A GEOGRAPHY OF PERMITTED TREE REMOVALS

IN AUSTIN, TEXAS, 2002 TO 2011

THESIS

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A GEOGRAPHY OF PERMITTED TREE REMOVALS

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For Louis Esparza Lavy,

May you grow, in all things, like a tree, deeply rooted and reaching for the sky.

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CHAPTER I

INTRODUCTION

If by rare good fortune [trees] are suffered to become beautiful, they still stand subject to be condemned to death at any time, as obstructions in the highway. What I would ask is, whether we might not with economy make special provision in some of our streets—in a twentieth or a fiftieth part, if you please—for trees to remain as a permanent furniture of the city?

~ Frederick Law Olmsted, 1870

Trees provide a range of environmental, economic, and social services to urban areas. Environmental services associated with urban trees include air pollution reduction (Beckett, Smith, and Taylor 2000; Akbari 2002; Nowak and Crane 2002; Nowak, Crane, and Stevens 2006), microclimate regulation (Sashua-Bar, Pearlmutter and Erell 2009), biodiversity (Jim and Chen 2009), energy conservation (Akbari, Pomerantz, and Taha 2001; Donovan and Butry 2009; Pandit and Laband 2010), runoff reduction, and flood mitigation (Xaio 2002). Economic services associated with urban trees include increased customer patronage (Wolf 2003; Wolf 2005), higher rental rates (Laverne and Winson-Geideman 2003), higher property values, and increased tax revenue (Anderson and Cordell 1987; Payton et al. 2008). Social services associated with urban trees include increased community cohesion (Westphal 2003), crime reduction (Kuo 2003), and a better quality of life (Dwyer, Schroeder, and Gobster 1991). Despite the numerous benefits of trees within urban areas, the structure of urban forests—their species composition, age, health, and distribution—is determined by a variety of anthropogenic factors and natural events at both small and large scales.

At small scales, climate is the primary factor that determines urban forest structure (Sanders 1984). Urban areas located in arid and semiarid climate zones tend to have fewer urban trees than urban areas located in humid climates. Humid climates typically receive regular precipitation throughout the year, creating an ideal living condition, which is capable of sustaining dense urban forests. Thus, in the United States, Western cities with predominantly dryer weather have less urban forest cover than Eastern and Southern cities that receive more precipitation due to variations in climate (Sanders 1984). Tree species also vary by climate zones. Aspen, Douglas fir, and Engelmann spruce thrive in cold climates, whereas mesquite and hackberry species tolerate hot, dry climates. Climatic events also impact urban forest structure. Hurricanes (Burley, Robinson, and Lundholm 2008; Staudhammer et al. 2011) and drought (Holopainen et al. 2006) damage and kill large swaths of urban trees each year.

At large scales, a mix of factors, including the unique physical, urban, socioeconomic, and regulatory landscape characteristics of a city, influence urban forest structure both positively and negatively and create discernable urban forest patterns. Physical landscape characteristics, such as topographic relief and proximity to water features, have been associated with increased urban forest density (Heynen and Lindsey 2003).

Socioeconomic and demographic characteristics have been associated with varying amounts of urban trees (Landry and Chakraborty 2009). Decreases in the amount and coverage of urban trees have been linked to lower socioeconomic statuses (Heynen, Perkins, and Roy 2006; Landry and Chakraborty 2009). Increases in the amount and coverage of urban trees have been associated with higher socioeconomic statuses (Heynen and Lindsey 2003; Heynen 2006; Landry and Chakraborty 2009).

Characteristics related to urban form also help shape the urban forest (Nowak and Walton 2005; Landry and Pu 2010; Nowak and Greenfield 2012). Urban development is generally associated with tree loss and is responsible for the loss of four million trees each year in the conterminous United States (Nowak and Greenfield 2012). Many of the negative externalities associated with urban development and increased population density affect urban forest structure. Urban pollution retards tree growth and causes tree mortality (Nowak 1993; Yang 2009; Tubby and Webber 2010; Chen et al. 2011). Rising urban temperatures decrease native tree species' growth, while permitting the establishment and spread of invasive tree species, tree diseases, and harmful tree pests (Chen et al. 2011). Also, soil compaction, high salinity, and vandalism harm tree vitality (McKinney 2002). Moreover, space availability in urban areas dictates where trees grow. Typically, urban forest density varies inversely with population density. Less populated urban areas, such as city suburbs, that are further away from densely populated urban cores tend to have more trees than areas closer to city centers.

Urban forest programs (Perkins, Heynen, and Wilson 2004) and the strength and coverage of urban tree policies (Conway and Urbani 2007; Landry and Pu 2010) also play a role in the production of urban forest patterns and coverage. For example, urban forest policies have been associated with increased tree canopy cover in urban areas (Conway and Urbani 2007; Landry and Pu 2010) and increased tree height (Sung 2012).

The purpose of this research is to analyze the geographic patterns of tree removals in Austin, Texas between 2002 and 2011 in an effort to understand how neighborhood-scale landscape characteristics influence urban deforestation and affect the overall distribution of Austin's urban forest. An understanding of the geographic patterns and landscape characteristics of urban deforestation will allow municipalities to anticipate vulnerable areas of urban forests and to move from reactive management responses to proactive management plans. Moreover, this research will contribute to the academic literature on geographic information science (GIS) methods and the geographic analysis of urban forestry. It explores the relationships between specific instances of tree-removals—a dataset not yet examined within the literature—and neighborhood-scale landscape characteristics to illuminate the spatiotemporal outcomes of geographic and regulatory influences on urban deforestation.

This research answers the following questions: 1) what are the spatiotemporal trends in Austin related to tree removals and how have they changed over time, 2) what physical and human landscape characteristics (physical, urban, and socioeconomic characteristics) are significantly associated with urban deforestation, and 3) to what degree can physical and human landscape characteristics explain occurrences of urban deforestation.

To address these questions, data acquired from the City of Austin representing tree removals from 2002 to 2011 was analyzed through a series of quantitative techniques. First, the dataset was entered into a GIS with relevant base data in order to cartographically visualize geographic patterns of urban deforestation during the period of study. Second, the dataset was interpreted through frequency and descriptive analysis with the intent of describing changes in urban deforestation in Austin over the ten-year study period. Last, physical, urban, and socioeconomic characteristics associated with tree removals were subjected to statistical analyses. Statistical tests of difference and multinomial logistic regression were employed to reveal which landscape characteristics significantly explain urban deforestation.

The conceptual framework guiding this research hypothesizes that the distribution of urban deforestation occurrences is the result of a set of interrelated geographic determinants. These determinants manifest themselves as characteristics of the physical, urban, and socioeconomic landscapes that occur across urban space (e.g., location, land use, percent slope, market value, income, and population) and influence where requests for tree removals will occur. At the same time, implementation of municipal urban forest regulations attenuates actual urban deforestation. Figure 1 represents a model of the conceptual framework that guides this research.

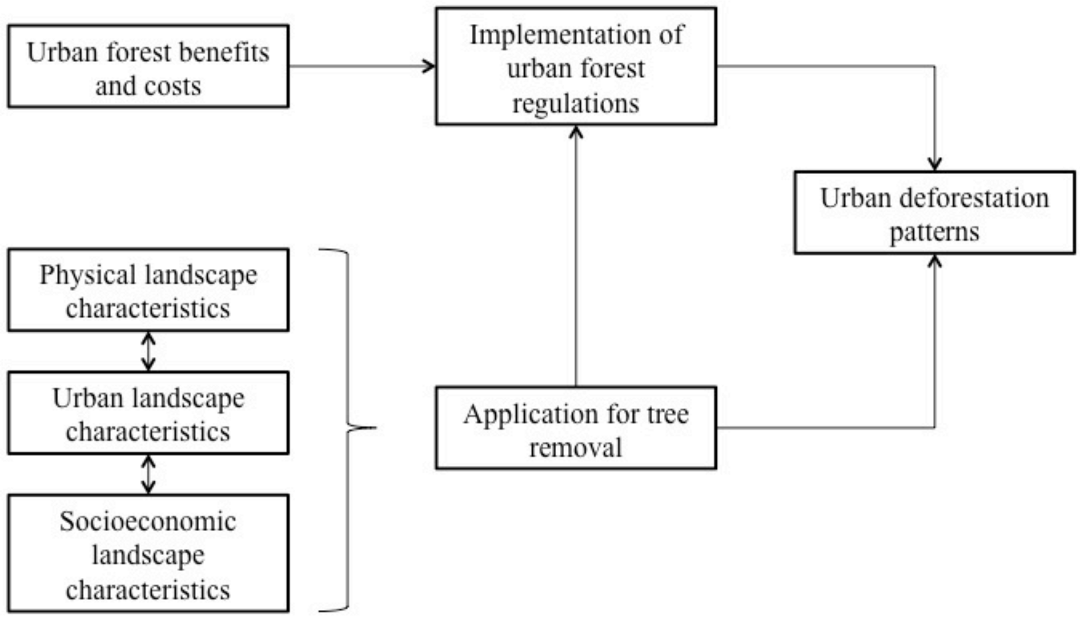


Figure 1. Conceptual model of urban deforestation patterns.

CHAPTER II

BACKGROUND

Urban Forests and Their Role in the Urban Environment

Urban forests are comprised of all woody vegetation in urban environments, from the urban core to suburban neighborhoods to the wildland-urban interface (Miller 2007). Urban forests include trees and shrubs on commercial, governmental, residential, and institutional lands. In the conterminous United States today, urban areas represent three percent of the total land area and support almost eighty percent of the U.S. population. Urban forests only cover around thirty-five percent of the total U.S. urban land area (Nowak et al. 2010), and the majority of urban forests reside in residential neighborhoods (McPherson 1998). Although the area that urban forests cover is small, the services they provide are not.

Environmental Benefits

Since the 1960s, urban foresters—professionals and academics alike—have conducted research within and on urban forests, revealing the role trees play in relieving urban environmental problems. For example, research has found that urban forests temper local climate effects, mitigate air pollution, combat global warming, reduce energy consumption, prevent water erosion, and provide habitat for wildlife. These benefits are accrued through many processes, including interception, absorption, reflection, sequestration, and transpiration.

Trees take in water, move it through their structure, and then release the water through stomata in their leaves through the process of transpiration trees, which in turn moderates local temperatures. When trees transpire water on warm summer days, large amounts of water vapor are released into the air, raising humidity levels and cooling temperatures beneath urban forest canopies (Grey and Deneke 1986).

Urban forests intercept, reflect, and absorb solar radiation throughout the year, tempering and moderating local climate effects. For example, the urban heat island phenomenon, where city temperatures are higher than surrounding areas as a result of heat accumulation within the built environment, is lessened by tree shade. In summer months, trees reduce surface temperatures by shading or covering buildings and surfaces. On the other hand, in winter months, deciduous trees, devoid of leaves, allow solar radiation to pass through to buildings and ground surfaces, raising temperatures.

The solar radiation effects of trees also have the concomitant benefit of energy conservation and, by extension, air pollution reduction. To generate energy, power plants burn fossil fuels, such as coal, natural gas, or crude oil, emitting large amounts of greenhouse gases into the atmosphere. As discussed above, trees, in summer months, absorb and reflect solar radiation, and in winter months, trees permit the transmission of solar radiation through their structures. The absorption, reflection, and transmission of solar radiation lead to reduced use of HVAC systems, which in turn, reduces the amount of greenhouse gases released into the atmosphere by power plants.

