p = 0.09; r = 0.16, p = 0.17; and $r_{partial}$ = 0.13, p = 0.27, respectively).

Three models were fitted for the percent of tree species vulnerable to climate change. The models were fitted with (1) the number of land use changes between T3: the rise of the automobile and T4: World War II, (2) the number of land use changes between T3: the rise of the automobile and T4: World War II and subdivision age, and (3) the number of land use changes between T3: the rise of the automobile and T4: World War II and the number of land cover changes between the period of settlement and natural resource exploitation (T2) and T3: rise of the automobile (adj. R^2 = 0.01, 0.02, 0.03, respectively). None of the models explained more than 3.5% of the variation and therefore no meaningful linear relationship exists between the three identified explanatory variables and the percent of tree species vulnerable to climate change. The same weak relationships were found when a randomization test for model F was run (Cassell, 2002). It is likely that the weakness of the model might be explained by the high number of samples characterized by an absence of trees species vulnerable to climate change (42%), shown as the row of horizontal sample points (Figure 4.8). A relationship with historical land factors does appear to exist with the samples where vulnerable tree species are found.

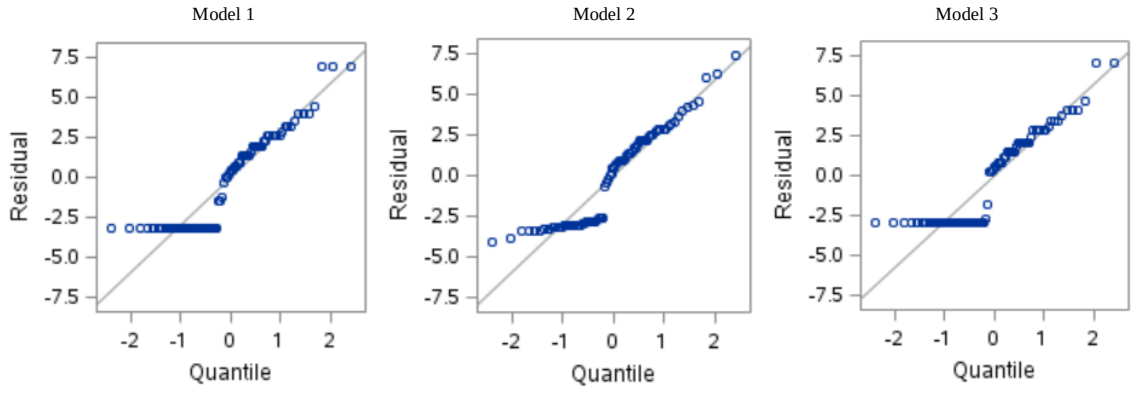


Figure 4.8 Modeling Tree Species Vulnerability and Historical Land Factors, QQ Plots. The points that are horizontal in Model 1 and Model 3 and near horizontal in Model 2 are the samples where none of the tree species were vulnerable to climate change. The samples where some portion of the sample had tree species vulnerable to climate change appear to have a linear relationship with three historical land factors: the number of land cover changes between the settlement and natural resources exploitation period (T2) and the T3: rise of the automobile period, the number of land use changes between T3: the rise of the automobile and T4: World War II, and subdivision age.

While there is no strong evidence about whether the percent of vulnerable tree species can be

explained by historical land factors, indicators do suggest a possible relationship and point to possible future studies.

Adaptive Capacity and Socio-Economic Factors

The survey included 76 random respondents from a wide range of socio-economic backgrounds across the study area. Adaptive capacity scores (n = 76), on a 0 to 1 scale, range from 0.54 to 0.92. Adaptive capacity scores show a symmetrical distribution with a mean of 0.71, 95% CI [0.69, 0.73], indicating that the sample size is adequate. Two factors contributing to adaptive capacity scores were assessed: income and proportion of minorities. The mean income of the 76 samples is $51,432.30, after a log10 transformation (M = 4.67, 95% CI [4.62, 4.71]). The mean for the proportion of minorities is 52.76%, 95% CI [46.92, 55.59] (Figure 4.9). Both income and the proportion of minorities appear to cover a sufficient cross-representation of the study area.

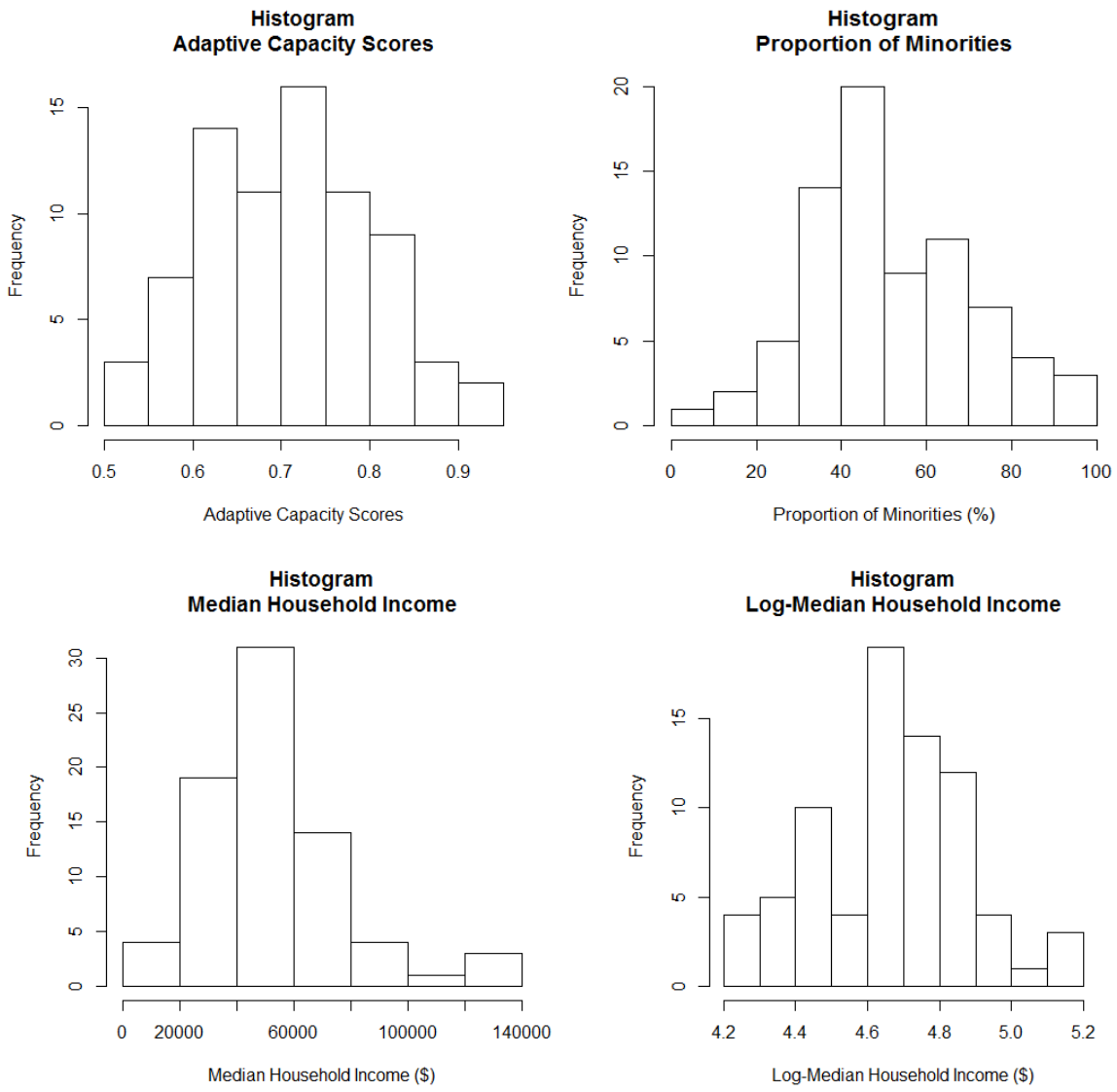


Figure 4.9 Histograms for Adaptive Capacity Scores and Potential Socio-Economic Factors that may Influence Adaptive Capacity Scores. All of the histograms have normal distributions robust enough for linear modeling.

Income and the proportion of minorities were explored to see if they were factors that could inhibit subdivisions from applying adaptive or mitigative strategies to overcome the impacts of climate change on the suburban forest. The spatial mapping of adaptive capacity scores and socio-economic factors suggest possible relationships (Figure 4.10).

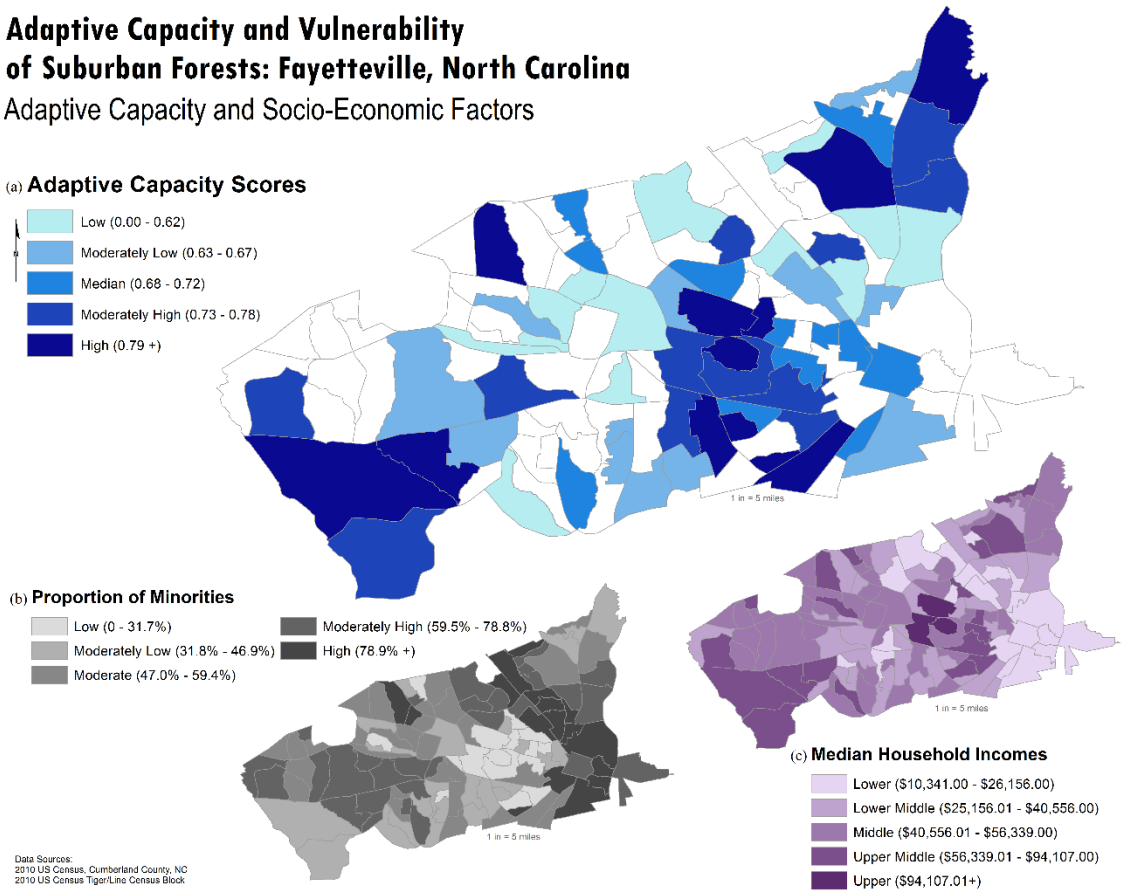


Figure 4.10 Spatial Relationship Between Adaptive Capacity Scores and Socio-Economic Factors. Figure (a) shows adaptive capacity survey scores (n=76). Figures (b) and (c) show socio-economic factors, the proportion of minorities and median household income, that may impact the adaptive capacity of subdivisions. As expected, there is a negative relationship between the proportion of minorities and median household incomes. There does appear to be a weak relationship between adaptive capacity scores and the two socio-economic factors.

Moreover, scatterplots of adaptive capacity scores and socio-economic factors also support the possibility of relationships (Figure 4.11). While not originally considered a factor, the scatterplot of the total land use changes variable and adaptive capacity scores showed an overall negative

linear trend, indicating that this relationship should be considered (Figure 4.11). It is important to note that the observation of 8 total land use changes might be the cause of this negative trend.

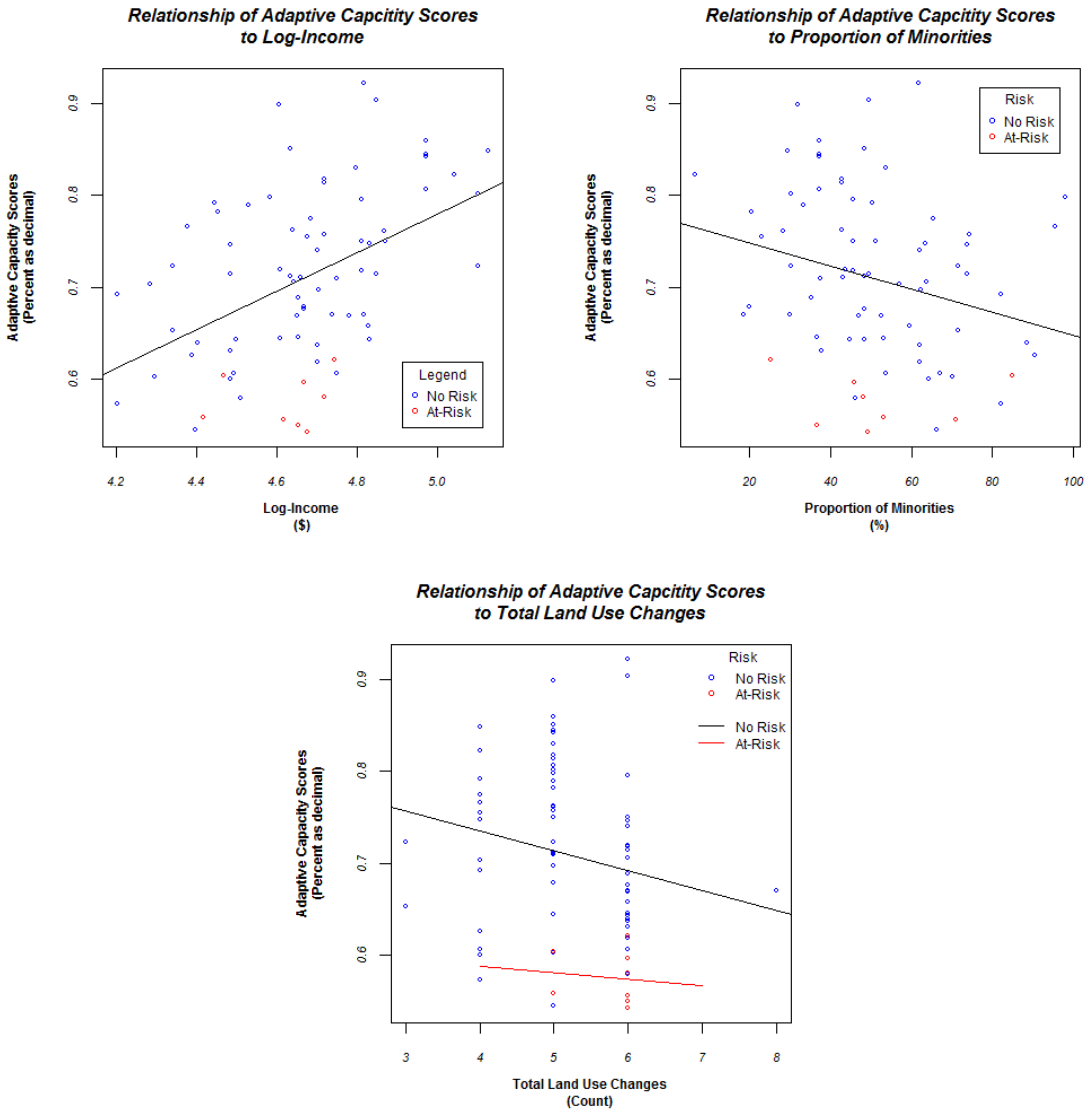


Figure 4.11: Scatterplots of Adaptive Capacity Scores and Log-Income, Proportion of Minorities, and Total Land Use Changes. There appears to be a weak, positive relationship between income and adaptive capacity scores and a slightly weaker negative relationship between the proportion of minorities and adaptive capacity scores. The third factor that may influence adaptive capacity scores is the total number of land use changes, which appears to have a linear trend for all samples and just samples identified as at-risk.