Urban forests also filter, absorb, disperse, and mask harmful air pollutants and their smells. Through dry deposition, trees' branches, stems, and leaves catch and trap air pollutants, such as nitric oxide and nitrogen dioxide, ozone, sulfur dioxide, and particulate matter (Akbari 2002; Nowak and Dwyer 2000). Trees also filter dust, pollen, smoke, and ash. Urban forests absorb ozone, sulfur dioxide, and nitric oxide. Trees increase wind turbulence, and increased turbulence aids air pollutant dispersal. Fragrant trees, such as magnolias and evergreens, and floral vegetation, are often used to mask foul and pungent odors (Grey and Deneke 1986).

Urban forests also slow and prevent global warming and climate change by absorbing and sequestering large amounts of carbon. The reduction in atmospheric carbon dioxide prevents excess heat build up in the earth's atmosphere (Nowak and Dwyer 2000). Large urban trees hold three metric tons of carbon and sequester around ninety kilograms of carbon each year. Chicago's urban forest alone sequesters 155,000 tons of carbon annually (Nowak 1994), whereas all of the urban trees in the conterminous United States store 700 million tons of carbon (Nowak and Crane 2002).

Urban forests also play an important role in the hydrologic cycle. Trees act as flood controls and prevent soil erosion. By intercepting precipitation, they slow the flow of precipitation to the ground. This allows more time for water to reach the ground and increases the amount of water that can infiltrate into the soil. Tree roots hold soil together in riparian and floodplain areas, preventing erosion and lessening runoff. Thus, trees are an important component to the health of watersheds and to reducing storm water runoff and flooding in urban areas.

Species abundance and diversity are indicators of healthy ecosystems, and urban forests provide vital habitat for wildlife. Deer, birds, raccoons, and squirrels are common inhabitants of urban forests, as well as many plant varieties. Urban forests typically host more bird species than rural areas (Grey and Deneke 1986). Urban forests also attract endangered species. For example, Cook County, Illinois, home to the City of Chicago, accommodates 20 threatened or endangered animal species and 130 threatened or endangered plant species (Nowak and Dwyer 2000).

Social Benefits

Besides providing environmental benefits to urban areas, urban forests also enhance and stimulate social ecosystems. From psychological influences to recreational opportunities to community cohesion, urban forests promote many beneficial activities that support human health and well-being at the individual and community levels.

Urban forests provide an aesthetic background for peoples' daily lives. The colors, lines, shapes, and textures formed by urban forests beautify urban landscapes. In the spring, ornamental trees, such as crape myrtles, dogwoods, and magnolias, bloom, producing beautiful flowers. In the fall, residential neighborhoods and urban parks radiate with color as abscission begins in the urban forest. The rustling of tree leaves provides soothing sounds and pleasing visual effects. For example, the contrasting colors of the front and back of aspen leaves produce a shimmering effect during spring and summer breezes. Furthermore, trees soften architectural edges and add an element of nature to heavily built-up urban areas. Landscape architects also employ trees to enhance and frame scenic urban vistas (Grey and Deneke 1986).

Urban forests promote a sense of well-being and wellness, and also encourage physical activity. Urban residents are reported to have felt more relaxed, pleasant, and focused if their homes afforded a view of trees and to have exhibited an overall satisfaction and pride in relation to neighborhood trees (Kaplan 1993). Moreover, workers in Seoul, South Korea, whose office windows framed a scenic forest view, were more satisfied with their jobs and complained less about job-related stress than those without a view of trees (Shin 2007). In a widely-cited study within the urban forestry community, a view of a small stand of deciduous trees in a Pennsylvania hospital wing was positively correlated with a decreased recovery time from cholecystectomy surgery (Ulrich 1984).

In addition, city residents recreate in and near urban forests. They jog, walk, cycle, and even meditate in forested urban parks. Increased physical activity can prevent common health problems, such as obesity and heart disease, promote a positive sense of well-being, and improve overall wellness. All of which have numerous positive psychological and physiological effects. Thus, urban forests indirectly reduce demands on social services and promote healthy living (Sullivan and Kuo 1996).

The presence of trees in neighborhoods strengthens community ties and encourages community cohesion. It has been shown that residents living in and around an urban forest relate better with their neighbors than residents living in areas without trees. Neighborhoods near urban forest areas have less domestic violence and neighbor-to-neighbor altercations than those in less forested areas (Sullivan and Kuo 1996). Furthermore, trees have been linked to decreased levels of property crime and violent crime (Kuo 2003). On the other hand, lack of green spaces has been correlated with social unrest, such as the 1960s Watts riots and the 1992 Rodney King riots in Los Angeles (Westphal 2003). Thus, urban forests are important to the healthy functioning of cities' social ecosystems, serving to empower and bring residents together (Westphal 2003).

Economic Benefits

Urban forests also create many beneficial economic services by reducing energy costs, increasing real estate values, and raising municipal revenue. The placement of trees can greatly reduce energy usage, which not only decreases air pollution but also has the concomitant effect of reducing the economic costs of energy consumption. It has been estimated that planting 11 million shade trees in the Los Angeles area would save the region $270 million per year (Akbari 2002). It has also been estimated for the Chicago urban environment that a 10 percent increase in residential tree cover would result in a five to 10 percent energy reduction or a $50 to $90 decrease in a homeowner's electricity bills per year (McPherson 1994).

Urban forests have a positive effect on residential and commercial real estate values. For example, single-family homes in Athens, Georgia, with tree landscaping sold for three to five percent more than homes without trees (Anderson and Cordell 1988). In a more recent study of housing prices, consumers pay a premium for homes with trees in Quebec, Canada (Des Rosiers et al. 2002). A 20 percent increase in the value of properties adjacent to the Barton Creek Greenbelt, a heavily forested area, was documented in Austin, Texas (Nicholls and Crompton 2005).

Commercial rent also benefits from an urban forest and tree landscaping. Commercial rental rates increase with well-maintained tree landscaping (Laverne and

Winson-Geideman 2003). Consumers also frequent commercial districts with trees more than those without, and they are willing to spend more money at businesses landscaped with trees (Wolf 2005).

Increased property values raise tax revenue for municipal governments. For example, in Charlotte, North Carolina, a proposed regional trail that would conserve an expansive urban forest and create recreation trails, was determined to generate as much as $600,000 more annually in property tax revenue for the city (Campbell, Jr. and Munroe 2007).

The benefits of urban forests are well known and well documented. Urban forests create a better, healthier urban environment for people, as well as for city flora and fauna. However, accruing the benefits of urban forests depends on expanding and protecting them through increased funding, effective management, and regulatory control. In order to inform urban forestry decisions, research on the geographic patterns and landscape characteristics associated with trees becomes essential to sustaining and enhancing trees in the city.

CHAPTER III

LITERATURE REVIEW

Within urban forest literature, studies on the structure of urban forests fall into two broad categories. The first group of studies is devoted to quantifying the environmental, economic, and social benefits associated with urban forests. These studies have illuminated a wide range of services provided by urban forests, from estimating the carbon capture of urban forests (Nowak and Crane 2002), to quantifying the household energy savings of residential shade trees (Pandit and Laband 2010), and to analyzing the amount of crime reduction associated with urban treescapes (Kuo 2003).

The second group of studies focuses on the geography of urban forests. This group explores the factors that explain urban forests' composition and distribution, awareness of urban forests and their benefits, and urban forest research methods. Geographic studies include surveys of people's perceptions of urban forests (e.g., Lohr et al. 2004; Zhang et al. 2007), examinations of the determinants that influence the distribution of urban forests across the urban landscape (e.g., Heynen and Lindsey 2003; Landry and Chakraborty 2009), and explorations of various methodological approaches to quantify urban forest structure (e.g., Jensen, Gatrell, Boulton, and Harper 2004).

These geographic studies have added to the understanding of the various factors—landscape characteristics, beliefs, policies, and programs—influencing urban forest canopy cover and distribution. Two of the geographic themes—those that examine the determinants of urban forest distribution and those that explore research methods to quantify urban forest structure—inform this study.

Determinants of Urban Forest Distribution

A wide-ranging set of physical, urban, demographic, socioeconomic, and policy characteristics determines the spatial distribution of urban forests. At a regional scale, physical characteristics such as temperature, precipitation, and soil type influence urban forest distribution and structure with precipitation being the major determinant of urban forest growth in the United States (Sanders 1984). Thus, humid regions in the United States generally have a higher percentage of tree canopy cover than arid regions. Other physical characteristics, at larger scales, influencing urban forest structure include topography and proximity to hydrologic features. Steep slopes and riparian areas are associated with increased canopy cover because they often preclude development (Heynen and Lindsey 2003). Still other physical characteristics, including air pollution, soil compaction, and increased urban heat, negatively affect urban tree growth (Bradley 1995).

While appropriate climatic and edaphic conditions are necessary for tree growth, urban morphology determines where trees grow (Sanders 1984). Land use affects urban forest structure. Transportation, industrial, and commercial land uses generally have a smaller proportion of trees than institutional, residential, and park land uses (Sanders 1984). Along the urban-rural gradient, trees become more abundant as the city shifts from high-density development at the urban core to larger residential parcels in suburban areas (Bradley 1995). Thus, areas with high building density are associated with decreased urban canopy cover (Landry and Pu 2010). Sidewalks, roads, and other impervious cover limit space for tree establishment (Sanders 1984). Decreases in urban canopy cover have been linked to increases in impervious cover (Kromroy et al. 2007; Nowak and Greenfield 2012). Another urban form variable, housing age, has been shown to be a significant indicator of increased urban forest canopy cover (Heynen and Lindsey 2003; Grove et al. 2006; Troy et al. 2007).

Demographics also determine the structure of urban forests; however, results vary within urban forests studies. In one study, population density has been negatively associated with canopy cover (Troy et al. 2007), whereas in another study, population density had no significant effect on canopy cover (Heynen and Lindsey 2003). Housing tenure tends to be a good predictor of canopy cover with homeowners having more canopy cover than renters (Perkins, Heynen, and Wilson 2004; Heynen, Perkins, and Roy 2006; Landry and Chakraborty 2009). Race and ethnicity have been reported as strong indicators of canopy cover as well. White populations have been associated with a greater proportion of canopy cover than minority populations (Heynen, Perkins, and Roy 2006; Landry and Chakraborty 2009; Landry and Pu 2010). Age of householder also contributes to urban forest canopy cover (Landry and Chakraborty 2009).

Socioeconomic status is another predictor of urban forest structure. Median household income (Perkins, Heynen, and Wilson 2004; Heynen 2006; Heynen, Perkin, and Roy 2006; Landry and Chakraborty 2009) and home value of residential housing has been associated with forest canopy cover (Troy et al. 2007; Payton et al. 2008; Landry and Pu 2010). In another study, income was found not to be significantly correlated with canopy cover (Heynen and Lindsey 2003). Level of educational attainment also has been show to explain urban forest canopy cover (Heynen and Lindsey 2003; Troy et al. 2007).

Finally, municipal policy affects urban forest structure. Studies have determined that the strength of municipal tree ordinances, which serve to protect urban forests, have a significant effect on urban canopy cover (Gatrell and Jensen 2002; Conway and Urbani 2007; Hill, Dorfman, and Kramer 2010; Landry and Pu 2010; Sung 2012).

Measuring Urban Forest Distribution

As discussed previously, urban forests are dynamic, shaped by a host of physical, urban, and social landscape features. As such, urban forest managers need access to accurate information regarding urban forest structure, such as their distribution and composition, in order to manage urban forests effectively. Researchers have met this need by employing a range of geospatial tools, including geographic information systems (GIS) and remote sensing, to quantify various features of urban forests (Ward and Johnson 2007). Most often, these tools are used in concert.

A GIS has the capacity to combine, analyze, and represent multiple geographic datasets, and it is a useful tool for urban forest researchers to determine the distribution and spatial patterns of urban forests across urban areas relative to various social, economic, and physical attributes (Pauleit and Duhme 2000). For example, combining an urban forest layer with a land use layer, researchers have determined that urban forest structure varies by urban land use. Urban forest structure is at its best in exurban and peri-urban areas and falls off in the densely developed and populated urban core. GIS analyses of urban forests, however, also have shown that open spaces harbor a higher proportion of urban trees, regardless of their location in the urban environment (Pauleit and Duhme 2000). Surface temperature and tree cover have been linked through a GIS, showing cooler temperatures in and around large stands of urban forests. Moreover, GIS studies have been used to link urban forests structure and patterns with important social indicators, such as quality of life (Jensen, Gatrell, Boulton, and Harper 2004). A GIS also has been used to locate tree-planting sites (Wu, Xiao, and McPherson 2008; McPherson et al. 2011) and to explore increased water demand from urban forest growth (Lowry Jr., Ramsey, and Kjelgren 2011).

The distribution, composition, and health of urban forests are of particular interest to urban foresters, and researchers are experimenting with different ways to measure and quantify urban forest structure. Although there are field-based methods to measure urban forest structure, they are time consuming because of the size of urban areas. An approach that allows for measures of the entirety of a city's urban forest is to analyze aerial and satellite imagery of urban forests through remote sensing techniques. Moreover, aerial and satellite imagery is widely available. As such, much research has been conducted on identifying urban forest cover and structure through a range of remote sensing techniques.

Remote sensing is the collection of data about an object without direct contact with the object. Remote sensors gather electromagnetic radiation information from the earth's surface to produce images of groundcover. In urban forest studies, researchers employ both passive and active remote sensing techniques to measure urban forest structure. Passive remote sensors collect electromagnetic radiation using sunlight and include aerial and satellite imagery. Active remote sensors collect electromagnetic radiation using artificial light sources and include radio detection and ranging (RADAR) and light detection and ranging (LiDAR) imagery.

A common approach to quantify urban forest structure is to employ passive remote sensing of satellite imagery to produce a vegetation index, called Normalized Difference Vegetation Index (NDVI). NDVI analysis illuminates urban forest structure by calculating the unique reflective properties of vegetation through the ratio of red- to near-infrared bands in satellite imagery. While NDVI is a relatively simple calculation, without further processing, it does not distinguish forestland from other vegetation, such as grass and shrub lands (Conway and Urbani 2007; Gong, Chen, and Yu 2011; McPherson et al. 2011). Nevertheless, NDVI analysis has been employed effectively to assess the relationship between urban forest policy and canopy cover (Conway and Urbani 2007), to detect temporal changes in urban forest carbon storage (Myeong, Nowak, and Duggin 2006), and to estimate urban forest health (Xiao and McPherson 2005).

Another index used to estimate urban forest structure is leaf area index (LAI). LAI is the ratio of the total leaf surface area of a tree to the ground surface area covered by the tree. It is used to indicate the amount of leaf material in the urban environment. Passive remote sensing methods have been shown to accurately produce LAI measurements compared to LAI field measures (Jensen and Hardin 2005). Remotely sensed LAI has been used to show that increases in LAI are correlated to decreases in energy use (Jensen, Boulton, and Harper 2003).

Besides index measures of urban forest structure, passive remote sensing techniques have been used to detect urban forest species composition (Xiao, Ustin, and

McPherson 2004; Pu 2009), assess spatiotemporal urban forest change (Gong, Chen, and Yu 2011; Moskal, Styers and Halabisky 2011), monitor urban forest health (Xiao and McPherson 2005), quantify social benefits of urban forests (Jensen et al. 2004).

Although active remote sensors are often cost prohibitive because of the nature of the gathering technique, LiDAR data has been used to assess urban forest structure in a limited number of studies. LiDAR data is derived from a remote sensor that emits artificial light, which measures distances to objects and the ground. LiDAR data can be used to create triangulated irregular networks (TIN) that display ground surface in a 3-D format. LiDAR data has been used to evaluate urban forest canopy heights and as another way to assess the efficacy of urban forest policies (Sung 2012).

CHAPTER IV

RESEARCH METHODS

Site and Situation

The City of Austin (30°15′N 97°45′W) is located in central Texas and has a population of approximately 812,000 and a footprint of 795 km^2 (Figure 2) (City of Austin 2011c). The physical area of the city occupies two distinct geographical provinces. The western half of the city lies on the Balcones Escarpment, and its physical landscape is hilly terrain. The eastern half of the city sits in the Blackland Prairies of the Gulf Coastal Plain. Its physical landscape is relatively flat. The city's climate is classified as humid subtropical but is highly variable. Summer temperatures reach 38 degrees Celsius or more for days or weeks, and winter temperatures occasionally dip below freezing (Woodruff, Jr. 1979). Despite the climatic variability and extreme heat, Austin is home to a variety of tree species. Many pecan trees, the Texas State Tree, thrive in Austin neighborhoods, along with a variety of oak, elm, juniper, and cypress species.

Austin's socioeconomic landscape mirrors that of its physical landscape. East Austin is home to the majority of the city's Hispanic and African-American population. Largely the result of early twentieth century segregation ordinances and deed restrictions, Austin's African-American residents have long called East Austin home. Beginning in the 1930s, deed restrictions, as well as limited access to public services, also relegated

Hispanics to the east side of the city (Humphrey 1997). Moreover, East Austin residents are predominantly associated with lower socioeconomic statuses than that of their western counterparts. Austin's Asian population tends to reside in far north Austin. While demographic shifts are occurring across the city (Castillo 2011), distinct ethnic conclaves still exist in Austin today.

Austin's urban landscape is typical of a southern U.S. city. A central downtown anchors Austin to the larger area of the city. Outside of the central business district a transition zone develops, which is characterized by light industry and poverty pockets and deteriorating residences. Just outside of the transition zone, there are working class neighborhoods, which give way to residential, suburban neighborhoods. As such, building density is greatest in the urban core.

Austin's Urban Forest

The urban forest is an important environmental amenity in Austin, spanning back to the region's earliest residents. The Tonkawa and Comanche tribes held religious ceremonies among a group of live oak trees, referred to as the Council Oaks, in what is now the downtown area (City of Austin 2011b). The remaining survivor of this oak grove, the Treaty Oak, is over 500 years old and is under the constant care of volunteers, foresters, and the city's parks department (Haislet 2011).

Austinites even considered trees with no historical significance sacred. Bicycling celebrity and cancer activist Lance Armstrong transplanted a 150-year-old live oak on his property when plans for his new home called for its destruction. While constructing the latest addition to their football stadium, the University of Texas at Austin temporarily relocated several live oaks before returning them to their previous locations after construction was completed.

The city government also has made urban forestry a priority. Austin has been designated a Tree City USA Community for 20 years, continuously meeting the four standards for this designation, possessing a tree board, a tree ordinance, an urban forestry program, and an Arbor Day observance and proclamation. Moreover, the city has managed and protected its urban forest for around thirty years through a variety of programs and regulations.

The city's urban forestry program, housed within the parks and recreation department, protects and plants public trees on right-of-ways and in city parks and preserves. The program's mission is "to provide, protect, and preserve the highest quality care of Austin's urban forest through planting, maintenance and replacement of trees in parks, along streets and in other public areas, thereby contributing to positive recreational, cultural and outdoor experiences for the Austin community" (City of Austin 2011e). The urban forestry program has a separate advisory board composed of seven community members appointed to three-year terms. The board and the urban forestry staff provide educational training to city residents and organize tree planting programs and special tree-centered events. The city's urban forestry program is developing a comprehensive plan to manage and maintain public trees (City of Austin 2011f).

Besides municipal government entities, state and federal agencies, non-profit organizations, private urban forestry and arboriculture companies, and power and utility companies shape and manage Austin's urban forest. The city receives funding from the U.S. Forest Service as well as Texas A&M Forest Service. The funds are used to implement urban forestry education and planting programs. The city also partners with non-profit environmental organizations to achieve urban forestry goals. For example, TreeFolks, an Austin-based non-profit organization, educates central Texas residents through tree plantings and workshops, and They Might Be Monkeys, a private Austin area company, assists residents with tree pruning and removals.

Urban Forest Protections

In 1983, the Austin City Council adopted a forward-looking ordinance to protect trees on private property. The city has amended and expanded the ordinance over the years; most recently, the city added a heritage tree ordinance in 2010. Contained within the city's land development code, the tree and natural area protection and heritage tree ordinances outline the rules and regulations in regards to the removal of protected trees on public and private property (City of Austin 2011d). According to the city code, a tree in Austin is considered a protected tree if it has a trunk diameter at breast height (DBH) (measured four and a half feet from the base of the tree) of 19 inches (48 centimeters) or greater. A heritage tree has a trunk DBH equal to or greater than 24 inches (64 centimeters). However, only certain species of tree are subject to the regulations of the heritage ordinance, while all tree species are subject to the regulations of the tree ordinance regulations.

A permit is required for the removal, encroachment into the critical root zone, or crown reduction of more than thirty percent of a protected or heritage tree. The city grants or denies permit applications based on a variety of factors during a site inspection. Factors taken into consideration during the inspection include variables such as age, condition, type, size, and the overall aesthetic of the tree. The primary goal of the ordinances is "to achieve a balance of re-forestation and preservation, frequently emphasizing one of the two elements to achieve the best long-term benefit for the community" (City of Austin 2011a).

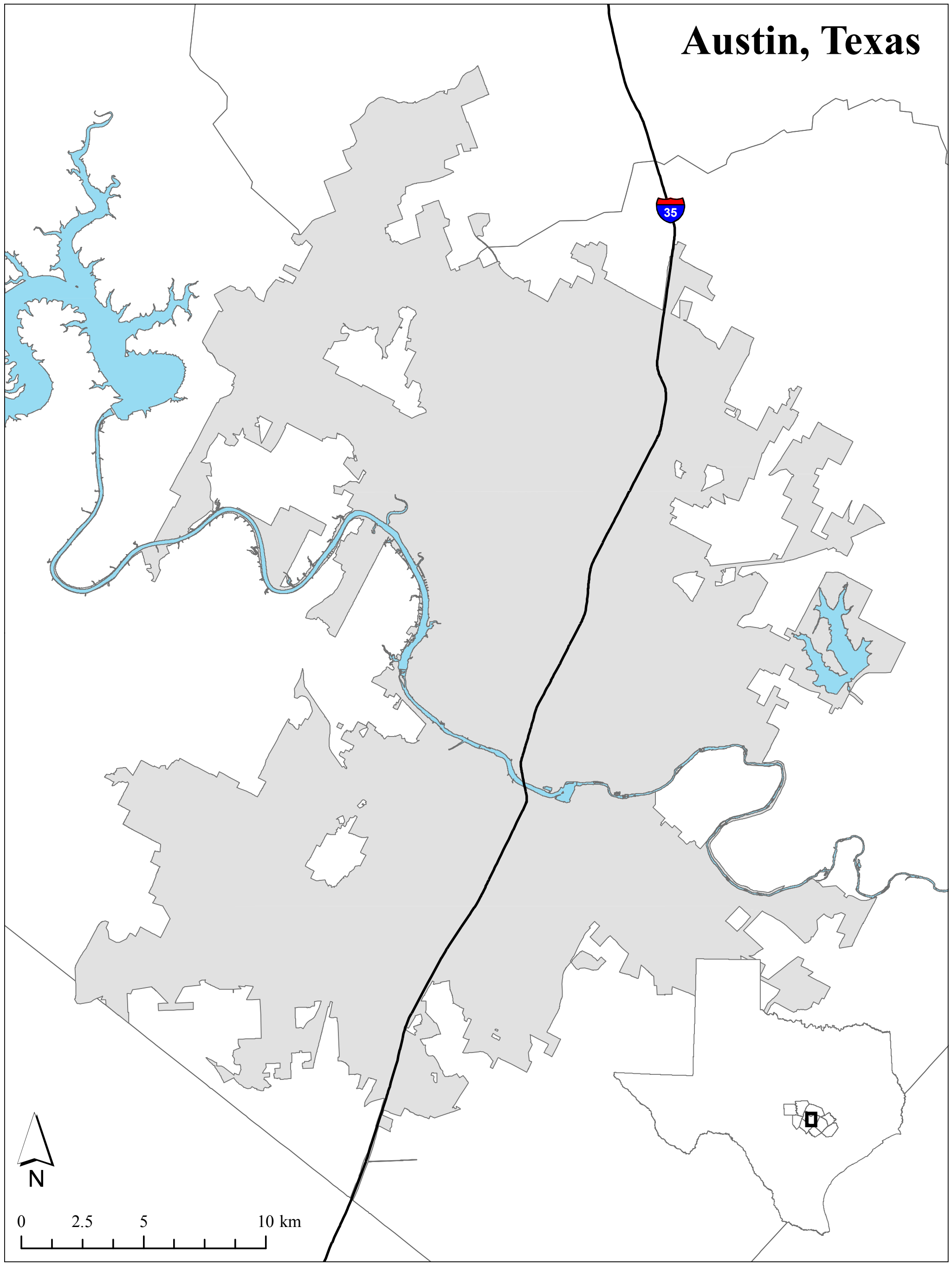


Figure 2. Map of the study area.