Using Pearson's Correlation Coefficient, adaptive capacity scores were found to be moderately correlated with log-income ($r = 0.46$, $p < 0.0001$). Both the total land use changes variable and the percent of minorities were found to have a weak, negative correlation with adaptive capacity score ($r = -0.20$, $p = 0.08$; $r = -0.25$, $p = 0.03$; respectively). The correlation

with total land use changes variable significantly improves after controlling for log-income (r = -0.3851; p = 0.0006), which supports the importance of these two variables when modeling adaptive capacity scores.

The models fitted for adaptive capacity scores were (1) log-income, (2) total land use change variable, and (3) both log-income and the total land use change variable (adj. R^2 = 0.20, 0.03, and 0.31, respectively). In model 3, income is a more important factor for determining adaptive capacity scores than total land use change variable (StdB = -0.36, 0.56, respectively). In the absence of adaptive capacity scores, the total number of land use changes and median household income can be used to estimate adaptive capacity scores using:

$$\widehat{ACS} = -0.278 + (-0.038) * Land\ Use\ Changes_{Total} + 0.255 * Log_{10} Income \quad \textbf{(Eqn 2)}$$

At-Risk Subdivisions

Subdivisions at-risk were defined as having adaptive capacity scores that fall below the 20th percentile and canopy covers that decrease below 30% or any decline if the canopy cover is currently below 30%. The 20th percentile adaptive capacity score is 0.62. Sixteen of 76 (21.1%) homeowners surveyed had adaptive capacity scores below the 20th percentile threshold. Twenty-five of 76 (32.9%) samples had canopies that were at risk of decreasing below the 30% canopy threshold or were already below 30% and are at risk of further decline in ecosystem services. Overall, eight out of 76 samples (10.5%) had adaptive capacity scores below the 20th percentile and large proportions of vulnerable tree species that may result in a decline in canopy below the 30% canopy threshold (Table 4.2 and Figure 4.12)

Table 4.2. At-Risk Subdivisions

Factors	***F9****	***G13****	***G8****	***I10****	***I8****	***M4****	***N7****	***I11****	***Mean***
Adaptive Capacity Score	0.5413	0.5960	0.5799	0.5573	0.5487	0.5547	0.6035	0.6200	0.5752
Proportion of Minorities (%)	49.23	45.70	47.96	53.18	36.64	71.05	84.99	25.22	51.75
Median Household Income ($)	47,401	46,635	52,422	26,122	45,187	41,412	29,306	55,444	42,991
Species Vulnerable (%)	25.0	33.3	33.3	40.0	22.2	50.0	20.0	20.0	30.5
Current Canopy Cover (%)	21.65	31.08	29.20	37.76	19.83	24.92	28.45	32.50	28.1
Canopy Cover Excluding Vulnerable (%)	16.24	20.72	19.47	22.66	15.42	12.46	22.76	26.00	19.5
Subdivision Age	1996	1986	1988	1976	2010	1976	1966	1956	1982
Total Land Use Changes	6	6	6	5	6	6	5	6	5.75
T1:T2 Land Use Changes	1	1	1	1	1	1	1	1	1
T2:T3 Land Use Changes	1	1	1	0	1	1	0	1	0.75
T3:T4 Land Use Changes	1	1	1	1	1	1	1	1	1
T4:T5 Land Use Changes	3	3	3	3	3	3	3	3	3
Total Land Cover Changes	7	8	7	8	9	9	10	8	8.25
T1:T2 Land Cover Changes	1	1	1	1	2	1	2	1	1.25
T2:T3 Land Cover Changes	2	2	2	2	2	2	2	2	2
T3:T4 Land Cover Changes	1	1	1	1	1	1	2	1	1.125
T4:T5 Land Cover Changes	3	4	3	4	4	5	4	4	3.875

* Denotes Site ID

T1: Pre-European Contact; T2: Settlement and Natural Resource Exploitation; T3: Rise of the Automobile; T4: World War II; T5: Post-war

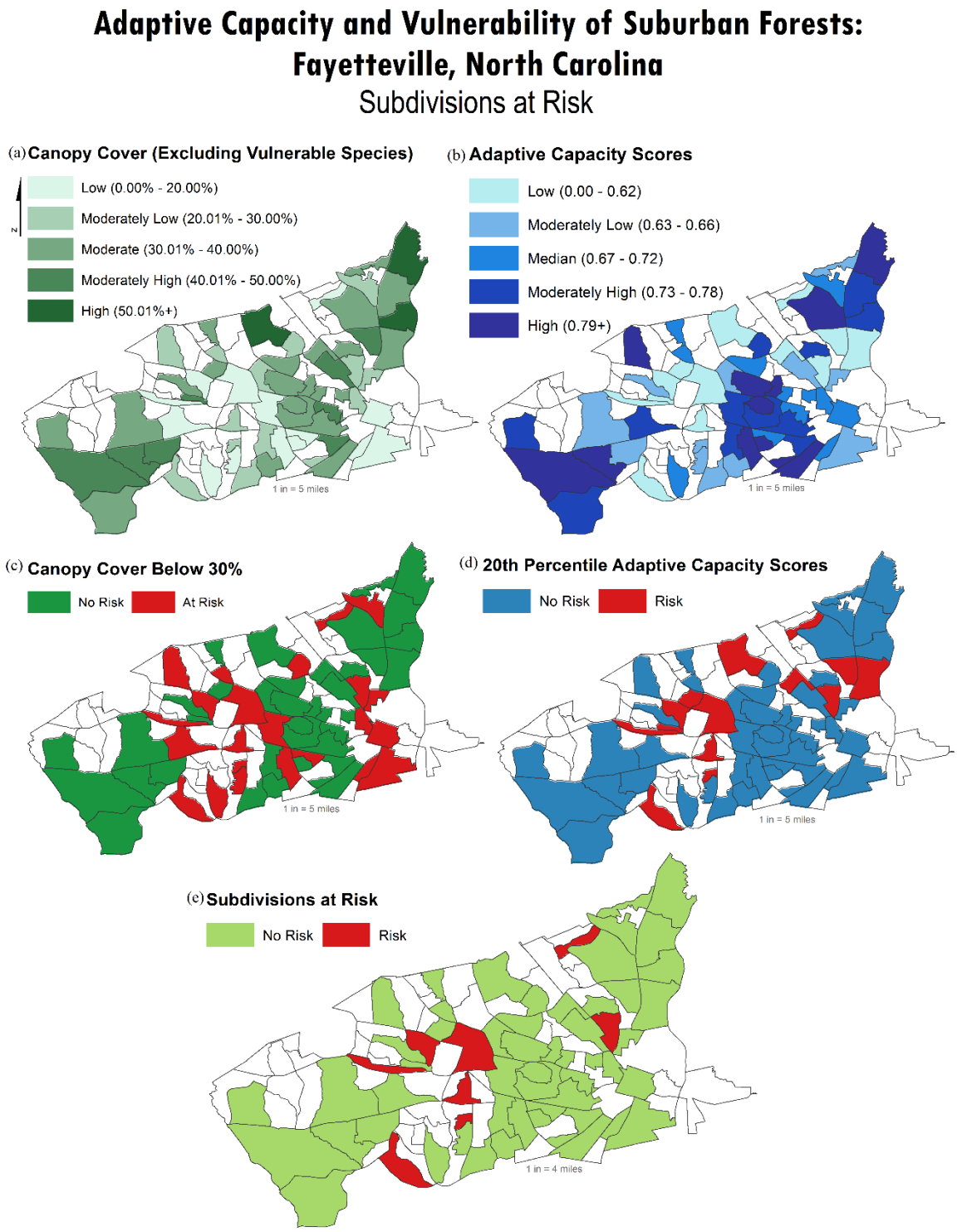


Figure 4.12 Maps for At-Risk Subdivisions. Figure (a) illustrates the canopy cover under climatic conditions, where the current canopy declines by the percent of vulnerable species (n=76). Figure (c) shows the resulting canopy cover, where at risk communities decline below 30% canopy cover. Figure (b) is the adaptive capacity scores and figure (d) shows the bottom 20th percentile of those scores. Figure (e) shows communities where both canopy cover declines below 30% and adaptive capacity scores are in the bottom 20th percentile. There are more subdivisions that exhibit canopy risk than subdivisions with low adaptive capacity scores, a factor that should not be overlooked. Should the demographics of subdivisions shift in the future, subdivisions that only exhibit canopy risk may become at-risk if the shifting population has a low adaptive capacity.

It appears that at-risk subdivisions have similar characteristics: moderately low income, socially diverse, developed after 1950 on land that had moderate land use and land cover changes (Table 4.2). However, when at-risk subdivisions are compared with subdivisions not at-risk and with the larger study area, only the total land use changes variable was found to be statistically different (Table 4.3). The mean of the overall number of land use changes variable for the subdivisions at-risk is different than both the subdivisions in the sample not at-risk and all of the subdivisions in the study area ($t(74) = 1.77$, $p = 0.08$, 95% CI [5.18, 5.75]; $t(7) = 4.58$, $p = 0.003$, 95% CI [5.36, 6.14]; respectively). The mean for land use changes between World War II (T4) and post-war (T5) for at-risk subdivisions is different than the subdivisions not at risk ($t(74) = 2.16$, $p = 0.03$, 95% CI [2.57, 3.00]). Since the total land use changes variable is a summation of land use changes between each period, only the land use changes between the World War II and post-war periods was analyzed. Results from Exact Fisher Test found an association between at-risk subdivisions and land use changes between the World War II and post-war periods ($p = 0.02$). Because the at-risk sample size is small ($n = 8$), a Monte Carlo simulation was run 10,000 times and no association was found ($p = 0.065$). Mantel-Haenzel testing found a linear correlation between the land use changes occurring between World War II and post-war periods and at-risk subdivisions, even after 100 simulations ($\chi^2(1, n = 76) = 4.46$, $p = 0.03$). Overall, the results are inconclusive, as there appears to be clustering of at-risk subdivisions around 3 land use changes between the World War II and post-war periods and Fisher Exact Test found no significant association.

Table 4.3 Comparing Socio-economic and Historical Land Factors by Sample, Census Block, and At-Risk

Minorities (%)

(%)	Sample	Census Block	Risk
6.41 - 31.74	12	17	1
31.75 - 46.92	22	25	2
46.93 - 59.45	16	31	3
59.46 - 78.84	19	29	1
78.85 - 98.99	7	16	1
n, N	76	118	8
□, μ	51.25	55.15	51.75
s	19.00	20.86	18.78

Median Household Income ($)

($)	Sample	Census Block	Risk
10,341.00-26,156.00	11	21	1
26,156.01-40,556.00	15	35	1
40,556.01-56,339.00	28	40	6
56,339.01-94,107.00	18	19	0
94,107.01-134,063.00	4	3	0
n, N	76	118	8
□, μ	51,432.30	44,824.54	42,991.13
s	25,381.07	20,880.55	10,391.66

Land Cover Transitions (f)

Frequency	Sample	Census Block	Risk
3	2	2	0
4	1	3	0
5	0	0	0
6	2	3	0
7	16	14	2
8	26	39	3
9	20	32	2
10	6	19	1
11	3	6	0
n, N	76	118	8
□, μ	8	8	8
s	1	1.5	1

Subdivision Age

Year	Sample	Census Block	Risk
1914 - 1923	5	5	0
1924 - 1933	3	7	0
1934 - 1942	0	0	0
1943 - 1952	0	0	0
1953 - 1962	10	15	1
1963 - 1971	10	17	1
1972 - 1981	18	31	2
1982 - 1990	7	17	2
1991 - 2000	16	16	1
2001 - 2010	7	10	1
n, N	76	118	8
□, μ	1975	1974	1982
s	24	22	17

Land Use Transitions (f)

Frequency	Sample	Census Block	Risk
3	2	2	0
4	13	18	0
5	28	31	2
6	32	62	6
7	0	4	0
8	1	1	0
n, N	76	118	8
□, μ	5	5	6
s	1	1	.5

CHAPTER 5

DISCUSSION

The Suburban Forest

Much of the suburban forest of Fayetteville, NC sampled corresponds with the regional forest type: oak-pine. The remaining species inventoried is a diverse mix of hardwood and softwood species, along with a hodge-podge of common nursery species. Cultural heritage has sustained and promoted a large number of North Carolina native species. The most numerically dominant native tree species in Fayetteville, NC is the Flowering Dogwood, which is also a culturally significant species, with an annual festival and a trail that highlights Flowering Dogwoods throughout the community. Despite global influences from soldiers who live in the Fayetteville area, there is a surprising amount of native species that have been retained; which may be the result of heightened cultural heritage awareness.