Data and Methods

The majority of urban forest research uses percent canopy cover to assess the distribution of trees across urban areas and to uncover the factors influencing the amount of canopy cover observed. Percent canopy cover offers useful insights into small-scale forest patterns, but it is not well situated to explain large-scale influences of diverse, urban landscapes on the dynamic structure of urban forests. This research attempts to determine large-scale influences that effect urban distribution by extracting, measuring, and analyzing physical, urban, and socioeconomic landscape characteristics associated with tree removals in the City of Austin from 2002 to 2011. Site-specific attributes of tree removals and their associated neighborhood-scale attributes were gathered through use of a geographic information system (GIS). The GIS was then used to reveal spatiotemporal patterns relative to tree removals. Statistical analyses were used to illuminate neighborhood-scale landscape characteristics that significantly explain tree removals.

Datasets

Derived from the literature, this research hypothesized that a mixture of physical, urban, and socioeconomic landscape characteristics would have an effect on the number and location of tree removals in Austin, Texas, over the ten-year study period. Thirteen variables related to these conceptual characteristics were operationalized through a number of datasets and measurements (see Table 1).

The physical landscape variables chosen for this research were percent slope and proximity to hydrologic features for each tree removal. Past research has shown that these physical landscape characteristics play a role in the distribution of urban forests (e.g., Heynen and Lindsey 2003; Davies et al. 2008). Urban landscape features may either effect positively or negatively tree vitality and by extension the distribution of urban forests (e.g., Troy et al. 2008; Landry and Pu 2010). As such, this research examined four variables related to urban landscape characteristics and their effects on tree removal: age of structure, proximity to major roads, land use, and population density. Socioeconomic landscape characteristics also effect the distribution of urban forests (e.g., Perkins, Heynen, and Wilson 2004; Landry and Chakraborty 2009). As such, this study examined whether five socioeconomic landscape characteristics had an impact on urban tree removals: percent white, percent owner occupancy, percent college graduates, median income, and market value. Finally, Austin's unique physical geographic zones inform the last two directional variables: east/west and north/south. Appendix B maps each variable by U.S. Census block group relative to tree removals.

Tree removal data

The City of Austin's City Arborist Program provided the dataset from which tree removals were derived (City of Austin 2011). Per Austin's tree ordinances, a permit is required to modify a protected tree on public or private lands. Landowners must submit an application, requesting permission to undertake the proposed modification. The urban deforestation dataset records information from these applications. It includes the following attribute fields: 1) address or site of requested tree modification, 2) date the application was submitted, 3) type of modification requested, 4) modification requested for development or nondevelopment reasons, and 5) whether a permit was granted.

Requests for tree removal fall into one of three categories: 1) total removal of the tree, 2) encroachment into the tree's critical root zone, and 3) excessive removal of the tree's canopy. Although the latter two categories do not remove the tree entirely, both damage tree health and structure. Encroachment into a tree's critical root zone may destabilize the tree and damage its vitality. Excessive canopy removal also damages a tree's vitality (Miller 2007). Because each category—removal, encroachment into the critical root zone, and excessive canopy removal—places the tree at risk of failure, this research considers all categories as tree removals.

The dataset contains 7,749 tree removal applications that were submitted to the city between 11 January 2002 and 12 October 2011. According to the dataset, the city "approved" 3,204 applications, "approved with conditions" 2,800 applications, and "denied" 409 applications. The city labeled the remaining 1,336 applications in the database as "closed," "in review," or "review completed." Because the dataset does not expand on the status of the 1,336 remaining applications as either approved or denied, they were omitted from the study.

After removing the 1,336 applications with no clear indication to their final status, the dataset included 6,413 applications for tree removal in Austin, Texas, from 2002 to 2011. Of these applications, the City of Austin approved or approved with conditions 6,004 applications and denied 409 applications. Since the purpose of this research is to present a geography of permitted urban deforestation in Austin, the researcher omitted the denied applications.

Recent state-level legislation has determined that cities may not enforce tree ordinances outside of their full-purpose jurisdiction. Upon further examination of the 6,004 approved applications, it was determined that 119 tree removals fell outside of the city's full-purpose jurisdiction and were removed from the final analysis. Thus, a total of

5,885 approved applications, representing tree removals inside Austin's city limits, are analyzed in this study.

Physical landscape data

Datasets comprising physical characteristics of Austin were obtained from the City of Austin and Texas Natural Resource Information System (TNRIS). They include major hydrologic features and digital elevation models (DEMs) for the Austin area. The DEM data files are products of the U.S. Geological Survey (USGS), representing ground surface topography by 30 meter cells (TNRIS 2011). Hydrologic features were derived from the City of Austin's major lakes (City of Austin 2003) and creek lines (City of Austin 1997) datasets. Percent slope and distance to hydrologic features were calculated in ArcGIS for each tree removal site.

Urban landscape data

Cadastral data, including descriptive parcel information, for Austin were obtained from the Travis Central Appraisal District (TCAD 2012) and the Williamson Central Appraisal District (WCAD 2012). From these datasets, information regarding the year the structure was constructed and the appraised value of the property was collected for parcels with tree removals. This information was used to explore their associations with tree removal across Austin over the ten-year study period and to test their significance in explaining urban deforestation patterns. Thus, parcel information was utilized in the descriptive and frequency analysis as well as the regression analysis.

Land use/land cover information at the parcel scale was obtained from the City of Austin's GIS datasets (City of Austin 2006). This dataset depicts land use and land cover at the parcel level as of 2006. The land use parcel geometry is based on the City of

Austin's 2003 Land Use Study and City of Austin base map and county appraisal district GIS and CAD files.

General land use classifications were included in the analysis because they cover the major land use categories relevant to this research. Descriptive and frequency analysis was run on the full set of general land use classifications associated with tree removals. However, the final regression analysis only distinguished between residential and nonresidential land uses for tree removals. Finally, population density for each block group in the study area was derived from U.S. Census block group areas and population counts.

Socioeconomic landscape data

Demographic and socioeconomic datasets for Austin were obtained from the U.S. Census Bureau's 2010 Census (U.S. Census Bureau 2010) and from the U.S. Census Bureau's American Community Survey 5-year estimates (2006-2010) (U.S. Census Bureau 2010a), respectively. American Community Survey datasets contain socioeconomic information, including educational attainment and median income. U.S. Census datasets include information on population, race and ethnicity, and housing occupancy status. Demographic and socioeconomic datasets were obtained at the block group level.

There are 552 block groups in Austin, Texas, and 460 of them contain at least one tree removal during the ten-year study period. Socioeconomic information for each of the 460 block groups with tree removals was used in the regression analysis to determine which socioeconomic landscape characteristics significantly explained urban deforestation. The market values of deforested properties were used as an additional socioeconomic predictor. Market values were obtained through the parcel information supplied by the appraisal districts.

Methods

This research used data representing tree removals in Austin, Texas, from 2002 to 2011 and datasets that capture physical, urban, and socioeconomic landscape characteristics relative to tree removal sites. In order to explore and draw conclusions from these disparate datasets, this research used a GIS and statistical analyses. The GIS was built using ESRI's ArcMap software, version 10.1, and data from the GIS were exported into IBM's Statistical Package for the Social Sciences (SPSS) software, version 21, for statistical analyses. Figure 3 presents a flow chart of the data and methods used, and Table 1 presents a list of conceptual and operational variables tested in this research.

GIS analysis

Spatial analysis illuminates linkages between the geographic distribution of a phenomenon and nearby spatial features and their non-spatial attributes to produce new and useful information about the phenomenon under analysis. Spatial analysis is conducted through the use of a GIS. A GIS uses software to integrate spatial and non-spatial data, to overlay multiple geographic datasets, and to explore connections between layers (Maantay and Ziegler 2006). For this research, a GIS was created to discover relationships between urban deforestation occurrences and neighborhood-landscape characteristics.

The GIS geocoding and geoprocessing functions were employed to create new information about the geographic distribution and associated characteristics of urban deforestation occurrences. First, the tree removal dataset was geocoded using the geocoding tool in ArcMap. Using descriptive information associated with a location, the geocoding process locates and places a point on a map for each description. In this case, a point layer was created that referenced the location of tree removals on a map of Austin and its surrounding areas.

Next, the datasets representing major roads and hydrologic features were entered into the GIS. Using the near tool located in the proximity toolset within the analysis toolbox, the distance was calculated from each tree removal to the nearest major road. The near tool was run again to calculate the distance from each tree removal to the nearest hydrologic feature. For each tree removal, both distances were added to the tree removal dataset.

The USGS 30m DEM was then added to the GIS. Using the slope tool located in the surface toolset within the spatial analyst toolbox, percent slope was calculated from the DEM and a new layer was created. From this layer, the percent slope for each tree removal site was extracted to the point layer using the extract values to points tool located in the extraction toolset within the spatial analyst toolbox. This tool added percent slope for each tree removal site to the tree removal dataset through a process of interpolation, where percent slope was calculated from adjacent cells.

Next, the cadastral and land use/land cover datasets were added to the GIS. Again, using the extract values to points tool located in the extraction toolset within the spatial analyst toolbox, the general land use associated with each tree removal was extracted and added to the tree removal dataset. The cadastral dataset was subjected to the same process. Data relating to market value and age of structure for each parcel with a tree removal point were extracted and added to the tree removal point layer.

The final attributes added to the tree removal point layer file were related to the location of each tree removal feature. Tree removals were separated into two directional locations: 1) topologically north or south of the Colorado River system, and 2) east or west of Interstate 35. Attribute fields for north/south and east/west were created for the tree removal point layer, and using the select by location tool located in the layers and table views toolset in the data management toolbox, tree removal features were selected and labeled based on their locations.

U.S. Census block group polygons were downloaded and entered into the GIS. Population density for each block group was calculated using the field calculator in ArcMap by dividing a block group's total population by its total area. Next, the block group polygons were joined with attribute information downloaded from the 2010 Census and the American Community Survey 5-year estimates (2006-2010) related to the socioeconomic landscape characteristics explored in this research—race and ethnicity, educational attainment, median income, and occupancy status.

Using the spatial join tool located in the overlay toolset within analysis toolbox, the tree removal point layer was spatially joined with the block group polygon layer. The spatial join tool joins attribute information from one layer to another layer based on their spatial relationship. In this case, attribute information from the tree removal point layer was aggregated to the block group polygon layer. The resulting polygon layer, then, included information specific to tree removals within that block group. The following join rules were chosen for attributes contained in the tree removal point layer when performing the spatial join to the block group polygon layer: total tree removals and tree removals associated with development were counted; median percent slope, median market value, median age of structure, median distance to roads and hydrologic features, and mode general land use were calculated.

ArcMap spatial statistics toolbox was then used to examine the spatial distribution and patterns of urban tree removal in Austin from 2002 to 2011. Using the directional distribution tool contained in the measuring geographic distributions toolset within the spatial statistics toolbox, standard deviational ellipses were created based on the tree removal point layer in order to observe the changes in the distribution of tree removals in Austin each year of the ten-year study period. Standard deviational ellipses measure the central tendency, dispersion, and directional trends of a group of geographic features. In the case of this research, the standard deviational ellipses measure the tendency, dispersion, and directional trends of tree removals by year. The tool creates a new layer with elliptical polygons in order to visualize changes by year.

Patterns of tree removal for the entire ten-year study period were analyzed at the block group level through the spatial autocorrelation tool and the hot spot analysis tool. First, the spatial autocorrelation tool was run on the block group polygon layer. The spatial autocorrelation tool generates the Global Moran's I statistic, a measure of spatial clustering. Multiple iterations of the spatial autocorrelation tool were run in order to obtain the most appropriate distance for use with the hot spot analysis tool. Next, the hot spot analysis tool was run.

The hot spot analysis tool calculates the Getis-Ord Gi* statistic. The Getis-Ord Gi* statistic identifies whether or not features with low or high values cluster together over a study area. It does this by evaluating the value of each feature in relation to the values of neighboring features. The resulting statistic is returned as a Z score for each feature, where high, positive Z scores represent clusters of features with statistically significant larger values, i.e., hot. Low, negative Z scores represent clusters of features with statistically significant smaller values, i.e. cold. The hot spot analysis, then for this research, distinguishes between statistically significant areas of high and low tree removals.

Finally, the results of the GIS analyses are used to produce a series of cartographic illustrations in order to visualize and understand the spatiotemporal patterns relative to urban deforestation in Austin from 2002 to 2011.

Statistical analysis

Frequency and descriptive analysis

To uncover historical trends and rates of change in urban deforestation since 2002 in Austin, the tree removal dataset was interpreted through frequency and descriptive analysis. Data from the tree removal point layer were exported to SPSS, where measures of central tendency (mean, median, and mode) and dispersion (range, variance and standard deviation) and frequency distributions were calculated using the frequency and descriptive tools. Frequencies and descriptive information, as well as overall rates of change, were calculated for each attribute contained in the tree removal point layer, which includes information related to the type of permit (development/nondevelopment), land use, age of structure, market value, proximity to major roads, proximity to hydrologic features, percent slope, and directional location.

Statistical tests of difference

In order to understand which neighborhood-scale landscape characteristics explain urban deforestation in Austin, this research tested the difference between categories of deforestation at the block group level first. Tests of difference in statistical analysis determine whether the difference between groups and their observed outcomes is statistically significant (i.e., not a product of chance). Moreover, statistical tests of difference are important to understanding group observations and informing further statistical analyses. The nonparametric Kruskal-Wallis H and the Mann-Whitney U Tests were chosen because the data used in this research are not normally distributed.

The Kruskal-Wallis H Test determines whether there is a statistical difference between three or more groups, whereas the Mann-Whitney U Test determines whether there is a difference between two groups. In this research, the Mann-Whitney U Test was used as a post-hoc test in order to determine between which two groups a statistical difference occurred (if one was observed) between the three groups of urban deforestation. Before running the tests, block groups were divided into three categories of deforestation—low, medium, and high—by the Jenks natural breaks classification method, which seeks to minimize the variance within and between classifications.

First, the nonparametric Kruskal-Wallis H Test was performed to determine if there was a difference between block groups of low, medium, and high deforestation relative to their values for the 13 explanatory variables. Statistically significant results were subjected to post-hoc Mann-Whitney U Tests to reveal between which groups the statistically significant difference occurred. Then, the mean ranks produced by post-hoc Mann-Whitney U Tests were compared to draw conclusions related to deforestation based on the variables tested.

Multinomial logistic regression analysis

To further explore the questions of what neighborhood-scale landscape characteristics—physical, urban, and socioeconomic—are significantly associated with urban deforestation and to what degree can these landscape characteristics explain patterns of observed urban deforestation in Austin, forward stepwise multinomial logistic regression analysis was employed. Multinomial logistic regression predicts the probability of membership in a given category for the dependent (outcome) variable based on a set of independent (predictor) variables, which can be discrete, continuous, or categorical. Forward stepwise multinomial logistic regression enters variables into the regression model based on their significance level. In order to enter the model, a variable must possess a significance level of 0.05. Once in the model, a variable must maintain a significance level of 0.10 in order to stay in the model as other variables are entered. Thus, the forward stepwise procedure selects only predictor variables that significantly contribute to the equation and, by extension, explain, in this research, urban deforestation. For this study, categories of deforestation by block group (low, medium, and high) served as the outcome variable. The predictor variables were the 13 variables related to the physical, urban, and socioeconomic landscape characteristics of tree removals in Austin.

Results of the multinomial logistic regression are interpreted through odds ratios and significance levels relative to the predictor variables. Odds ratios are a ratio of the odds for membership in each group (Meyers, Gamst, and Guarino 2006). SPSS produces an odds ratio for each predictor variable, as well as its significance value. For this research, odds ratios will determine the odds of belonging to either the medium or high deforestation groups relative to the low deforestation group, which is the referent group. Predictor variables with odds ratios greater than one signify that the likelihood of belonging to the low deforestation group decreases as the variable increases. Likewise, predictor variables with odds ratios less than one signify that the likelihood of belonging to the low deforestation group increases as the variable decreases. A significance value less than 0.05 for a variable will indicate that the null hypothesis is rejected and that they are statistically significant explanatory variables of deforestation. Thus, interpreting the output of the multinomial logistic regression analysis, both odds ratios and significance levels, details the landscape characteristics that significantly explain urban deforestation at the neighborhood-scale in Austin, Texas, from 2002 to 2011.

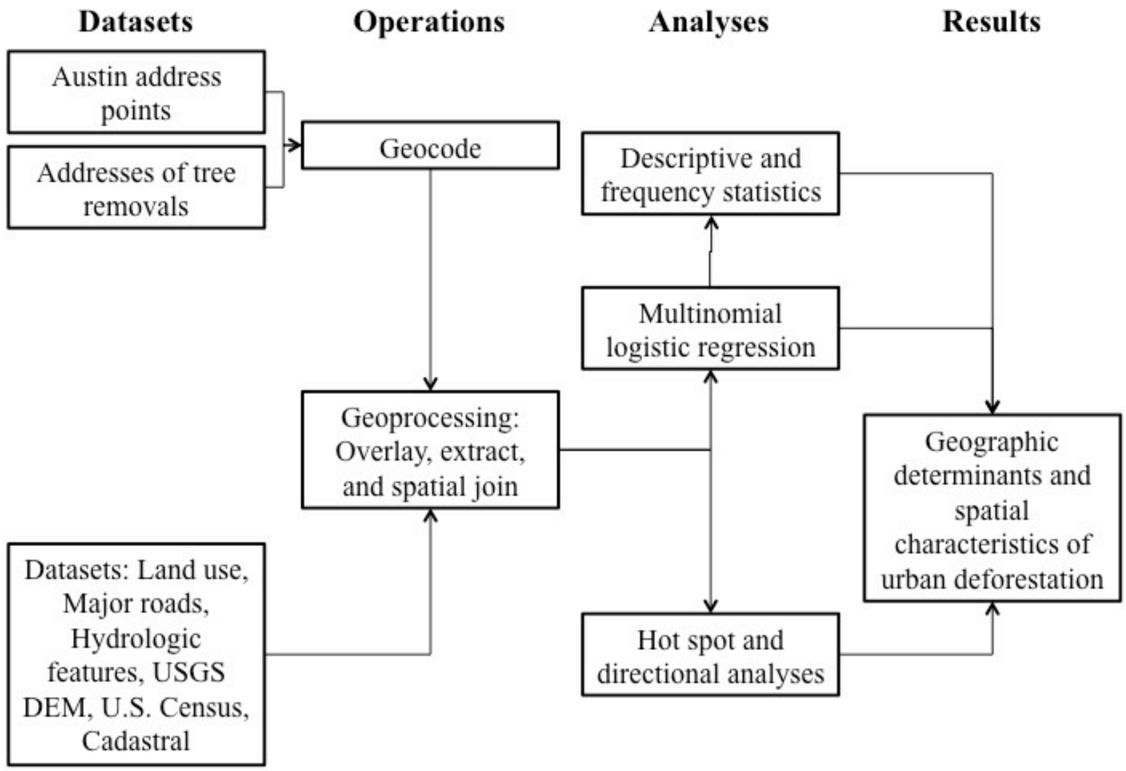


Figure 3. Flow chart of datasets, GIS operations, statistical and spatial analyses, and results.

Table 1. Conceptual and operational variables relative to research design and analyses.

Conceptual Variables	Operational Variables
Urban landscape characteristics	Population density
	Age of structure
	General landuse
	Proximity to major roads
	North/South
	East/West
Socioeconomic landscape characteristics	Percent white
	Percent college graduate
	Percent owner occupied
	Median income
	Market value
Physical landscape characteristics	Percent slope
	Proximity to hydrologic features

CHAPTER V

RESULTS

GIS Analysis

Geocoding Results

The results of the geocoding process—locating the addresses of approved permit applications on a map—on the 5,885 approved applications returned 5,693 good matches—a 96.7 percent accuracy rate. The researcher could not rectify and locate the remaining 192 approved permit application addresses. Thus, the results of this study reflect the 5,693 good matches produced by the geocoding process. Figure 4 reflects cartographically the results of the geocoding process, displaying the sites of tree removals for the entire ten-year study period. Appendix A includes maps of tree removals by year.