In this study, 30% of tree species identified were characterized as having moderate-high to high vulnerability to climate change. This is high compared to the Brandt et. al study (2016), where estimates for vulnerable tree species was (15%). However, when compared to Lanza and Stone (2016) where estimates for vulnerable tree species in Atlanta, GA and Washington, D.C. were 36.5% and 24.1% of tree species, respectively, the vulnerability in Fayetteville is midway. Since Atlanta, GA, Washington, D.C. and Fayetteville, NC are all within the same ecoregion and have similar tree species richness, the results are as expected (Waring et. al, 2006).

However, only 6.3% of the total number of trees inventoried were vulnerable to climate change. This is low compared to estimates of Philadelphia, where 27% of trees (33% of species) had moderately high or high vulnerability to climate change (Brandt, n.d.). There may be some factors suppressing the number of vulnerable trees. The most likely cause for a low percentage

of trees susceptible to climate change is that the quantity of trees in my sample size may have been too small. While each sample was based on the lot size of the respondent, even a conservative estimate of 1 acre lots with 100% canopy cover would be 76 acres of canopy cover sampled. Of approximately 21,140 acres with canopy cover in the study area, approximately 0.4% was sampled. In addition, some of the subdivisions sampled may be better characterized as low density rural areas (Gordon and Shirokoff, 2014) and could be skewing the results. For example, two sample sites on the edge of the study area accounted for 15% of the trees in the study. Fifty-five percent of the trees at these two sites account for one third of the top 3 species (Longleaf Pine, Loblolly Pine, and Flowering Dogwood), which have low vulnerability to climate change. These two sites indicate that some of the samples are better characterized as low density rural areas than auto suburbs. Lastly, in several clusters no samples could be obtained. It may be that subdivisions with more trees vulnerable to climate change were also less likely to participate in the study. Compared with the entire study area, subdivisions with a total of six land use changes, subdivisions built between 1960 and 1990, and middle to lower-middle income subdivisions were underrepresented (table 4.3). The underrepresentation suggests that subdivisions with lower proportions of tree species vulnerability may be skewing the overall number of trees vulnerable to climate change.

It is important to note that none of the trees were categorized as highly vulnerable to the effects of climate change. This may be due to the wide climatic variations in the region, where both northern and southern species can grow, along with being situated along the fall line transitioning western and eastern species. Therefore, species growing in the study area can withstand large climatic variations, thereby buffering vulnerability. Noticeably, the species that are currently at the edge of a contracting range, such as American Beech and Eastern White Pine,

were found to also be the most vulnerable based on the risk matrix developed for this study (Appendix D).

The risk matrix used in this study to identify tree species vulnerable to climate change appears to have produced comparable results in the proportion of overall tree species vulnerable to climate change as Lanza and Stone (2016) and Brandt et. al (2016). While the method for evaluating tree species vulnerability to climate change in this study is fairly simplistic, the results were not tested with alternative risk matrices, such as the method suggested by Iverson et. al (2012). The matrices proposed by Iverson et. al (2012) are more complicated, but also provide a more detailed picture of non-vulnerable species, especially for species with ranges that are expected to expand. Therefore, future studies should evaluate various risk matrices to determine the limitations, suitable uses, and effectiveness for determining risk. Furthermore, because both urban and suburban forests are a conglomerate of species, evaluating the risk of non-forest species to climate change is needed (Brandt et. al, 2016; Nitoslawski and Duinker, 2016; Pickett et. al, 2008).

Approximately 40% of the subdivisions currently below the 30% canopy cover threshold did not exhibit canopy risk, while 56% of the subdivisions currently above the 30% threshold showed canopy risk. Therefore, targeting communities with low canopy cover may not be the most effective method for identifying communities requiring assistance for improving their canopy cover. Prioritization for increasing canopy cover should not be solely based on current estimates, but must also account for changes in canopy cover predicted due to changes in climatic conditions.

To add further gravity to the investigation of suburban forests, the estimate of at-risk subdivisions is very likely conservative. Thirty-three percent of the subdivisions sampled in

Fayetteville, NC were found to be at risk of significant canopy losses under predicted climatic conditions. However, this finding does not account for decreasing canopy cover in the future due to development and may actually be significantly higher. While suburban canopy cover thresholds may be variable (Maco and McPherson, 2002), it is likely that thresholds will be approached in the future as a result of climate change and development. Mitigative and adaptive plans enacted now can lessen the effects on suburban forest ecosystems and the services they provide to the people living in them (Brudvig and Damschen, 2011).

Tree Species Vulnerability and Historical Land Factors

While weak correlations were found between tree species vulnerability and a few historical factors, none of the models showed a meaningful linear relationship. However, a significant relationship was found between the percent of vulnerable tree species and the combination of the number of land cover changes between the settlement and natural resources exploitation period (T2) and the rise of the automobile (T3) and the number of land use changes between periods of the rise of the automobile (T3) and World War II (T4). Because there was a large proportion of non-vulnerable species, a relationship between tree vulnerability and historical factors was not found to be significant. The QQ-plots for each of the models, however, show that there is a possible meaningful relationship between historical factors and the percent of tree species vulnerable to climate change (Figure 4.8). The land use change pathways did, however, reveal a pattern of historical land use changes that might be a strong indicator of tree species vulnerability. Further testing and confirmation is needed to link a specific historical land use trend with the presence of vulnerable tree species. Conservatively, not enough statistical evidence exists to conclude that the presences of trees vulnerable to climate change is due to

historical factors; however, there is enough evidence to suggest a possible relationship that warrants further investigation.

A few possible reasons could explain why the relationship between historical land factors and the proportion of trees vulnerable to climate change is inconclusive. First, the sample size may have been too small (n=76), as illustrated by the histogram (Figure 4.1). Ultimately, this may be the greatest hurdle in determining whether and what historical factors could point to increased numbers of tree species vulnerable to climate change. Because suburban forests are managed by individuals, obtaining a sample size large enough to detect a relationship could be problematic. While remote sensing tools are available, its application to suburban forests is insufficient. For example, a recent study using remote sensing and forest inventory data to model carbon storage of trees outside of forests found that these models performed poorly when applied to urban areas (Price et. al, 2017). It is no surprise that suburban forest inventories are lacking. The sourcing of trees by residents is not typically from neighboring forests, but from local nurseries and gardening centers, thereby playing a significant role in shaping the suburban forest composition (Nitoslawski and Duinker, 2016; Summit and McPherson, 1998; Zipperer, 2008; Conway and Vecht, 2015). Therefore, a method for inventorying suburban forests remotely is needed. Advances in lidar and the employment of cost-effective Unmanned Aerial Systems may offer the solution in the near future for a suburban forest inventory. An accurate, remote suburban forest inventory may be the crucial link to establishing a relationship between historical factors and the presence of tree species vulnerable to climate change.

The second possible explanation for not detecting any relationship between the presence of tree species vulnerable to climate change and historical land factors is the scale of analysis. While the proper scale of analysis is still under debate, there is agreement on the importance of

historical factors in explaining the current species composition (Waring et. al, 2006). Therefore, it may be that the scale for detecting this relationship is better suited for the regional rather than the local levels.

Scaling to the regional level may lose some of the clarity of land use changes occurring at a local level using a purely quantitative approach (Gragson and Bolstad, 2006); however, it is possible that the combined quantitative and qualitative approach used in this study may be able to retain some clarity at the regional level. This approach needs to be tested against both the back-casting approach proposed by Tayyebi et. al (2015) and purely qualitative approaches to determine the efficacies and limitations of each approach. In addition to retaining as much clarity as possible at the regional level, any approach needs to be feasible for use in planning and management tools. Currently, historical factors are not available through i-Tree, a popular tool used for assessing urban and suburban forests (Nowak, 2013). While incorporating historical factors into a large-scale tool is challenging, there is promise. Historical census data is now available in GIS-compatible boundary files from the National Historical Geographic Information System (Manson et. al, 2017). This data could be integrated with historical maps from the USGS Historical Topographic Map Collection (Fishburn et. al, 2017), user provided maps, and the average age homes are built by Census Block Group from the US Census. The integration of historical land factors could open up a larger body of research on the prevalence of vulnerable tree species and could substantially improve the evaluation of subdivisions at-risk to climate change.

Lastly, the lack of a significant relationship between historical land factors and the presence of tree species vulnerable to the effects of climate change may be due to factors that this study cannot explain. Because the suburban landscape is like a palimpsest, the constant

editing of the landscape may make it difficult to understand all the factors that result in the presence of vulnerable tree species. While an understanding of the ecological factors that may aid in *identifying* vulnerable tree species exists, a dearth of knowledge on the factors that have led up to the *presence* of vulnerable tree species prevails. This gap in knowledge points to the critical need to improve our understanding of the suburban forest.

Adaptive Capacity and Socio-Economic Factors

Correlations between adaptive capacity scores and individual socio-economic factors were as expected and correspond with similar findings for canopy cover (Locke and Grove, 2016; Danford et. al, 2014; Heynen and Lindsey, 2003). While the correlations for the study area are as expected, these results may not be different based on suburban typologies and geography (Schwarz et. al, 2015). Moreover, more factors should be considered and may be more influential in determining adaptive capacity of suburban residents. Other socio-economic factors along with factors not traditionally associated with adaptive capacity should be explored.

Including the total land use changes variable helped to improve the model for determining adaptive capacity. To understand how the total land use changes variable is related to adaptive capacity, we turn to the history of the study area for a possible explanation. This study found that former farmland, especially those areas between five and ten miles from the city, experienced turbulent changes and exploitation until the mid-20th century. These lands experienced intense industrialization, followed by field abandonment during the Great Depression, and subsequent exploitation during WWII. By mid-century, the land began transitioning to postwar suburbs. This pattern is echoed in the changes in land use type pathway diagram, where canopy risk and at-risk subdivisions tend to follow this pattern of change (see Figure 4.5). The literature of place stratification theory helps to explain the connection between

the historical land use of postwar subdivisions and adaptive capacity. A growing body of research based on place stratification theory has linked older, postwar suburbs to the growth of suburban poverty (Anacker et. al, 2017; Pfeiffer, 2016; Anacker, 2015b; Kneebone and Berube, 2013; Vicino, 2012; Orfield, 2011; Allard, 2009). Older postwar suburbs are linked to both a clear pattern of land use changes and a growth of suburban poverty, which helps to identify subdivisions with low adaptive capacity.

In the absence of readily accessible adaptive capacity data, income and minorities are frequently used as proxies. Our research suggests exploring factors outside of the traditional socio-economic factors used for determining subdivisions with low adaptive capacity. More important, though, is the need for greater caution when using proxies, especially with respect to the suburbs. We find that the average for at-risk subdivisions is neither low income nor predominately minority subdivisions. At-risk subdivisions are lower-middle income and diverse communities. Therefore, it is critical that mitigation and adaptation planning not strictly target specific socio-economic communities but expand to a holistic approach, looking at a large suite of factors both human and ecological, current and historical.

At-Risk Subdivisions

The relationship between at-risk subdivisions and the number of land use changes occurring between the World War II and post-war periods is inconclusive, likely due to the small sample size. The total land use changes variable, however, was found to be associated with at-risk subdivisions. Since the number of land use changes occurring between the World War II and post-war periods is a function of the total land use changes variable, it is possible that the number land use changes that occurred between the World War II and post-war periods are also associated with at-risk subdivisions. Moreover, the pattern indicated in the changes in land use

type pathway diagram (Figure 4.5), combined with the substantial body of evidence regarding income and postwar suburbs, bolsters the results, indicating a significant association of land use changes in older postwar subdivisions and at-risk subdivisions.

With nearly 50% of the US population (and growing) living in the suburbs and receiving ecosystem services provided by the suburban forest, it is critical that researchers seriously consider studying suburban forests (Frey, 2012). This research indicates that historical information plays a role in adaptive capacity and may be a factor in the presence of tree species vulnerable to climate change and, therefore, needs to be included in assessment, planning, and management tools. Governments, municipalities, key actors, subdivisions, and individuals need this information now, so that they can plan and act to lessen the impact of future climate changes. Failure to improve our understanding of the vulnerabilities and adaptive capacities of suburban forests could result in overestimating or incorrectly identifying at-risk subdivisions. The results may be detrimental; not only could the desired outcome not be achieved, but the argument for taking mitigative and adaptive actions in the future could be substantially weakened.

CHAPTER 6

CONCLUSION

Without a complete understanding of which subdivisions are at risk of ecosystem service degradation due to declines in canopy cover from climate change, adaptation and mitigation actions may be fruitless. A growing body of research regarding the general composition of the suburban forest has informed and been confirmed by this study. Half of the suburban forest in Fayetteville, NC was dominated by three native species: Flowering Dogwood, Longleaf Pine, and Loblolly Pine. The most dominant forest type was oak-pine; the remainder being a hodge-podge of species to include two known invasive species. These results confirm previous findings, where the composition of the suburban forest was found to be a conglomerate of native, non-native, and invasive species (Brandt et. al, 2016; Nitoslawski and Duinker, 2016; Pickett et. al, 2008). Thirty percent of tree species identified were characterized as having moderate-high vulnerability to climate change, corresponding with estimates within in the ecoregion (Lanza and Stone, 2016; Waring et. al, 2006). Both subdivisions currently above the 30% canopy cover threshold and below the threshold had approximately the same proportion of subdivisions exhibiting canopy risk, indicating that prioritization for increasing canopy cover must consider not only the current canopy cover, but also the expected canopy cover under future climatic conditions. Moreover, these findings are likely conservative as they do not account for the impacts of future urbanization.