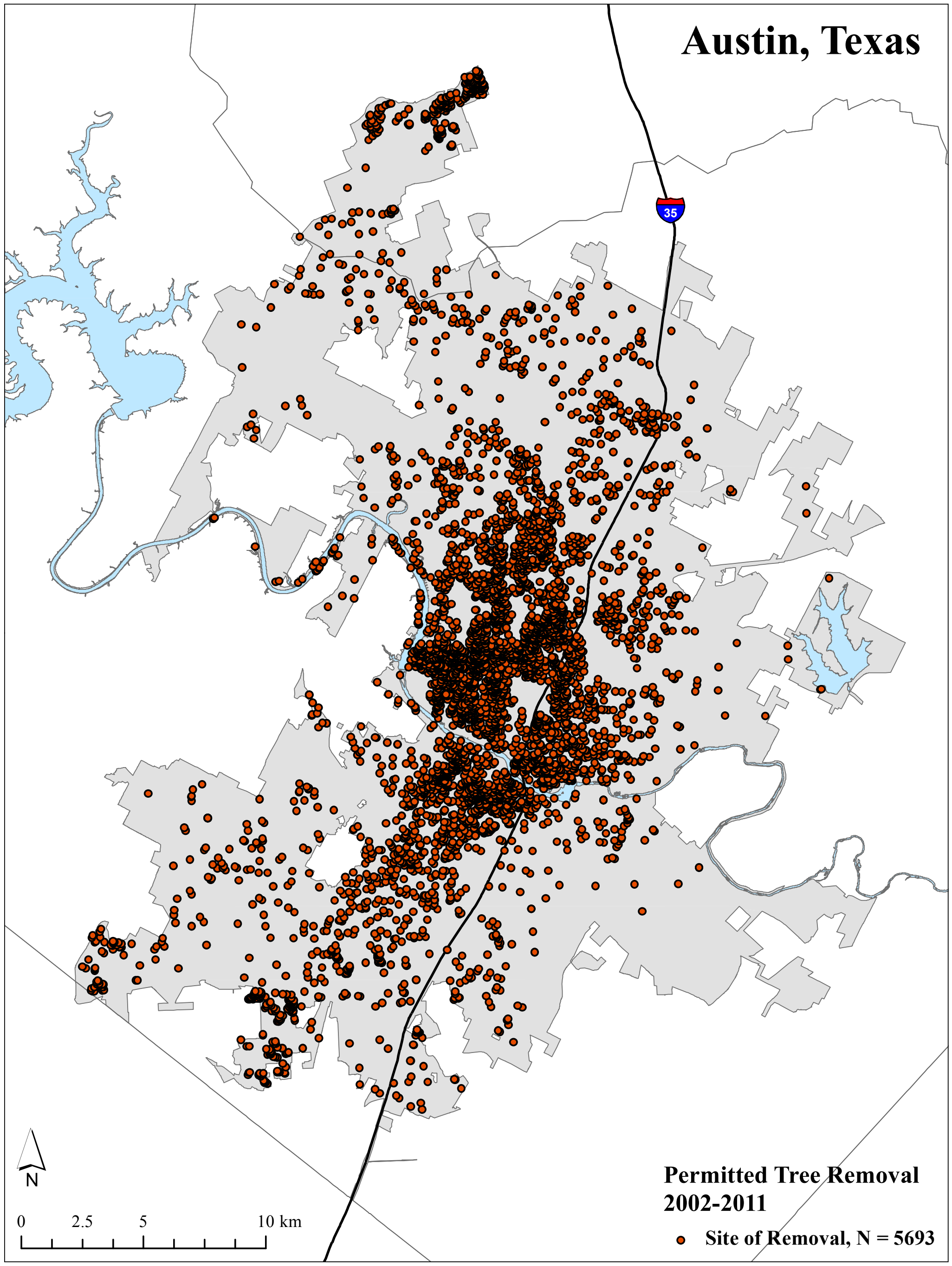


Figure 4. Sites of permitted tree removals in Austin, Texas, from 2002 to 2011 (N = 5,693).

Spatiotemporal Trends

This research employed directional distribution measures and hot spot analysis in order to discern spatiotemporal trends of tree removals in Austin, Texas, from 2002 to 2011. Results of these analyses are illustrated cartographically in Figures 5 through 8 and are recounted below.

The results of the directional distribution analysis, which created standard deviational ellipses for tree removals by year, indicated that the distribution of the majority of tree removals (i.e., within one standard deviation of the mean center) has become more concentrated over the ten-year study period (see Figure 5). The elliptical polygons indicate a diffuse distribution of tree removals across the city in the early years of this study, and an increasingly condensed distribution around Austin's urban core in the latter years of this study. No measureable directional shift, either east/west or north/south, was observed between the mean centers of the standard deviational ellipses, indicating that the mean center of tree removals has remained relatively constant between 2002 and 2011. The mean distance between the mean centers of each standard deviational ellipse was 249 meters.

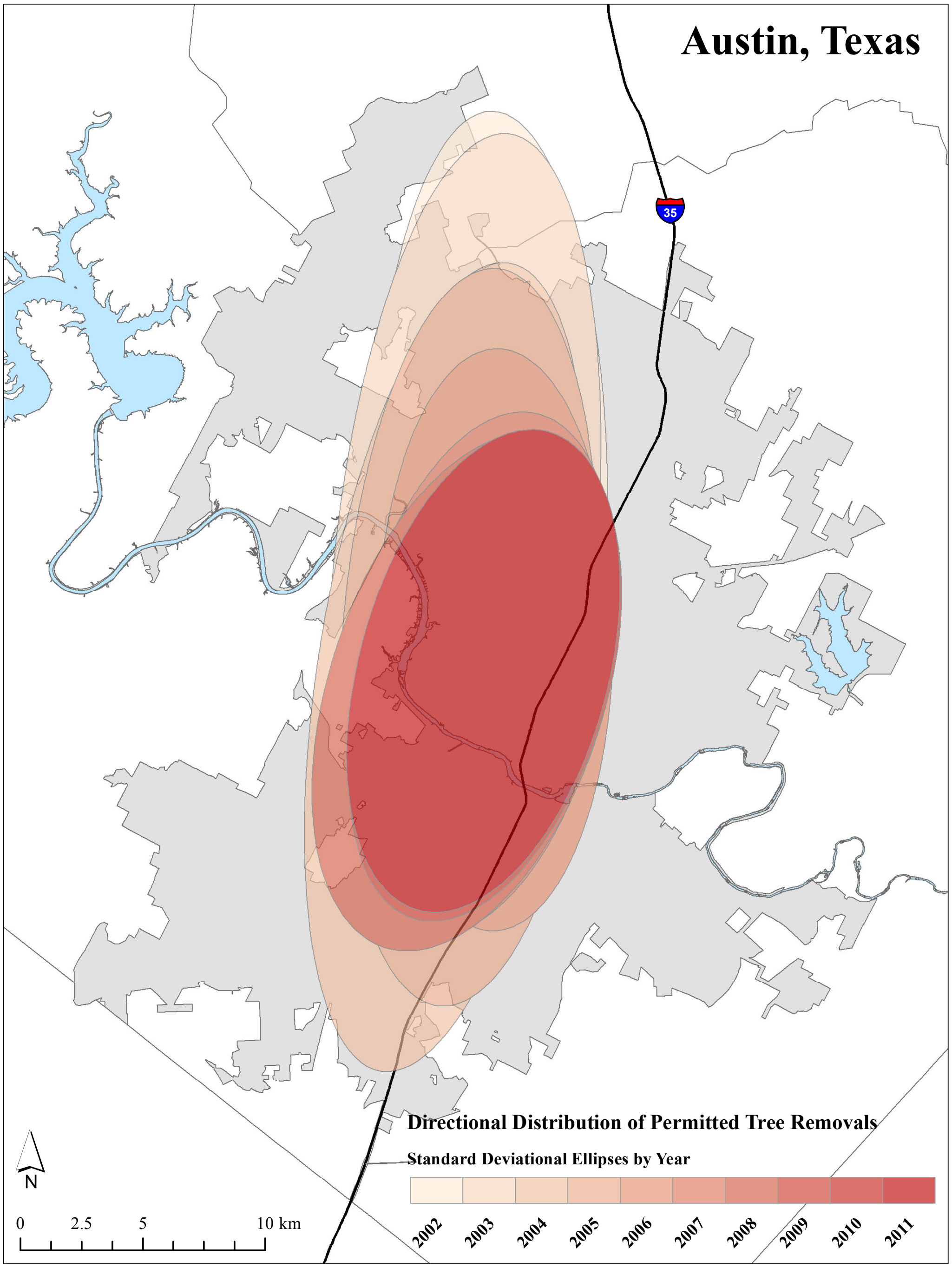


Figure 5. Directional distribution of permitted tree removals in Austin, Texas, from 2002 to 2011.

Instances of tree removal over the entire ten-year study period were aggregated to the U.S. Census block group level and hot spot analysis was performed on three categories of tree removals: 1) all tree removals, 2) development-related tree removals, and 3) nondevelopment-related tree removals.

Results of the hot spot analysis for all tree removals from 2002 to 2011 indicate a statistically significant clustering of high instances of tree removals in and around Austin's urban core, as well as a statistically significant cluster of high instances of tree removals in the city's northern periphery (see Figure 6). Statistically significant cold spots, representing low tree removals, exist along two clustered bands north and south of Austin's urban core.

Results of the hot spot analysis for development-related tree removals show statistically significant clusters on the city's northern and southern peripheries, as well as the urban core (see Figure 7). However, in relation to the nondevelopment and all tree removals' hot spot analyses, the southern cold spot band has disappeared. Thus, there is no statistically significant clustering for development-related tree removals, either low or high, across a large swath of southern Austin.

On the other hand, results of the hot spot analysis for nondevelopment-related tree removals from 2002 to 2011 are similar to all tree removals (see Figure 8). However, the urban core hot spot is expanded slightly north and south, and the cold spot bands extend into the northern and southern peripheries of the city.

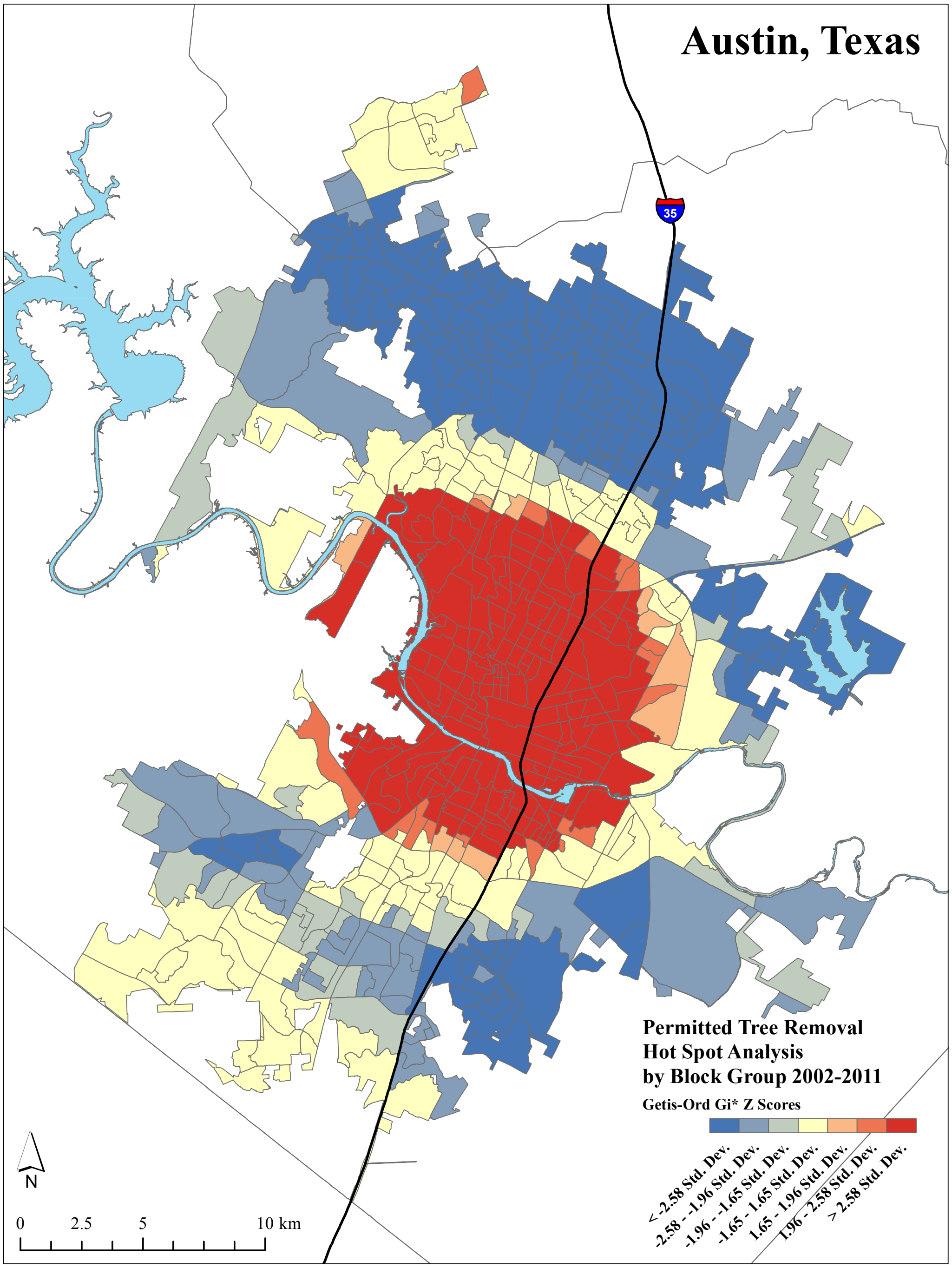


Figure 6. Hot spot analysis of tree removals in Austin, Texas, from 2002 to 2011.