Historical land factors were explored as possible factors that may have led to the presence of vulnerable tree species. Only weak correlations were found between the presence of vulnerable tree species and three historical land factors: (1) the number of land cover changes between the period of settlement and natural resource exploitation (T2) and the rise of the

automobile (T3), (2) the number of land use changes that occurred between the periods of the rise of the automobile (T3) to World War II (T4), and (3) subdivision age. There appears to be a relationship between the presence of vulnerable tree species and the pathway of historical land use changes, suggesting that a relationship exists. Moreover, historical land factors were found to be significantly associated with overall risk and play a significant role in assessing adaptive capacity. It is recognized that historical land practices shape the structure, composition, and function of forests and that acknowledging the importance history has on the landscape can increase the effectiveness of management (Christensen et. al, 1996; Swetnam et. al, 1999; Foster et. al, 2003). Because the auto-suburban forest is managed by individual homeowners, the incorporation of historical land factors plays an important role for municipalities, policy-makers, stakeholders, and individuals to make informed decisions (Dale, 1997). The identification of historical land trends, such as the potential relationship between the vulnerability of the modern suburban forest and agricultural abandonment, can be valuable not only in terms of where potential risk lies, but can also serve as valuable lesson (Quigley et. al, 1996; Kauffman et. al, 1998; Swetnam et. al, 1999). By understanding the historical trends, we are informed of not only what is possible, but also can use this information to help guide and even limit management actions (Pickett et. al, 1992; Swetnam, 1999). Moreover, the role that historical land factors play in the vulnerability and adaptive capacity in suburban forests adds to the explanatory power of our understanding of the suburban forest and could improve predictive models (Swetnam et. al, 1999). The understanding of the role historical land factors plays in the current composition and, thereby, the vulnerabilities of the suburban forest may be crucial in improving inventorying, modeling the future suburban forest, and identifying at-risk subdivisions. Even if potential inventorying methods improve, the knowledge pertaining to the vulnerability of non-forest

species is limited. Thus, knowing the relationship between species vulnerability and historical land factors can be a valuable tool. Despite the absence of a larger body of research, historical land factors such as land use, land cover, and development age should not be discounted when evaluating subdivisions at risk to changes in ecosystem services due to climatic changes and should be further explored and incorporated into planning tools.

Human adaptive capacity and the factors that impact adaptive capacity are perhaps the best understood aspects of suburban landscape vulnerability. The results found in this research support the findings that income is positively correlated with adaptive capacity, while the proportion of minorities is negatively correlated (Leichenko and Solecki, 2013; Tol and Yohe, 2007; Torres, 2008). Income was found to be more strongly correlated to adaptive capacity than the proportion of minorities. Moreover, expanding beyond traditional socio-economic factors to include historical land factors significantly improved the estimation of suburban adaptive capacity. Interestingly, the average income for the at-risk subdivisions was not low-income, but middle income. Moreover, the average demographic ratio for at-risk subdivisions was not predominately minority subdivisions. These results indicate that proxies should be used with caution.

Subdivisions at-risk were found to be unique from other subdivisions in one regard: total land use change. The association between at-risk subdivisions and land use changes occurring between the World War II and post-war periods were inconclusive. The many indications that historical land factors are associated with adaptive capacity, vulnerable species, and at-risk subdivisions points to a need to integrate historical land factors, along with socio-economic and ecological factors into planning, decision-making, and management tools. While the complexity and dynamic nature of suburban landscapes and tree vulnerability make identifying vulnerable

subdivisions challenging, its understanding is of vital importance for sustaining the ecosystem services suburban forests provide long into the future.

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APPENDICES

Appendix A

Suburban Forest Survey

NC STATE UNIVERSITY

Principal Investigator: Stephanie Karp ***Faculty Sponsor***: Dr. Gary Blank

Title of Study: Vulnerability and Adaptive Capacity of Suburban Forests to Climate Change

Introduction: Thank you for taking the time to complete this survey. The purpose of this study is to understand the vulnerability of suburban forests and the degree to which residents are able to adapt to those changes. These results will help us understand the impacts of climate change on the suburban forest and provide an understanding of where climate change mitigation efforts are needed.

Time to Complete Survey: 10-15 minutes

Confidentiality: The information in the study records will be kept confidential to the full extent allowed by the law. Data will be stored securely in a password protected, encrypted file, on a secured and restricted computer. No reference will be made in oral or written reports that could link you to the study.

Mark the box that best describes your response to the following statements.

	Definitely	Very Probably	Probably	Possibly	Probably Not	Definitely Not
If you wanted to build a patio or an addition to your home where a healthy tree stands, how likely would you be to remove the tree, assuming you have no restrictions?						
If you were to plant a tree, how likely would you use the same type or species of trees already present on your property?						
If you were to plant a tree, how likely would you use the same type or species of trees already present on your street?						
How likely are you to plant trees based on predicted climate conditions, assuming you have no restrictions?						
If you were to plant a tree, how likely would you select a southern native tree, such as the saw palmetto? *Trees that are naturally occurring south of North Carolina and not introduced by people.*						
How likely would you plant a certain type of tree, assuming you had no restrictions, even if a disease or insect infestation that affects that type of tree is known in the area?						
After taxes, bills, etc., do you feel you *could* afford to spend money on trees, such as new plantings, installations, maintenance?						

After taxes, bills, etc., *would* you spend money on trees, such as new plantings, installations, and maintenance?						

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Do you believe that planting native trees will help your community in the future? *Native trees are trees that are naturally occurring in an area and not introduced by people.*					
Do you believe maintaining older trees will help your community in the future?					
Do you believe increasing the number of different kinds of trees will help your community in the future?					
If you intended to plant 3 trees, would you feel that planting all 3 trees now is better than over an extended period of time, assuming you had no restrictions?					
Do you believe having different aged trees will help your community in the future?					
Do you believe that in the next 50-100 years the temperatures in Fayetteville, North Carolina will increase?					
Do you believe that droughts will occur more often and last longer during the next 50-100 years in Fayetteville, North Carolina?					
Assisted migration is the deliberate, human-assisted movement of plants from their current habitat (home) to an area expected to be a better habitat (home) in the future. How do you feel about assisted migration?					
For this question, native trees are trees naturally occurring and not introduced by people. How do you feel about planting trees native to southern areas such as Georgia and Florida?					
If you intended to plant a tree, would you feel that planting a disease or insect-resistant type of tree is *better* than a similar type of tree that is not disease or insect-resistant, assuming you had no restrictions?					
A hybrid tree is a tree that is the result of two different breeds, varieties, species or genera. How do you feel about using hybrid trees that are disease or insect-resistant?					

	Very Important	Somewhat Important	Neutral	Not Very Important	Not at All Important
In general, how do you value old trees?					
How do you value having different kinds of trees on your property?					

If you could plant any tree on your property, which tree would you choose? (Select one from each pair)		
	Magnolia  Photo: Jenny Willoughby	Bradford Pear  Photo: Steve Bender
	Flowering Dogwood  Photo: Aaron Dalton	Mimosa  Photo: Will Cook
	Tulip (Yellow) Poplar  Photo: Lakes edibles	Norway Maple  Photo: Pat Breen, OSU
	Sycamore  Image: Wendy Smith	Ginkgo  Image: Robert O'Brien

	Old	Mature	Near Maturity	Young
Assuming you had an old, mature, near maturity, and young tree on your property that are each healthy, which tree would you likely remove, assuming you have no restrictions?				

	Very	Moderately	Slightly	Not at all
How familiar are you with trees native to Fayetteville, NC? (Can you name, identify, or have some knowledge of trees that are native to Fayetteville, NC)? *Native trees are trees that are naturally occurring in an area and not introduced by people*				

	Not Applicable	During the same season	Over 2-3 Years	Over 4-6 Years	Over 7+ Years
If you have planted multiple trees in the past on the same property, did you plant each tree during the same planting season or over the course of multiple years?					

Do you have any *restrictions* that would prevent you from planting (a) tree(s) or maintaining your tree(s)? (Please select all that apply)

___HOA rules

___Renter that does not have permission

___Unable or don't feel safe to do the work myself

___Too expensive

___ I do not have the time

__Other (Please specify): _____

__ I do not wish to answer

Appendix B

T1: Pre-European Contact, pre-1730s.

***Historical Narrative*.**

Little is known about the Native Americans living in North Carolina, let alone in the Cumberland County area. Regionally, historians have associated Native Americans living in the vicinity of Cumberland County with the Siouan language group (Smith, 2011). However, there is no written record of Native American settlements in the Fayetteville area at the time of European exploration (Smith, 2011). Archeological evidence of hunting and fishing in the Fayetteville area does exist, suggesting that Fayetteville was likely a managed hunting ground (Smith, 2011). Archaeological evidence has been found in mounds on the eastern side of the Cape Fear, approximately 10 miles south of Fayetteville, indicating settlements in the area (MacCord, 1966). Since Fayetteville is not located directly adjacent to any known Native American settlement, it seems improbable that the area was used for agricultural purposes, thus supporting the idea that Fayetteville was managed hunting grounds.

Pollen records of the southeastern United States, which include Fayetteville, indicate that the forest composition prior to European contact had been in place for approximately 5,000 years (Landers et. al, 1995). Additionally, the records indicate that 65% of the forest was pine, 15% was oak, and the remainder being elements of the modern, species-rich forest (Landers et. al, 1995). Much of the pine type would have been longleaf pine (*Pinus Palustris)* and oak, specifically, turkey oak (*Quercus laevis*) (Landers et. al, 1995). It is known that Native Americans used fire as a landscape management tool. Longleaf pine, the dominant tree species found in Fayetteville at the time, exhibits a high fire tolerance, adding further gravitas to the

belief that Fayetteville was formerly a Native American game preserve managed by fire. (Mann, 2005).

Interpretation.

The absence of Native Americans in Fayetteville in European written records, limited archeological evidence, pollen records, and the significant presence of high fire tolerant species, indicates that the land use prior to European contact was all game reserve. The pollen records combined with a substantial amount of remnant longleaf pine suggests that the land-cover prior to European contact was 65% longleaf pine, 15% turkey oak, and the remaining 20% of the modern, species-rich forest (Landers et. al, 1995). In the absence of a specific species or forest type that was used to identify the "modern, species-rich forest," the characterization of species richness was used. Ecotones, marked by high species richness, are likely the modern, species-rich forest identified in the pollen records. Given the extensive waterways in the study area, the riparian ecotone, which accounts for 20% of the current land cover, was used to characterize the remaining 20% land cover.

Land use.

First, it was assumed that the modern riparian hardwood species that existed along the Cape Fear river, creeks, and wetlands during this period have not substantially changed based on the pollen records discussed in the findings of Landers et. al (1995). It was also assumed that the amount of area covered by water remained approximately the same and in the same location. While man has altered waterways, the historical maps (see Figure B.3) show that much of the historical waterways of Fayetteville still exist today in the same proximal location. The remaining land was assumed to be all game land reserve, with open areas and longleaf mixed w/ oak. Using ArcGIS, the 2011 NLCD map, and the census block tiger/line shape file, the amount

of each land use for each census block was tabulated. Woody wetlands and emergent herbaceous wetlands were combined to make the land use category wetland. Excluding the wetlands and open water, the sum of the remaining area was the game land reserve.

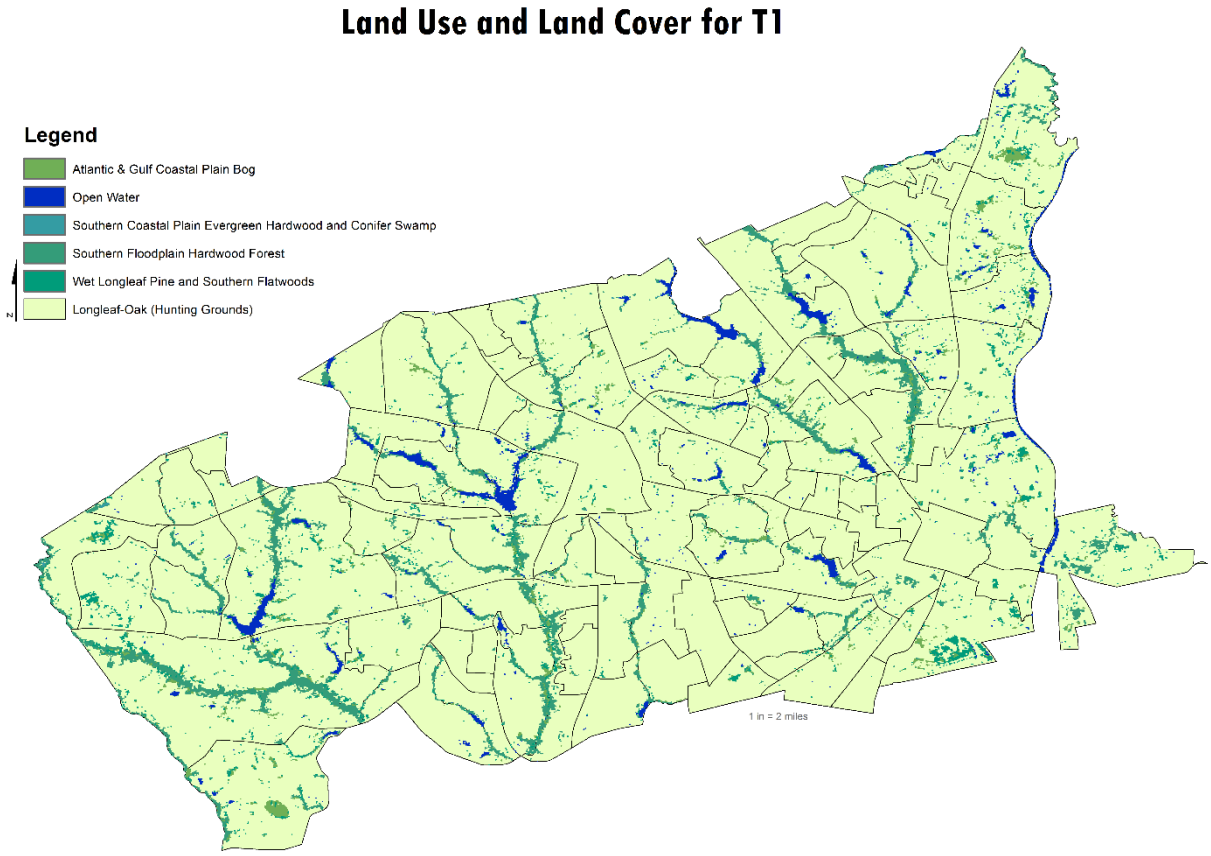

Figure B.1 Land Use and Land Cover Estimated for T1: Pre-European Contact.

Land-cover

Again, it was assumed that wetlands and open water remain constant. It was also assumed that barren areas and scrubland were unchanged from the baseline map. These areas would have existed in the landscape following natural disturbances, such as fire or flooding. However, these areas would have changed frequently through the course of time and are impossible to capture as exact locations for specific times. The amount of each land-cover category for each census block was tabulated using the 2011 GAP map, the census block shape

file, and ArcGIS. The coverage for longleaf pine is 65% of the total area for each census block. The coverage for oak-southern hardwood species was the remaining area, which varied for each census block. The average area of longleaf pine and oak-southern hardwood species for Fayetteville 65.76% and 16.21% respectively, which corresponds with the pollen records (Landers et. al, 1995).

T2: Settlement, Natural Resource Exploitation and War, 1730s - 1918.