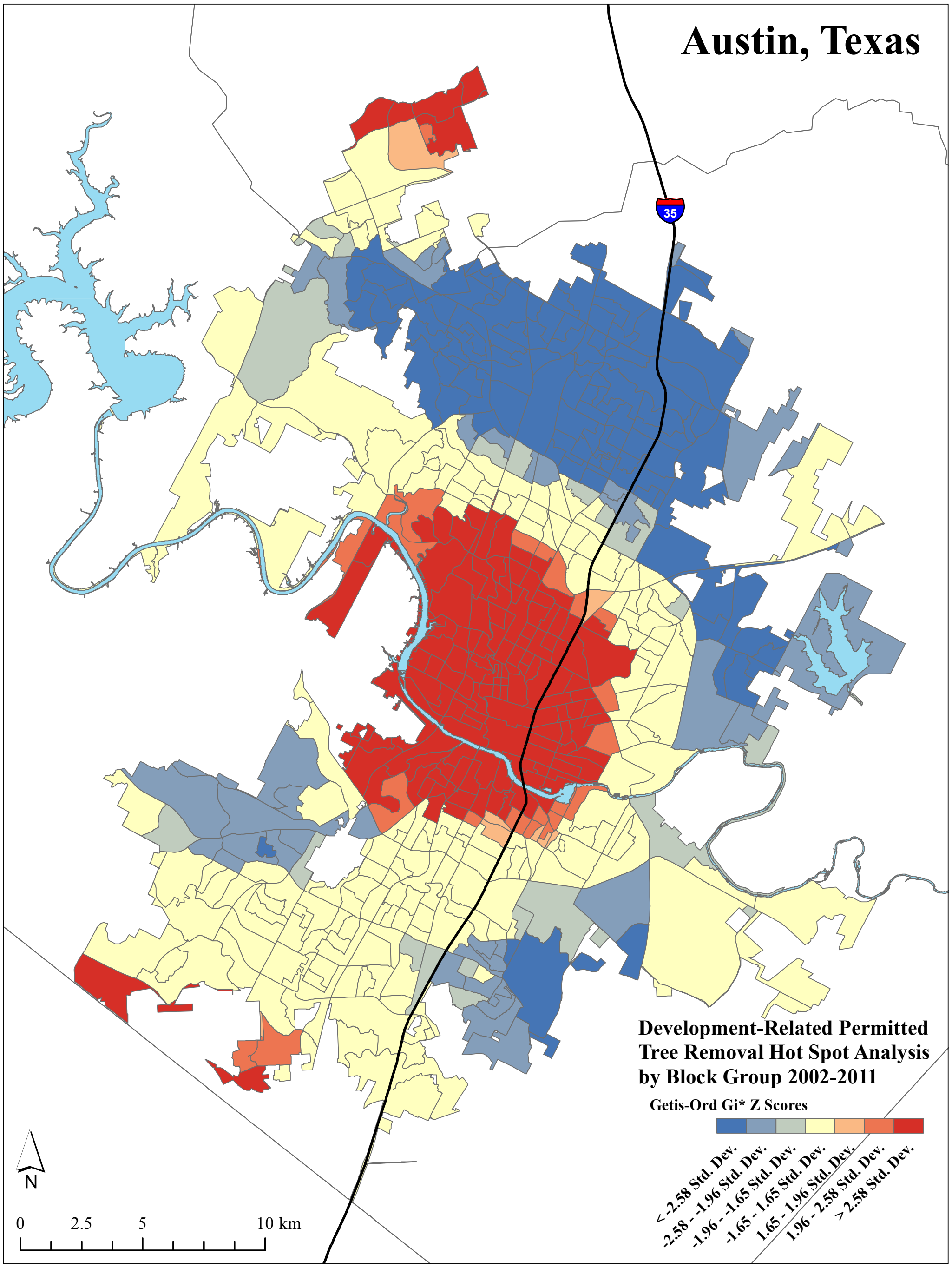


Figure 7. Hot spot analysis of development-related tree removals in Austin, Texas, from 2002 to 2011.

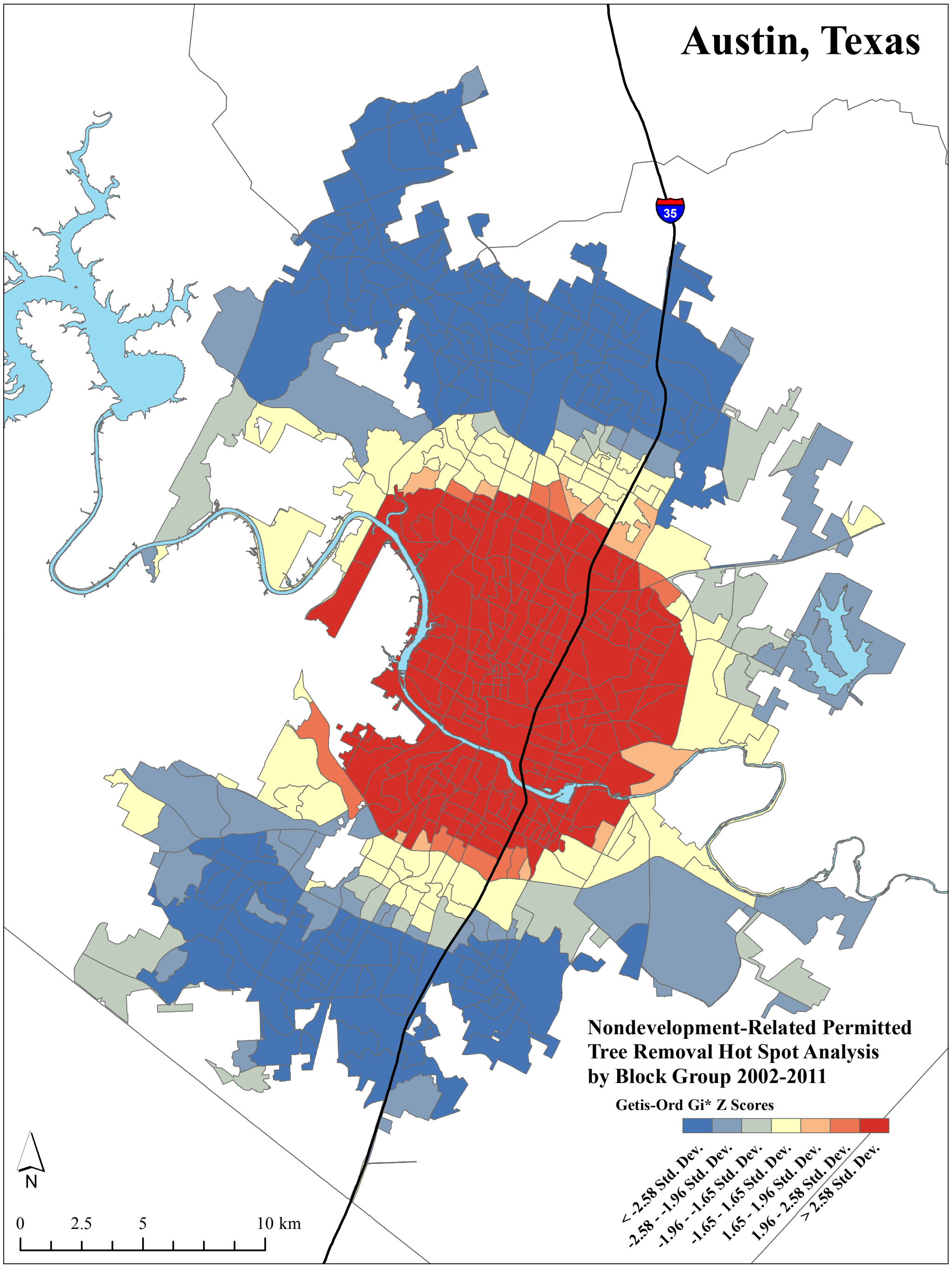


Figure 8. Hot spot analysis of nondevelopment-related tree removals in Austin, Texas, from 2002 to 2011.

Statistical Analysis

To further explore the observed spatiotemporal trends of urban deforestation in Austin, Texas, between 2002 and 2011, statistical analyses were performed on the urban deforestation dataset. First, measures of central tendency and dispersion and frequency distributions were calculated in order to illuminate overall and yearly trends and rates of change for tree removal occurrences relative to their associated physical, urban, and socioeconomic landscape characteristics. Next, differences of groups tests were employed to discern whether statistically significant differences occurred between categories of deforestation related to urban, physical, and socioeconomic landscape characteristics at the block group level. The nonparametric Kruskal-Wallis H Test was used to assess the difference between block groups with high, medium, and low urban deforestation and the 13 operationalized variables related to the physical, urban, and socioeconomic neighborhood landscape characteristics. Statistically significant results from the Kruskal-Wallis H Test were subjected to a post-hoc analysis using the Mann-Whitney U Test in order to determine between which categorical groups the difference occurred. Finally, multinomial logistic regression was used to uncover the probability of belonging to high, medium, or low deforestation block groups based on the operationalized variables.

Frequency and Descriptive Analysis of Permitted Tree Removals

Results of the frequency and distribution analysis indicate an overall increase in tree removals over the study period (see Table 2). The city approved 93 applications in 2002 and 1,258 applications in 2011. This represents a 125 percent increase in tree removals from 2002 to 2011, and a growth rate of 30 percent over the ten-year study period. The increase and growth rate of tree removals corresponds to an overall rise in the number of tree removal applications received by the City of Austin from 2002 to 2011 (see Table 2). In 2002, the city received 99 applications, and in 2011, the city received 1,643 applications.

An evaluation of the yearly rates of change for tree removals portrays similar increases. Yearly rates of change range from 15 percent to 77 percent (see Table 3). The only outlier is 2009, where there was a 17 percent decrease from 2008. Tree removals rebounded in 2010 with a 77 percent increase from 2009. On average, the yearly rate of change for tree removal over the ten-year study period was 37 percent.

Percentages of development-related tree removals remained relatively stable between 2002 and 2008, averaging 56 percent of the total approved tree removals. Recent years have seen a decrease in development-related tree removals. For years 2009, 2010, and 2011, development-related permits averaged 35 percent of the total approved tree removals. Nondevelopment-related permits are related inversely to development related permits and averaged 44 percent of the total tree removals. Nondevelopment-related permits remained relatively low and steady between 2002 and 2008 and surged in 2009, 2010, and 2011, making up 65 percent of total tree removals.

A majority of tree removals is associated with residential land uses. Approximately 70 percent of all approved tree removals were associated with single family and duplex residences, whereas mobile homes, large-lot single family, and multi-family residences represented six percent of all approved tree removals. The remaining 24 percent of approved tree removals were associated with nonresidential land uses, which include commercial, office, industrial, resource extraction, civic, open space, transportation, streets and roads, utilities, and undeveloped land uses. Of the nonresidential land uses, undeveloped land (37 percent), open space (17 percent), office (12 percent), and commercial parcels (11 percent) accounted for the majority of approved tree removals.