***Historical Narrative*.**

Beginning in the 1730s, a wave of Highland Scots immigrated to North Carolina, where they began to settle the Upper Cape Fear (Meyer, 2014). In 1705, the British Parliament passed the Naval Stores Act, subsidizing the production of naval stores of tar, pitch, and turpentine. Coinciding with the settlement of the Upper Cape Fear, North Carolina went from exporting 47,541 barrels of tar and pitch to 135,000 barrels between 1730 and 1768 (Williams, 1935). The naval stores industry persisted in North Carolina until World War I. Due to its proximity to the Cape Fear River, which extends to the ports of Wilmington, NC, longleaf pine was intensively exploited for naval stores in Cumberland County. Moreover, the combination of being one of the last stops accessible to boats on the Cape Fear and the blossoming carriage manufacturing

industry gave rise to Fayetteville's status as a leading trade center (Myrover, 1905). By 1852, the Plank Road had been built, connecting the westerly territories to Fayetteville and on to the ports of Wilmington (Starling, 1939). However, as the Plank Road failed it was quickly followed by the Western Railroad of North Carolina in 1861, which connected Fayetteville with coal fields in the region as depicted in Figure B.2 (Low, 1861). The amalgamation of an arsenal, abundant resources in the region and trade network made Fayetteville a strategic target during the Civil War. When the Union Army had reached Fayetteville in March of 1865, General Sherman ordered the destruction of the arsenal, railroad, factories, tanneries, and all but one mill (Sherman, 1865). In the wake of the Civil War, Fayetteville began reconstruction. Again, Fayetteville focused on re-establishing its status as a premier trade center. Between 1870 and 1900 it built an expansive railroad network that was interlinked with the regional urban centers of Raleigh and Wilmington. Meanwhile, the importance of the shipping industry on the Cape Fear deteriorated rapidly from the competition of the railroads and the fading naval stores industry (Tooker et. al, 2011). By the turn of the century, mills, factories, roads and railroads had been rebuilt. The extent of

Figure B.2 Fayetteville's Transportation Network (Cohon, 1863).

development that occurred since the first Highland Scot settlements in the 1730s can be seen in Figure B.3.

Figure B.3 1782 Sketch of Cumberland County (top) and McDuffie's Map of Cumberland County, 1884 (bottom)

Interpretation.

The land use until the first European settlements in Fayetteville had been game preserves managed by Native Americans in the region. The combination of land clearing for settlements

and the lucrative naval stores industry resulted in significant deforestation and dramatic declines in longleaf pine populations (Landers et. al, 1995). By 1935, the longleaf pine population was reduced by two thirds (Outcalt and Sheffield,1996; Frost, 2007). As the naval stores industry faded, the plank railroad followed shortly after by the railroad industry, which decimated the remaining forests of Fayetteville. By 1880, commercial timber within a mile of railroads, streams, and likely plank roads had been completely cleared (Frost, 1993). Moreover, the first railroad in Fayetteville extended to regional coal fields, indicating that in the 1860s, the region was beginning the transition from predominately wood fuel to coal (Williams, 1987). The Department of Agriculture published a bulletin in 1913 with the output of timber products by species for each state in the country. In North Carolina, the top lumber outputs from 1913 were yellow pine, oak and yellow poplar, pointing to a significant shift in forest composition (UNC, 1916). Meanwhile, agricultural land became increasingly fragmented by stock laws, which ended the era of open ranges and provided a window of opportunity for the forest, especially longleaf pine to regenerate (Frost, 2007). The combination of woodlots and stock laws likely resulted in a mottled agricultural landscape. Finally, the rise of Fayetteville as a prominent trading city also came with increased urbanization. The Sanborn Insurance Maps from 1914 and 1923 show the rapidly expanding residential areas of Fayetteville; by 1923, approximately 2500 acres had become residential (Sanborn, 1914; Sanborn 1923). Growth patterns expanded from downtown Fayetteville northwards and westwards along plank roads. Northward, the growth was along Hillsboro Street, Ramsey Street, and North Street, while westward growth was on Morganton, Lumberton, and Yadkin Roads (Michael, 2001).

Land use

As previously discussed, it was assumed that the riparian areas and open water remain constant. To determine the land use for each census block, a two-step process was used. First, ArcGIS was used to determine amount of area for each census block based on 15 land use categories and 7 limiting buffers. Next, the categories for each census block were calculated using assumed percentages of land uses within each of these buffers.

ArcGIS

Using McDuffie's map and the 1923 Sanborn Insurance map, a new polygon feature class encompassing the new urban areas of Fayetteville at this time was outlined. Continuing with ArcGIS, McDuffie's map, the 1923 Sanborn Insurance map, and the current map, 1-mile buffers were created around roads and railroads. A 5-mile and 10-mile buffer were created around the downtown market. With the intersection tool in ArcGIS, the census blocks were divided by the buffers and urban areas. The resulting polygons were then intersected with the NLCD layer, which generated nearly 36,000 polygons with the census block, land use, and limiting buffer attributes. The area of the resulting polygons was calculated using the Calculate Geometry tool in ArcGIS (Figure B.4).

Calculations

Because transportation was relatively slow, it is assumed that the amount of land converted to farmland and related industries would decrease the further one was from downtown. Correspondingly, managed woodlots would have increased, as the density of railroads and roads decreased outwards, reducing the pressure for timber for infrastructure and the fuel necessity for homes in the hinterland that had not converted to coal. The remaining land would have been unmanaged forests, wildland. Moreover, the amount of cropland increased with proximity to roads and railroads, as the land would have been completely cleared making the transition to

farmland easier and easy access to a market would have made these areas especially attractive. See Table B.1 for percentages of land uses for each buffer area. Then the results were evaluated to ensure they were reasonable with respect to the land use from T1: Pre-European Contact, the post-war period (T5), and the interpretation of T2: period of settlement and natural resources exploitation.

Table B.1 Percentages of Land Uses for Each Buffer Area

Buffer Area	No Roads/Railways	With Roads/Railways
> 10 miles from market	(a) 10% Cultivated crops and related industries	(a) 20% Cultivated crops and related industries
	(b) 20% of (a) is woodlot	(b) 20% of (a) is woodlot
	(c) Remaining amount is wildland	(c) Remaining amount is wildland
> 5 miles and < 10 miles from market	(a) 50% Cultivated crops and related industries	(a) 60% Cultivated crops and related industries
	(b) 10% of (a) is woodlot	(b) 10% of (a) is woodlot
	(c) Remaining amount is wildland	(c) Remaining amount is wildland
< 5 miles, excluding urban area	(a) 80% Cultivated crops and related industries	(a) 80% Cultivated crops and related industries
	(b) 5% of (a) is woodlot	(b) 0% of (a) is woodlot
	(c) Remaining amount is wildland	(c) Remaining amount is wildland

The area near downtown Fayetteville and some portions of Haymount had converted to urban and developed uses. It was assumed that barren land, cultivated crops, and mixed forest could still be found in the urban areas. The amount of each use calculated for the whole of the urban area were approximately 2, 3, and 88 acres, respectively, which are as expected.

Land-cover

Like the land use for this period, the riparian areas and open water remained constant. The developed/urban and herbaceous agricultural land-cover were equivalent to the period of settlement and natural resource exploitation, T2, land use urban and cultivated crops. Since the top lumber outputs from 1913 were yellow pine, oak and yellow poplar, it was assumed that woodlots were composed of a mixture of these species (UNC, 1916). Thus, the yellow pine-oak-yellow poplar category equaled woodlots of the period of settlement and exploitation (T2).

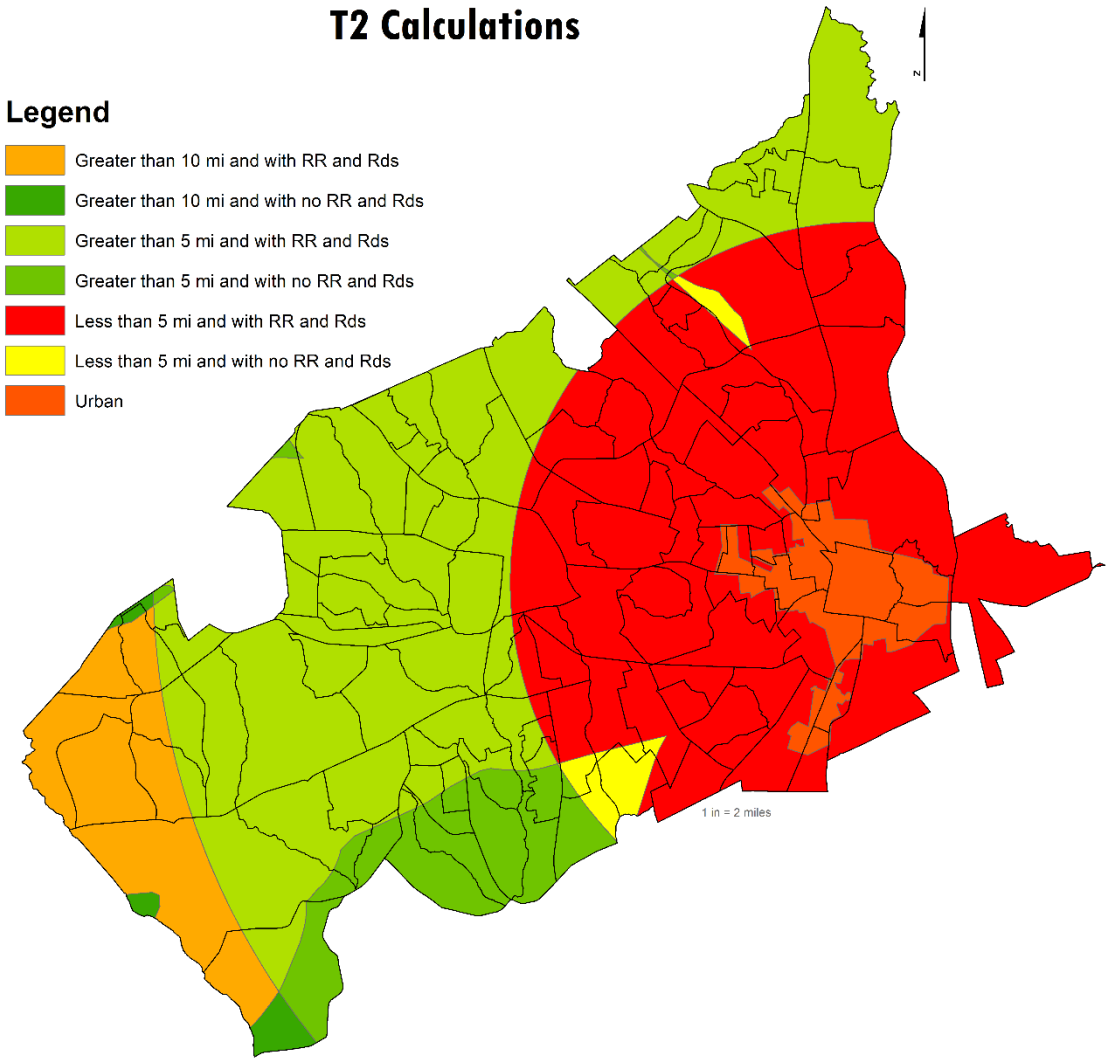

Figure B.4 Intersection of Census Blocks and Buffers for T2: Settlement and Natural Resource Exploitation Calculations

Lastly, it was assumed that wildlands during the period of settlement and natural resource exploitation (T2) were dominated by the remnant longleaf pine-oak forest of the past.

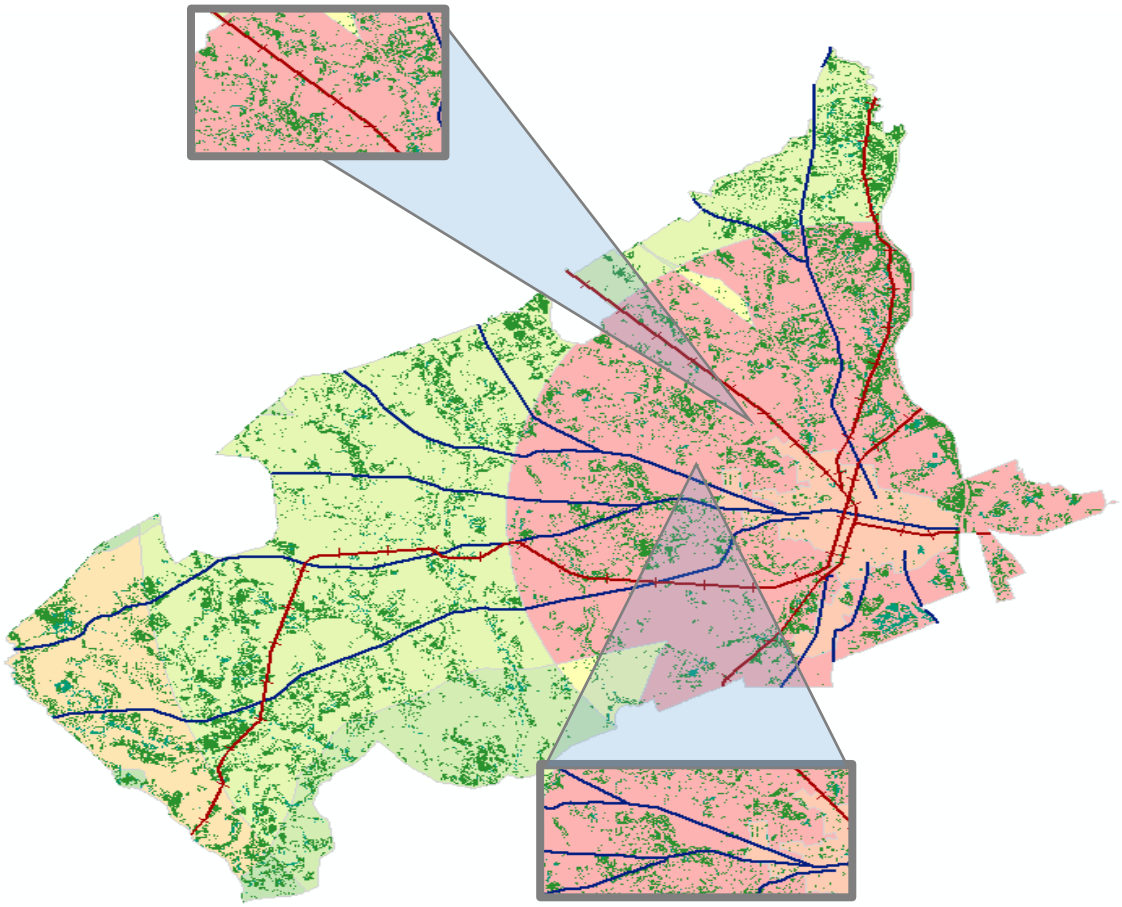

Figure B.5 Current Longleaf Pine and Historical Railways and Roads, T2: Settlement and Natural Resources Exploitation. The removal of Longleaf Pine, especially adjacent to historical roadways (blue) and historical railways (red). The exploitation of Longleaf Pine still resonates on the landscape.

T3: Fort Bragg and the Automobile, 1918 - 1939.

Historical Narrative.

During this period two noteworthy events transformed Fayetteville's landscape and laid the foundation for future landscape alterations. The first was the establishment of a US Army camp. Cumberland County's hinterland proved to be an ideal location for field artillery training for the US Army. Camp Bragg offered year-round training, access to railroad networks, and was not prime farmland. On 4 September 1918, the US Army leased 50,000 acres of land for the new Camp Bragg and began immediate construction: roads, hundreds of wooden buildings, and

waste, water, and sewer systems (Tooker et. al, 2011). By the summer of 1919, Camp Bragg was connected to Fayetteville with a gravel highway (Michael, 2001). Using this highway was the ever-increasing number of automobiles. This technology was the second significant event that began to alter the landscape in Fayetteville. With automobiles, development was no longer constricted to downtown Fayetteville. Subsequently, roads and developments began to appear, extending towards Camp Bragg (Michael, 2001). By 1921, the US Army purchased the leases for Camp Bragg and progress was underway to connect it to Fayetteville by a rail line. The following year, Camp Bragg was designated as a permanent installation and changed its name to Fort Bragg. During this period, the number of troops assigned went from 1,200 troops to 20,000 troops. (Tooker et. al, 2011). At the onset of the Depression, Fort Bragg began its first phase of permanent construction, requiring a large labor force and natural resources (Tooker et. al, 2011). This meant an increase in automobiles, roadways, and residential developments. In Haymount, a subdivision adjacent to downtown Fayetteville, approximately 902 homes were built between 1930 and 1939 (Michael, 2001). However, it appears that many of the homes were built on vacant land cleared at the beginning of the period and subsequent growth waned during the Depression (Sanborn, 1923; Sanborn, 1930). The pre-WWII landscape of Fayetteville was dramatically altered by the establishment of Fort Bragg and automobiles, both of which brought growth and development.

***Interpretation*.**

The establishment and growth of Fort Bragg brought changes to land uses in Fayetteville. The initial camp required a substantial amount of wood to build facilities. Subsequent development on Fort Bragg was extensive and required lumber. Moreover, the rail line connecting Fayetteville and Fort Bragg meant that forest clearing, like that of the late 19th

century, occurred. Thus, timber on woodlots likely declined. Locally, we see evidence of this

Figure B.6 Photograph of the Rail Line extending to Fort Bragg, undated (Tooker et. al, 2011).

decline. By the 1920 census, woodlots on farms in Cumberland County had decreased from 288,207 acres to 130,864 acres and by the 1930 census, they had plummeted to approximately 90,000 acres (Manson et. al, 2017). However, these numbers are slightly askew, as they include the decline attributed to the leasing and successive purchase of 50,000 acres of land by the government for Fort Bragg. When excluding this transaction, the decline in woodlots is approximately 150,000 acres, which is still a substantial decline. Statewide, lumber production reached its lowest point in 1932 (Cruikshank, 1944). The rail line extending to Fort Bragg began construction in 1921 (Tooker et. al, 2011). In Figure B.6, the forest clearing for the rail line is evident; particularly in the left-hand corner of the image. Between the purchase of Fort Bragg and 1930, farm land dropped nearly a quarter in Cumberland County (Manson et. al, 2017). During this time, large portions of farmland in the southeastern states were abandoned, especially on former cotton fields. By the end of this period, old field succession was beginning to change the vegetation from agricultural fields to southern pine stands (Golley et. al, 1994). On smaller abandoned fields, pine invasion is most successful with loblolly pine colonizing

nearly two-thirds of former longleaf pine habitat (Oswalt et. al, 2012). In 1920, eighty-five percent of farms in Cumberland County were small farms of less than 100 acres, thus suggesting a significant increase in pine, specifically loblolly pine (Golley et. al, 1994, Manson et. al, 2017). Moreover, managed woodlots were also changing in composition. In 1913, the top lumber outputs were yellow pine, oak, and yellow poplar. However, guidance published in 1926 suggested loblolly pine, sweetgum, and yellow poplar as choice species, all of which are commonly used for construction or utilitarian purposes and veneers and top lumber outputs by 1943 (Frothingham, 1926; Cruikshank, 1944). Moreover, a 1938 forest inventory of the coastal plain, showed that southern pines such as loblolly and shortleaf accounted for 64% of the forest, hardwoods were 28%, and longleaf was 8% (Cruikshank, 1944). Meanwhile, second-growth longleaf pine on undeveloped land was negatively affected, as modern fire laws suppressed the natural fire regime needed for regeneration (Frost, 2007). Second-growth longleaf established on only a third of where it historically occurred (Frost, 2007; Oswalt et. al, 2012).

Land use

Riparian areas and open water remained constant. When comparing the urban areas from the T2: settlement and natural resource exploitation and the 1930 Sanborn Insurance map, the latest map available for this period, approximately 74 acres of development were added to one census block. Census block 370510007021 was adjusted to increase the amount of urban/developed land and decreased in the other categories to account for the loss of land to development. The amount of urban area stayed the same as urban/development from the period of settlement and natural resources exploitation (T2), with the one exception. During this period, the number of woodlots in Cumberland County dropped from 288,207 acres to 130,864 acres, approximately 50%. Assuming the decline in the county approximates the decline in

Fayetteville, the woodlots for T3: rise of the automobile were determined by decreasing woodlots from the T2: settlement and natural resources exploitation period by 50%. For Cumberland County, the amount of farm land dropped approximately 25%, from 233,840 acres to 174,792 acres. Again, assuming the decline in the county approximates that seen in Fayetteville, cropland during the T3: rise of the automobile was calculated by decreasing cropland of the settlement and natural resources exploitation period, T2, by approximately 25%. The difference in cropland is likely due to the fields abandoned during this period and accounts for the land use category for the abandoned cropland during the T3: rise of the automobile period. For the barren category of the T3: rise of the automobile period, it was assumed that there was no significant difference from the period of settlement and natural resources exploitation (T2). Since the woodlots decreased, it was assumed that the land had been totally deforested and/or fell into disuse. Thus, the abandoned woodlots would have likely reverted to wildland. Using these assumptions, wildland during the time of the rise of the automobile (T3) equaled the wildland from the period of settlement and natural resources exploitation (T2) plus

the loss off woodlots between these periods.

Figure B.7 Changes in Urban Spread, 1923 to 1930. The increases in urban land use between the settlement and natural resources exploitation period (T2) and the T3: rise of the automobile period were small, relative to the study area.

Land-cover

Like the land use from the period of the rise of the automobile (T3), the riparian areas and open water remain constant. The barren land-cover for T3: rise of the automobile, like the land use, was assumed that there was no significant difference from the settlement and natural resources exploitation period (T2). Again, the only census block with a change in urban land-cover was census block 370510007021 and was adjusted in the same manner. The herbaceous agricultural land-cover was equivalent to the cropland of T3: rise of the automobile period. It was assumed that abandoned cropland was covered in ruderal species, so the land use from the T3: rise of the automobile period that was calculated as abandoned cropland equaled the T3: rise of the automobile land-cover category, ruderal species. Using table 36 from *North Carolina Forest Resources and Industries* (No. 533), the land-cover for oak-southern hardwoods, southern

pines, and longleaf pine was calculated by taking the inventory percentage of the woodlots from the T3: rise of the automobile period, 28%, 64%, and 8%, respectively. To this, the wildlands were added using the historical composition: 65% longleaf, 15% oak-southern hardwood, and the remainder southern pines. To check the accuracy of the quantities, the longleaf pine, with accessible information about historical extent, was used. The longleaf pine total for the period was 10,539.70 acres, which is 28.25% of its original extent of 37,311.23 acres and corresponds with known approximations (Frost, 2007; Oswalt et. al, 2012).

T4: WWII, 1939 - 1945.

***Historical Narrative*.**

Between 1939 and 1941, Fort Bragg was under constant construction. The construction involved a workforce of approximately 31,000 men, most of whom lived within a 90-mile radius, working virtually around the clock (Tooker et. al, 2011). The building material necessary for construction was astronomical: 700 lumber mills in the region were used, 65 freight cars brought supplies daily, and trucks loaded with supplies added to the already congested highways leading to Fort Bragg (Tooker et. al, 2011). The number of troops stationed at Fort Bragg rose from 20,000 to 67,000 by the summer of 1941 (Tooker et. al, 2011). While many of these troops resided on the base, many lived in the surrounding areas. Correspondingly, over 1400 homes were built during this period, despite recovering from the Depression (Michael, 2001). By 1941, the demand for construction products locally and for the war effort caused a drain in timber. The drain was more prevalent with softwoods than hardwoods. In addition, the war was increasing the demand for container veneer, a forest product that was produced in Fayetteville (Cruikshank, 1944).

***Interpretation*.**

The expansion of Fort Bragg combined with WWII, had a significant impact on the vegetation and the land use of Fayetteville. The small amount of residential construction slightly expanded adjacent to areas that were previously developed (Figure B.8). From the 1930 census

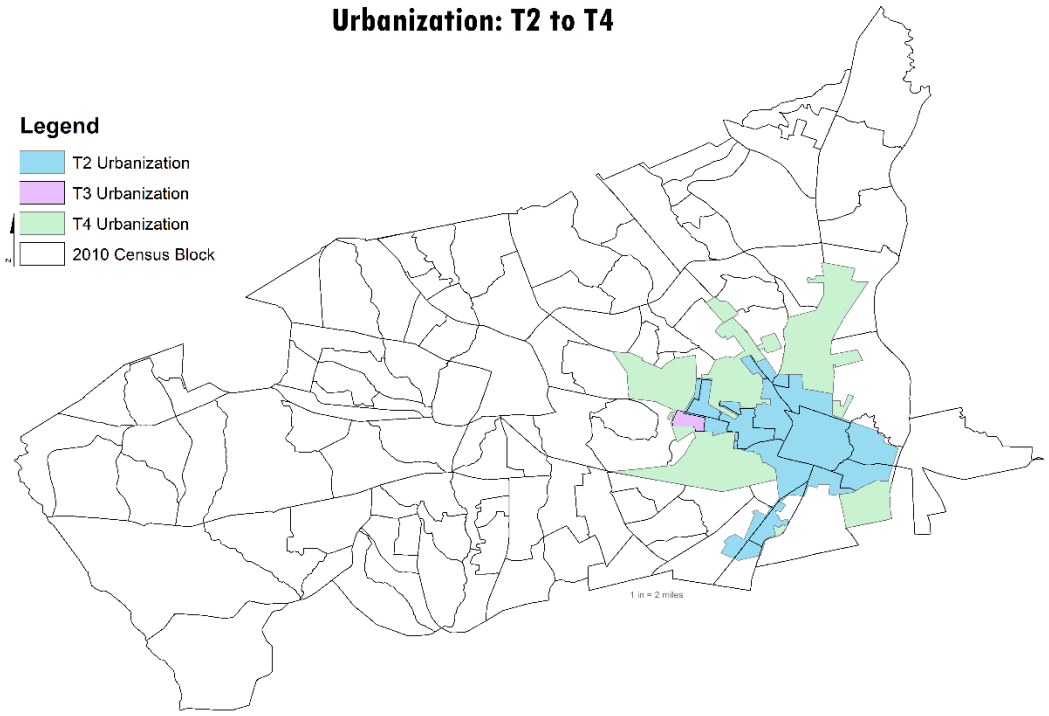

Figure B.8 Expanding Urbanization. Urbanization at the end of T2: settlement and natural resources exploitation period (Blue), T3: rise of the automobile (Purple), T4: World War II (Green).

to the 1940 census of Cumberland County, the number of farms rose along with the number of acres in farmland; but the number tapers off by 1950, leveling off to nearly the same level as the 1920s (Manson et. al, 2017). At the beginning of this period, old growth forests were mostly cleared; however, the forest industry was adjusting by experimenting with plantations (Wakeley, 1935) and managing second-growth timber (Cruikshank, 1944). Thus, formerly abandoned farmland in the 1920s and 1930s was likely returning to use both in agriculture and forest. However, the forest that returned on the abandoned farmland was not the same as it had been in the past. The longleaf pine forest, formerly extensive in Fayetteville, was converted into agricultural fields that, after abandonment, were replaced by loblolly pine. Areas likely

remained second-growth longleaf pine would be in western Fayetteville, as it is farthest from downtown Fayetteville and has limited roads and railroads (Cruikshank, 1944). Meanwhile, managed woodlots were focused on meeting the demands of the local economy, Fort Bragg, and the war. This means that the demand for construction lumber, especially for softwoods, exceeded the volume of growing stock (Cruikshank, 1944). The trucks bringing supplies to Fort Bragg were likely carrying lumber from all over North and South Carolina, as the regional stock was likely too low or too young.

Land use

The open water and riparian areas remained unchanged. Up until this point, barren land only increased within urban areas. However, circumstantial evidence such as alarmingly low volumes of growing stock and outsourcing lumber for Fort Bragg, suggests that the barren land was likely more extensive than in the past. Without reference points, it was assumed that barren land from the World War II period (T4) equaled the barren land from the post-war period (T5). The urban areas from the T3: rise of the automobile period and the 1950 Sanborn Insurance map, the closest map available for this period, were compared to determine the amount of area converted to urban/development. The 27 census blocks were adjusted to increase the amount of urban/developed land and decreased in the other categories to account for the loss of land to development. The remaining amount of urban area remained the same as the T3: rise of the automobile period. Since formerly abandoned farmland likely returned to use, it was assumed that at least half returned to farmland, 40% to woodlots, and 10% remained wildland. The calculated cropland from T2: settlement and natural resources exploitation, at the end of 1918, was 29,403.34 acres; the calculated cropland from the World War II period (T4) was 24,568.81 acres, which supports the use of 50% as a value of abandoned farmland returned to cropland.

For woodlots, 40% was used, as there was increased interest in forestry on a larger, industrial-scale and the ruderal species on previously abandoned fields would have likely been pine and other softwoods that were in demand. It was assumed that not all of the formerly abandoned cropland returned to agriculture or forestry; thus, it was assumed that 10% was wildland. The woodlot and wildland categories from the World War II period (T4) were compared with the deciduous, evergreen, mixed forest, and scrub/shrubland categories from the post-war period (T5), as it was expected that the combined woodlot and wildland from the World War II period (T4) would exceed the forest categories from the post-war period (T5). Despite the absence of qualitative data for cropland, woodlots, and wildlands, the assumed percentages correlate well with the limited quantitative and qualitative data available.

Land-cover

The assumption about open water and riparian areas remains. The barren land, urban/development, and cropland land uses from the World War II period (T4) equate to the barren, urban, and the herbaceous agricultural land-covers. The oak-southern hardwoods, sand pines, and longleaf pine was assumed to be the same as the land-cover the from the T3: rise of the automobile period. The ruderal species was determined by reducing the ruderal species from the T3: rise of the automobile period by the increases in agriculture that occurred between the T3: rise of the automobile period and World War II (T4). Generally, the combined oak-southern hardwoods and sand pines exceeded the woodlot from T4: World War II and the combined longleaf pine and ruderal species was below the T4: World War II wildland. This was expected, due to the invasive qualities of sand pines and early abandoned cropland maturing from ruderal to sand pine. Like the land use from T4: World War II, the urban areas affected 27 census blocks and were adjusted to increase the amount of urban land, while decreasing the other

categories to account for the change in land cover. Comparing the land-cover from the World War II (T4) period to the post-war (T5) period, vegetation is significantly higher for the World War II (T4) period, which is expected, as significant urban development occurs during the post-war (T5) period, converting the majority of the land into urban land.

T5: Post-WWII, 1945 - 2011.

***Historical Narrative*.**

Following the Great Depression and then WWII, a severe shortage of housing occurred across the country, which was exacerbated by the number of troops returning home (Von Hoffman, 2000). Fayetteville was no exception. The housing shortage was quickly on the policy agenda. The resulting series of policy initiatives, along with popular Levittown-inspired communities, perpetuated unprecedented suburban development across the United States. For Fayetteville, the Serviceman's Readjustment Act of 1944 was, perhaps, the most influential piece of legislation that affected suburban growth. The Serviceman's Readjustment Act, also known as the G.I. Bill, provided WWII veterans a zero-down payment loan for new houses in the suburbs (Vicino, 2008). Since Fayetteville is a "military town," it saw higher than usual settlement of troops returning from the war, who could use their new G.I. Bill benefits to build a suburban home in Fayetteville. Hence, we see a dramatic increase in the number of homes built between 1950 and 1959. In subsequent years, the number of troops stationed at Fort Bragg has fluctuated. On the whole, the number of troops during this period has increased over time, thus continuing the trend of suburban sprawl in Fayetteville. Compounding the need for homes, is the number of retiring troops who remain in Fayetteville. Development is the heaviest along the original roads that connected Fayetteville to the rest of the state. Moreover, suburban development has fanned out from central Fayetteville and moved westward, leaving pockets of

remnant landscapes in its wake. Suburban sprawl goes beyond just single-family homes; it means cars and an expansive network of roads. The number of automobiles in the United States during this period astronomically jumped from 20 million to over 210 million, thus demonstrating the pervasiveness of suburban sprawl (Vicino, 2008). The consequence is a highly-fragmented landscape. It is no surprise that Fayetteville has become a suburban city, with approximately 55% of all the land developed into a fragmented suburban landscape (GAP, 2011).

***Interpretation*.**

Between 1950 and 1959, suburban growth took off in Fayetteville. Land use was dramatically altered, shifting former forests and farms into 56,000 acres of development. Because development is complex, pockets of remnant landscapes still exist. Although, these pockets are unlikely to represent the landscape prior to European contact. However, second-growth of longleaf pine may still remain in the western part of Fayetteville and areas adjacent to Fort Bragg. These areas have relatively low pressures for development and there might be enough regenerative stock to sustain it. Despite recent development pressures, Fayetteville has been working to protect and conserve the riparian zones of its creeks and rivers. Other areas that have not been touched by development, sustain the limited agriculture and woodlots. These are found at the furthest points from downtown, away from corridors leading to Fort Bragg, away from historical roads, and in the center of the spokes (roads) stemming from downtown Fayetteville. Most of the wooded areas that remain are parks or conservation areas designated by the city and are associated with open waters. They include the Cape Fear river trail, Mazarick

Park, Clark Park, and the Cape Fear Botanical Garden. See Figures B.9 and B.10 for the current land use and land cover, respectively, in Fayetteville, North Carolina.

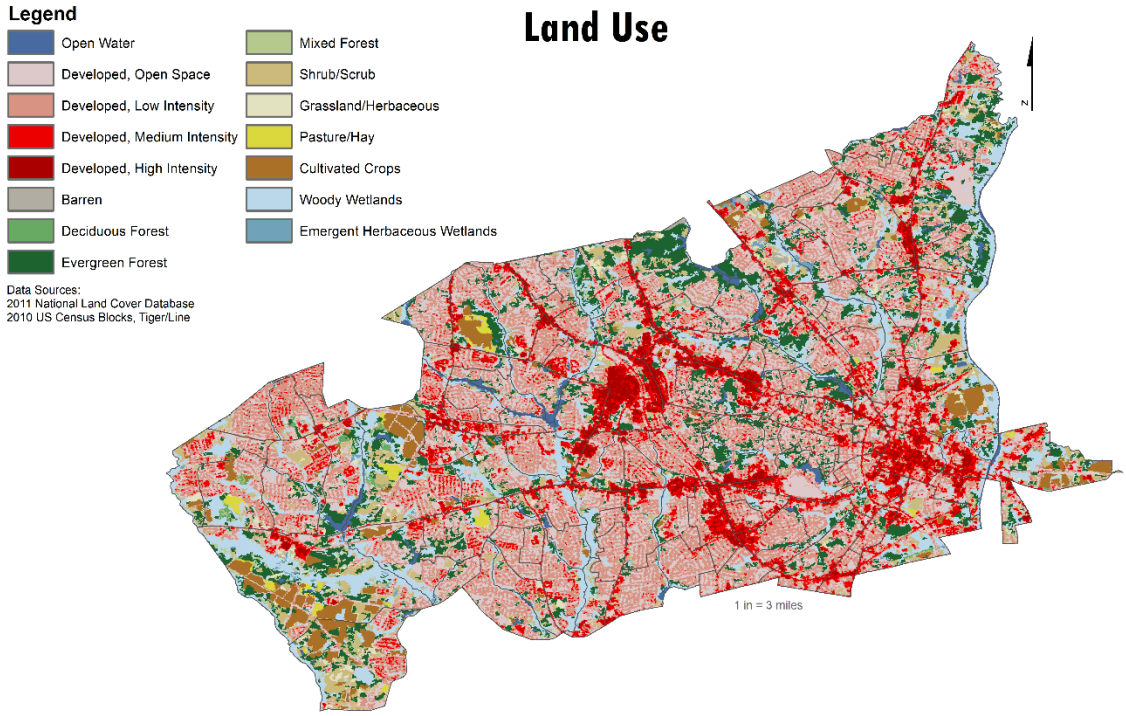

Figure B.9 Current Land Use at the end of T5: Post-WWII.

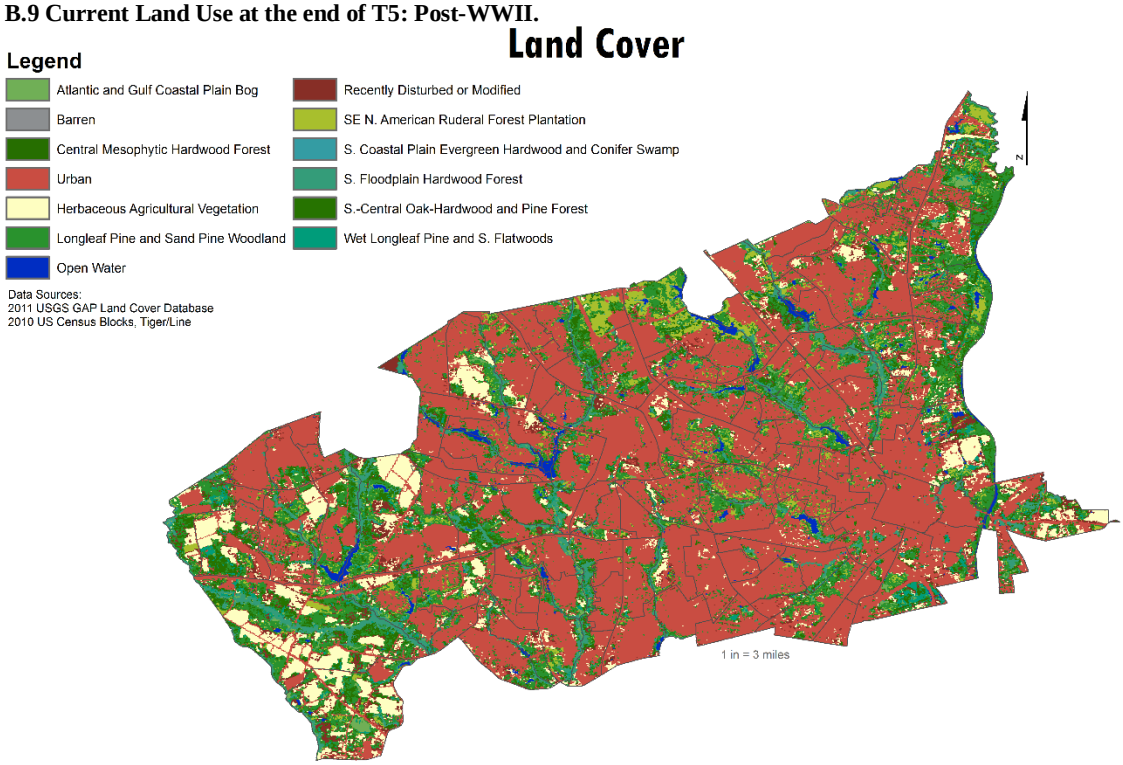

Figure B.10 Current Land Cover at the end of T5: Post-WWII.

Land use

The baseline map for the land use was generated using data from the USGS National Land Cover Database (NLCD) from 2011. 2011 was selected as it corresponded with the decennial census data. The baseline land use map displays the land use class, which is modified from the Anderson Land Cover Classification System (Homer et. al, 2015). Both GAP and NLCD have land use classifications; however, NLCD has delineated development into 4 classes, thus providing greater detail of the intensity of development.

Land-cover

The baseline map for the land cover was generated using data from the USGS National Gap Analysis Program (GAP) from 2011. The baseline land cover map displays the macro group national vegetation classification level, which features regionally distinct vegetation (GAP, 2011).

Appendix C

```
#Read Table
Data<-
read.table("C:\\Users\\skarp\\Desktop\\School\\Thesis\\Spreadsheets\\Data.csv",header=T,sep=",
")
str(Data)

#Transformed Data
tINCOME<-log10(Data$INCOME)
tPERVULNSP<-sqrt(Data$PERVULNSP)

#Summary stats
summary(Data)

#Histograms
hist(Data$INCOME, xlab="Median Household Income ($)", main="Histogram\nMedian
Household Income")
hist(tINCOME, xlab="Log-Median Household Income ($)", main="Histogram\nLog-Median
Household Income")
hist(Data$MIN, xlab="Proportion of Minorities (%)", main="Histogram\nProportion of
Minorities")
hist(Data$ACSCORE, xlab="Adaptive Capacity Scores (Percent as decimal)",
main="Histogram\nAdaptive Capacity Scores")
hist(Data$PERVULNSP, xlab="Percentage of Tree Species Vulnerable (%)",
main="Histogram\nPercentage of Tree Species Vulnerable")
hist(tPERVULNSP, xlab="SQRT-Percentage of Tree Species Vulnerable (%)",
main="Histogram\nSQRT-Percentage of Tree Species Vulnerable")
hist(Data$SYR, breaks=c(1910,1920,1930,1940,1950,1960,1970,1980,1990,2000,2010),
xlab="Subdivision Age (Year)", main="Histogram\nSubdivision Age")
hist(Data$SYR, breaks=seq(1900,2010,10), xlim=c(1900,2020), xlab="Subdivision Age (Year)",
main="Histogram\nSubdivision Age",axes=F)
axis(2)
axis(1, at=seq(1900,2010,10),
labels=c(1900,1910,1920,1930,1940,1950,1960,1970,1980,1990,2000,2010))
hist(Data$LUFREQTOT, xlab="Total Land Use Changes (Count)", main="Histogram\nTotal
Land Use Changes")
hist(Data$LUT12F,breaks=seq(0,4,1), xlim=c(0,4), xlab="T1:T2 Land Use Changes (Count)",
main="Histogram\nT1:T2 Land Use Changes")
hist(Data$LUT23F,breaks=seq(0,4,1), xlim=c(0,4), xlab="T2:T3 Land Use Changes (Count)",
main="Histogram\nT2:T3 Land Use Changes")
hist(Data$LUT34F,breaks=seq(0,4,1), xlim=c(0,4), xlab="T3:T4 Land Use Changes (Count)",
main="Histogram\nT3:T4 Land Use Changes")
hist(Data$LUT45F,breaks=seq(0,4,1), xlim=c(0,4), xlab="T4:T5 Land Use Changes (Count)",
main="Histogram\nT4:T5 Land Use Changes")
```

```
hist(Data$LCFREQTOT,breaks=seq(0,11,1), xlim=c(0,12), xlab="Total Land Cover Changes
(Count)", main="Histogram\nTotal Land Cover Changes")
hist(Data$LCT12F,breaks=seq(0,4,1), xlim=c(0,4), xlab="T1:T2 Land Cover Changes (Count)",
main="Histogram\nT1:T2 Land Cover Changes")
hist(Data$LCT23F,breaks=seq(0,4,1), xlim=c(0,4), xlab="T2:T3 Land Cover Changes (Count)",
main="Histogram\nT2:T3 Land Cover Changes")
hist(Data$LCT34F,breaks=seq(0,5,1), xlim=c(0,5), xlab="T3:T4 Land Cover Changes (Count)",
main="Histogram\nT3:T4 Land Cover Changes")
hist(Data$LCT34F,breaks=seq(0,5,1), xlim=c(0,5), xlab="T4:T5 Land Cover Changes (Count)",
main="Histogram\nT4:T5 Land Cover Changes")

#Scatterplots
par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(Data$ACSCORE~tINCOME,
                        xlab="Log-Income \n($)",ylab="Adaptive Capacity Scores\n(Percent as
decimal)",
                        font.main=4,font.lab=2,font.axis=3,
                        cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,
                        col=ifelse(Data$TOTRISK==1,'red','blue'),
                        main="Relationship of Adaptive Capcitity Scores\nto Log-Income")
abline(lm(Data$ACSCORE~tINCOME))
labels<-c("No Risk", "At-Risk")
legend("bottomright",inset=.05,title="Risk",labels,pch=1,
                        col=c("blue","red","green"),cex=0.75)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(Data$ACSCORE~Data$MIN,
                        xlab="Proportion of Minorities\n(%)",ylab="Adaptive Capacity
Scores\n(Percent as decimal)",
                        font.main=4,font.lab=2,font.axis=3,
                        cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,
                        col=ifelse(Data$TOTRISK==1,'red','blue'),
                        main="Relationship of Adaptive Capcitity Scores\nto Proportion of
Minorities")
abline(lm(Data$ACSCORE~Data$MIN))
labels<-c("No Risk", "At-Risk")
legend("topright",inset=.05,title="Risk",labels,pch=1,
                        col=c("blue","red","green"),cex=0.75)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(Data$ACSCORE~Data$LUFREQTOT,
                        xlab="Total Land Use Changes\n(Count)",ylab="Adaptive Capacity
Scores\n(Percent as decimal)",
                        font.main=4,font.lab=2,font.axis=3,
                        cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,
                        col=ifelse(Data$TOTRISK==1,'red','blue'),
```

```
                    main="Relationship of Adaptive Capcitity Scores\nto Total Land Use
Changes")
abline(lm(Data$ACSCORE~Data$LUFREQTOT))
AtRisk<-subset(Data,TOTRISK==1 and LUFREQTOT>=4 and LUFREQTOT<=7)
#Need plotrix to use ablineclip()
ablineclip(lm(AtRisk$ACSCORE~AtRisk$LUFREQTOT),col="red",x1=4,x2=7)
labels<-c("No Risk", "At-Risk")
legend("topright",title="Risk",legend = c("No Risk", "At-Risk", " ", "No Risk", "At-Risk"), bty =
"n",
     lwd = 1, cex = .75, col = c("blue", "red", "white", "black","red"), pch = c(1, 1, NA, NA,
NA), lty = c(NA, NA, NA,1,1))

par(mar=c(5,5,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$SYR,
                    xlab="Subdivision Age\n(Year)",ylab="SQRT-Tree Species Vulnerable to
Climate Change\n(%)",
                    font.main=4,font.lab=2,font.axis=3,at=seq(1900,2010,10),
                    cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,
                    col=ifelse(Data$TOTRISK==1,'red','blue'),
                    main="Relationship of SQRT-Percent of Vulnerable Tree Species\nto
Subdivision Age")
abline(lm(tPERVULNSP~Data$SYR))
labels<-c("No Risk", "At-Risk")
legend("top",inset=.05,title="Risk",labels,pch=1,
                    col=c("blue","red","green"),cex=0.75)
axis(2, at=seq(0,10,1),cex.lab=.75,cex.axis=.7)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$LUFREQTOT,
                    xlab="Total Land Use Changes\n(Count)",ylab="SQRT-Tree Species
Vulnerable to Climate Change\n(%)",
                    font.main=4,font.lab=2,font.axis=3,
                    cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,
                    col=ifelse(Data$TOTRISK==1,'red','blue'),
                    main="Relationship of SQRT-Percent of Vulnerable Tree\nSpecies to
Total Land Use Changes")
labels<-c("No Risk", "At-Risk")
legend("topright",inset=.05,title="Risk",labels,pch=1,
                    col=c("blue","red","green"),cex=0.75)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$LUT12F,
                    xlab="T1:T2 Land Use Changes\n(Count)",ylab="SQRT-Tree Species
Vulnerable to Climate Change\n(%)",
                    font.main=4,font.lab=2,font.axis=3,
                    cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,xlim=c(0,4),
```

```
                col=ifelse(Data$TOTRISK==1,'red','blue'),
                main="Relationship of SQRT-Percent of Vulnerable Tree\nSpecies to
T1:T2 Land Use Changes")
labels<-c("No Risk", "At-Risk")
legend("topright",inset=.05,title="Risk",labels,pch=1,
                col=c("blue","red","green"),cex=0.75)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$LUT23F,
                xlab="T2:T3 Land Use Changes\n(Count)",ylab="SQRT-Tree Species
Vulnerable to Climate Change\n(%)",
                font.main=4,font.lab=2,font.axis=3,
                cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,xlim=c(0,4),
                col=ifelse(Data$TOTRISK==1,'red','blue'),
                main="Relationship of SQRT-Percent of Vulnerable Tree\nSpecies to
T2:T3 Land Use Changes")
labels<-c("No Risk", "At-Risk")
legend("topright",inset=.05,title="Risk",labels,pch=1,
                col=c("blue","red","green"),cex=0.75)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$LUT34F,
                xlab="T3:T4 Land Use Changes\n(Count)",ylab="SQRT-Tree Species
Vulnerable to Climate Change\n(%)",
                font.main=4,font.lab=2,font.axis=3,
                cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,xlim=c(0,4),
                col=ifelse(Data$TOTRISK==1,'red','blue'),
                main="Relationship of SQRT-Percent of Vulnerable Tree\nSpecies to
T3:T4 Land Use Changes")
labels<-c("No Risk", "At-Risk")
legend("topright",inset=.05,title="Risk",labels,pch=1,
                col=c("blue","red","green"),cex=0.75)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$LUT45F,
                xlab="T4:T5 Land Use Changes\n(Count)",ylab="SQRT-Tree Species
Vulnerable to Climate Change\n(%)",
                font.main=4,font.lab=2,font.axis=3,
                cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,xlim=c(0,4),
                col=ifelse(Data$TOTRISK==1,'red','blue'),
                main="Relationship of SQRT-Percent of Vulnerable Tree\nSpecies to
T4:T5 Land Use Changes")
labels<-c("No Risk", "At-Risk")
legend("topleft",inset=.05,title="Risk",labels,pch=1,
                col=c("blue","red","green"),cex=0.75)
```

```
par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$LCFREQTOT,
                        xlab="Total Land Cover Changes\n(Count)",ylab="SQRT-Tree Species
Vulnerable to Climate Change\n(%)",
                        font.main=4,font.lab=2,font.axis=3,
                        cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,
                        col=ifelse(Data$TOTRISK==1,'red','blue'),
                        main="Relationship of SQRT-Percent of Vulnerable Tree\nSpecies to
Total Land Cover Changes")
labels<-c("No Risk", "At-Risk")
legend("topleft",inset=.05,title="Risk",labels,pch=1,
                        col=c("blue","red","green"),cex=0.75)
axis(1, at=seq(0,11,1),cex.lab=.75,cex.axis=.7)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$LCT12F,
                        xlab="T1:T2 Land Cover Changes\n(Count)",ylab="SQRT-Tree Species
Vulnerable to Climate Change\n(%)",
                        font.main=4,font.lab=2,font.axis=3,
                        cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,xlim=c(0,4),
                        col=ifelse(Data$TOTRISK==1,'red','blue'),
                        main="Relationship of SQRT-Percent of Vulnerable Tree\nSpecies to
T1:T2 Land Cover Changes")
labels<-c("No Risk", "At-Risk")
legend("topright",inset=.05,title="Risk",labels,pch=1,
                        col=c("blue","red","green"),cex=0.75)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$LCT23F,
                        xlab="T2:T3 Land Cover Changes\n(Count)",ylab="SQRT-Tree Species
Vulnerable to Climate Change\n(%)",
                        font.main=4,font.lab=2,font.axis=3,
                        cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,xlim=c(0,4),
                        col=ifelse(Data$TOTRISK==1,'red','blue'),
                        main="Relationship of SQRT-Percent of Vulnerable Tree\nSpecies to
T2:T3 Land Cover Changes")
labels<-c("No Risk", "At-Risk")
legend("topright",inset=.05,title="Risk",labels,pch=1,
                        col=c("blue","red","green"),cex=0.75)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$LCT34F,
                        xlab="T3:T4 Land Cover Changes\n(Count)",ylab="SQRT-Tree Species
Vulnerable to Climate Change\n(%)",
                        font.main=4,font.lab=2,font.axis=3,
                        cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,xlim=c(0,5),
```

```
                col=ifelse(Data$TOTRISK==1,'red','blue'),
                main="Relationship of SQRT-Percent of Vulnerable Tree\nSpecies to
T3:T4 Land Cover Changes")
labels<-c("No Risk", "At-Risk")
legend("topright",inset=.05,title="Risk",labels,pch=1,
                col=c("blue","red","green"),cex=0.75)

par(mar=c(5,6,4,2)+0.1,mgp=c(3,1,0))
plot(tPERVULNSP~Data$LCT45F,
                xlab="T4:T5 Land Cover Changes\n(Count)",ylab="SQRT-Tree Species
Vulnerable to Climate Change\n(%)",
                font.main=4,font.lab=2,font.axis=3,
                cex=0.5,cex.main=1,cex.lab=.75,cex.axis=.7,xlim=c(0,5),
                col=ifelse(Data$TOTRISK==1,'red','blue'),
                main="Relationship of SQRT-Percent of Vulnerable Tree\nSpecies to
T4:T5 Land Cover Changes")
labels<-c("No Risk", "At-Risk")
legend("topleft",inset=.05,title="Risk",labels,pch=1,
                col=c("blue","red","green"),cex=0.75)

# 1 sample t-test, where mu is census block mean
# Is sample different that the census block?
# Explantory variables MIN, INCOME, SAGE, LUFREQTOT, LCFREQTOT
# If p-val is less than .05, then can conlude that significantly different

a<-Data$MIN[Data$TOTRISK==1]
t.test (a, mu=55.15)
# t=-0.51257, df = 7, p = 0.624

b<-tINCOME[Data$TOTRISK==1]
t.test (b, mu=4.63)
# t=-0.22884, df = 7, p = 0.8255

c<-Data$SAGE[Data$TOTRISK==1]
t.test (c, mu=36)
# t=-1.2855, df = 7, p = 0.2395

d<-Data$LUFREQTOT[Data$TOTRISK==1]
t.test (d, mu=5)
# t=4.5826, df = 7, p = 0.002536, 95% CI[5.362998, 6.137002]

e<-Data$LCFREQTOT[Data$TOTRISK==1]
t.test (e, mu=8)
# t=0.68313, df = 7, p = 0.5165

#2 sample t-test
```

```
# Is there a significant difference between at-risk and not at-risk subdivisions?
# Explanatory variables: ACSCORE, MIN, tINCOME, tPERVULNSP, SAGE, LUFREQTOT,
# LUT12F, LUT23F, LUT34F, LUT45F, LCFREQTOT, LCT12F, LCT23F, LCT34F, LCT45F

a<-Data$ACSCORE[Data$TOTRISK==1]
b<-Data$ACSCORE[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# Since threshold is bottom 20th percentile, this will be sig. different
# t=-4.806, df=74, p<0.0001

a<-Data$MIN[Data$TOTRISK==1]
b<-Data$MIN[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=0.077276, df=74, p=0.9386

a<-tINCOME[Data$TOTRISK==1]
b<-tINCOME[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=-0.61563, df = 74, p=0.54

a<-tPERVULNSP[Data$TOTRISK==1]
b<-tPERVULNSP[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# Since threshold is below 30%, this will be sig. different
# t=2.4241, df = 74, p =0.01779

a<-Data$SAGE[Data$TOTRISK==1]
b<-Data$SAGE[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=-0.82728, df=74, p=0.4107

a<-Data$LUFREQTOT[Data$TOTRISK==1]
b<-Data$LUFREQTOT[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=1.7737, df = 74, p = 0.08023, 95% CI[5.75, 5.176471]

a<-Data$LCFREQTOT[Data$TOTRISK==1]
b<-Data$LCFREQTOT[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=0.32095, df =74, p = 0.7492

a<-Data$LUT12F[Data$TOTRISK==1]
b<-Data$LUT12F[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# All of the data is constant, therefore would not expect difference
```

```
a<-Data$LUT23F[Data$TOTRISK==1]
b<-Data$LUT23F[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=0.69406, df=74, p=0.4898

a<-Data$LUT34F[Data$TOTRISK==1]
b<-Data$LUT34F[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=0, df=74, p=1

a<-Data$LUT45F[Data$TOTRISK==1]
b<-Data$LUT45F[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=2.1608, df=74, p=0.03394, 95% CI[3.00, 2.573529]

a<-Data$LCT12F[Data$TOTRISK==1]
b<-Data$LCT12F[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=-1.2506, df=74, p=0.215

a<-Data$LCT23F[Data$TOTRISK==1]
b<-Data$LCT23F[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=0.69774, df=74, p=0.4875

a<-Data$LCT34F[Data$TOTRISK==1]
b<-Data$LCT34F[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=-0.36381, df=74, p=0.717

a<-Data$LCT45F[Data$TOTRISK==1]
b<-Data$LCT45F[Data$TOTRISK==0]
t.test (a, b, var.equal=TRUE)
# t=1.6796, df=74, p=0.09725, 95% CI[3.875, 3.338235]
```

Appendix D

Species, Common Name * >= 5 trees	**Vulnerability Score**	**Count**	**Range** Northern, Southern, Mid
Pine, Loblolly	Low	129	Central
Oak, Water	Low	52	Central
Magnolia, Southern	Low	48	Central
Maple, Red	Low	16	Central
Sweetgum	Low	14	Central
Leland Cypress	Low	12	Central
Crape Myrtle (Treeform)	Low	9	Central
Oak, Laurel	Low	8	Central
Cherry, Black	Low	6	Central
Pine, Longleaf	Low	133	Northern
Camelia	Low	5	Northern
Flowering Dogwood	ModLo	213	Central
Holly, American	ModLo	30	Central
Maple, Japanese	ModLo	30	Central
Hickory, Mockernut	ModLo	15	Central
Oak, White	ModLo	11	Central
Pecan	ModLo	7	Central
Poplar, Tulip	ModLo	6	Central
Oak, Turkey	ModLo	20	Northern
Pine, Shortleaf	Mod	19	Central
Oak, Post	Mod	13	Central
Oak, Willow	Mod	6	Central
Sycamore	Mod	5	Central
Pear, Bradford	ModHi	20	Central
Sassafras	ModHi	17	Central
Oak, Blackjack	ModHi	8	Central
Cedar, Eastern Red	ModHi	13	E. Central
Eastern Redbud	ModHi	8	E. Central
Hickory, Bitternut	ModHi	8	S. Central
Beech, Am	ModHi	5	S. Central
Pine, Eastern White	ModHi	7	Southern