Tree removals associated with residential and nonresidential land uses varied over the ten-year study period with distinct peaks and valleys. Tree removals on residential parcels peaked over the years 2003, 2004, and 2005. In those years, tree removals on residential parcels accounted for 85 percent, 89 percent, and 80 percent of all tree removals. The following years—2006 to 2008—saw tree removals on residential parcels decline, but increase again from 2009 to 2011. The years 2007 and 2008 had the lowest percentage of tree removals on residential parcels—69 percent and 66 percent, respectively. At the same time, tree removals on nonresidential parcels peaked in 2007 and 2008. In those years, tree removals on nonresidential parcels accounted for 28 percent, 31 percent, and 34 percent of all tree removals. The percentage of all tree removals on nonresidential parcels were lowest from 2003 to 2005, and after their peak, tree removals on nonresidential parcels declined from 2009 to 2011.

Tree removals in relation to their proximity to major roads are consistent across the ten-year study period. The overall median distance was 250 meters from tree removals to major roads, with a rate of change from 2002 to 2011 of one percent. The maximum distance from tree removals to major roads occurred in 2010 and was 1,760 meters. The minimum distance, recorded in 2010, was 0.3 meters.

The median age of structures (relative to the ending year of this research, i.e., 2011) on parcels where tree removals took place increased over the ten-year study period, with a 19 percent rate of change from 2002 to 2011. The overall median age of structures for the ten-year study period is 48 years old, which corresponds to a build year of 1963. The maximum age of a structure associated with a tree removal occurred in 2009 and was 136 years old or built in 1875. The minimum age of a structure associated with a tree removal, recorded in 2011, was zero or built in the same year.

The median market value of parcels where tree removals took place varied over the ten-year study period, with peaks in 2002 and in 2006, 2007, and 2008, and a negative three percent rate of change from 2002 to 2011. The overall median market value for the ten-year study period was $327,410. The maximum market value of a parcel where a tree was removed occurred in 2011 and was $318,757,790. The minimum market value of a parcel where a tree was removed, recorded in 2009, was $300.

Tree removals relative to percent slope have declined slightly over the ten-year study period. The overall median slope for tree removals was 1.2 percent, with a negative two percent rate of change from 2002 to 2011. The maximum slope for a tree removal occurred in 2007 and was 12.2 percent. The minimum slope, also recorded in 2007, was zero percent or flat.

Tree removals in relation to their distance to hydrologic features—creeks, stream, rivers, and lakes—are consistent across the ten-year study period. The overall median was 145 meters from tree removals to hydrologic features, with no discernible rate of change from 2002 to 2011. The maximum distance from a tree removal to a hydrologic feature occurred in 2009 and was 849 meters. The minimum distance, recorded in 2007, was 0.1 meters.

A majority of tree removals occurred topologically north of the Colorado River system, which includes Lakes Travis, Austin, and Lady Bird, and the Colorado River, and west of Interstate 35, compared to trees removed in south and east Austin, respectively (see Table 2). The average percentage of tree removals for north Austin over the ten-year study period is 70 percent of the total approved tree removals, and the average percentage of tree removals for west Austin is 83 percent.

Table 2. Results of the frequency and descriptive analysis of tree removals in Austin, Texas, from 2002 to 2011.

		2002	2003	2004	2005
Applications		98	160	251	451
Denied Applications		3	4	24	50
Approved Applications		93	153	223	388
Development Related		51	82	139	221
Nondevelopment Related		42	71	84	167
Residential		69	130	198	309
Non-residential		24	23	25	79
North		78	111	132	257
South		15	42	91	131
East		19	19	24	58
West		74	134	199	330
Proximity to	**Mean**	165	154	180	168
Hydrologic Features*[1]	**Median**	148	135	144	145
	Mode	201	.	107	201
	Range	568	523	670	669
	Variance	17,459	11,318	16,818	15,015
	SD	132	106	130	123
Percent Slope*	**Mean**	1.09%	1.26%	1.17%	1.17%
	Median	1.06%	1.12%	0.90%	1.01%
	Mode	1.23%	.	1.01%	1.23%
	Range	3.00%	6.00%	6.00%	7.00%
	Variance	0.62%	1.17%	1.01%	1.06%
	SD	0.79%	1.08%	1.01%	1.03%
Proximity to	**Mean**	298	354	324	335
Major Roads*[1]	**Median**	238	279	290	278
	Mode	132	.	492	132
	Range	1,364	1,608	1,586	1,562
	Variance	76,587	85,984	57,162	71,519
	SD	276	293	240	267
Age of Structure[2]**	**Mean**	30	28	27	31
	Median	10	8	7	19
	Mode	9	8	7	6
	Range	88	82	89	98
	Variance	741	755	722	825
	SD	27	27	27	29
Market Value*[3]**	**Mean**	$1,005,986	$590,207	$541,353	$738,504
	Median	$372,687	$301,181	$279,998	$340,028
	Mode	$5,633,397	$206,768	$208,461	$235,000
	Range	$9,305,624	$5,545,257	$6,390,093	$9,868,806
	Variance	$2,900,000,000,000	$840,000,000,000	$632,500,000,000	$1,596,000,000,000
	SD	$1,703,029	$916,496	$795,299	$1,263,189

Table 2 continued. Results of the frequency and descriptive analysis of tree removals in Austin, Texas, from 2002 to 2011.

		2006	2007	2008	2009
Applications		624	739	822	673
Denied Applications		65	78	67	23
Approved Applications		551	632	726	602
Development Related		262	377	425	209
Nondevelopment Related		289	255	301	393
Residential		395	435	476	435
Non-residential		156	197	250	167
North		402	443	469	409
South		149	189	257	193
East		129	111	119	119
West		422	521	607	483
Proximity to	**Mean**	165	174	164	171
Hydrologic Features*[1]	**Median**	143	158	132	148
	Mode	275	96	183	201
	Range	712	606	710	844
	Variance	13,801	15,688	16,424	15,873
	SD	117	125	128	126
Percent Slope*	**Mean**	1.18%	1.20%	1.16%	1.20%
	Median	0.88%	0.89%	0.91%	0.90%
	Mode	0.71%	0.70%	2.47%	1.23%
	Range	10.00%	12.00%	11.00%	8.00%
	Variance	1.33%	1.55%	1.37%	1.45%
	SD	1.15%	1.25%	1.17%	1.20%
Proximity to	**Mean**	278	309	297	276
Major Roads*[1]	**Median**	222	248	244	213
	Mode	174	41	129	132
	Range	1,353	1,481	1,505	1,481
	Variance	52,209	64,350	63,218	56,830
	SD	228	254	251	238
Age of Structure[2]**	**Mean**	36	33	37	44
	Median	42	38	43	51
	Mode	5	3	3	1
	Range	91	99	99	97
	Variance	829	842	872	718
	SD	29	29	30	27
Market Value*[3]**	**Mean**	$1,456,744	$1,518,033	$802,173	$749,639
	Median	$348,792	$366,454	$372,387	$351,918
	Mode	$235,000	$500,000	$235,000	$235,000
	Range	$61,682,967	$96,033,046	$9,990,966	$9,605,147
	Variance	$23,990,000,000,000	$43,240,000,000,000	$1,916,000,000,000	$1,506,000,000,000
	SD	$4,898,128	$6,575,989	$1,384,145	$1,227,032

Table 2 continued. Results of the frequency and descriptive analysis of tree removals in Austin, Texas, from 2002 to 2011.

		2010	2011	2002 to 2011
Applications		1,227	1,369	6,414
Denied Applications		70	26	410
Approved Applications		1,067	1,258	5,693
Development Related		331	504	2,601
Nondevelopment Related		736	754	3,092
Residential		843	1,012	4,302
Non-residential		224	246	1,391
North		747	876	3,924
South		320	382	1,769
East		201	241	1,040
West		866	1,017	4,653
Proximity to Hydrologic Features*[1]	**Mean**	169	172	169
	Median	144	148	145
	Mode	170	8	275
	Range	648	661	849
	Variance	14,826	14,967	15,203
	SD	122	122	123
Percent Slope*	**Mean**	1.16%	1.14%	1.19%
	Median	0.88%	0.84%	0.89%
	Mode	2.04%	0.78%	0.71%
	Range	10.00%	12.00%	12.20%
	Variance	1.43%	1.39%	1.22%
	SD	1.19%	1.18%	1.10%
Proximity to Major Roads*[1]	**Mean**	312	335	310
	Median	254	271	250
	Mode	730	575	174
	Range	1,760	1,595	1,759
	Variance	67,056	69,808	65,313
	SD	259	264	256
Age of Structure[2]**	**Mean**	47	51	43
	Median	56	55	48
	Mode	1	61	3.00
	Range	96	121	136.00
	Variance	657	548	846.00
	SD	26	23	29.00
Market Value*[3]**	**Mean**	$652,898	$1,310,508	$1,481,884
	Median	$317,740	$280,751	$327,441
	Mode	$235,000	$235,000	$235,000
	Range	$7,795,053	$318,757,290	$318,757,490
	Variance	$1,134,000,000,000	$111,300,000,000,000	$62,600,000,000,000
	SD	$1,065,054	$10,551,539	$7,913,039

*N = 5693; **N = 4700; ***N = 5346

[1]Meters; [2]Years; [3]USD

Table 3. Rates of change of tree removals in Austin, Texas, from 2002 to 2011.

		Rate of Change										
		2002 to 2003	2003 to 2004	2004 to 2005	2005 to 2006	2006 to 2007	2007 to 2008	2008 to 2009	2009 to 2010	2010 to 2011	2002 to 2011	Compound Growth Rate
Applications		63.27%	56.88%	79.68%	38.36%	18.43%	11.23%	-18.13%	82.32%	11.57%	129.69%	30%
Denied Applications		33.33%	500.00%	108.33%	30.00%	20.00%	-14.10%	-65.67%	204.35%	-62.86%	76.67%	24%
Approved Applications		64.52%	45.75%	73.99%	42.01%	14.70%	14.87%	-17.08%	77.24%	17.90%	125.27%	30%
Development Related		60.78%	69.51%	58.99%	18.55%	43.89%	12.73%	-50.82%	58.37%	52.27%	88.82%	26%
Nondevelopment Related		69.05%	18.31%	98.81%	73.05%	-11.76%	18.04%	30.56%	87.28%	2.45%	169.52%	33%
Residential		88.41%	52.31%	56.06%	27.83%	10.13%	9.43%	-8.61%	93.79%	20.05%	136.67%	31%
Non-residential		-4.17%	8.70%	216.00%	97.47%	26.28%	26.90%	-33.20%	34.13%	9.82%	92.50%	26%
North		42.31%	18.92%	94.70%	56.42%	10.20%	5.87%	-12.79%	82.64%	17.27%	102.31%	27%
South		180.00%	116.67%	43.96%	13.74%	26.85%	35.98%	-24.90%	65.80%	19.38%	244.67%	38%
East		0.00%	26.32%	141.67%	122.41%	-13.95%	7.21%	0.00%	68.91%	19.90%	116.84%	29%
West		81.08%	48.51%	65.83%	27.88%	23.46%	16.51%	-20.43%	79.30%	17.44%	127.43%	30%
Proximity to	**Mean**	18.75%	-8.62%	3.63%	-17.11%	11.05%	-3.72%	-7.04%	12.75%	7.52%	1.23%	1%
Major Roads	**Median**	17.20%	4.03%	-4.12%	-20.03%	11.70%	-1.85%	-12.62%	19.40%	6.66%	1.41%	1%
Proximity to	**Mean**	-6.32%	16.57%	-6.46%	-2.02%	5.41%	-5.77%	4.08%	-0.64%	1.31%	0.42%	0%
Hydrologic Features	**Median**	-8.83%	7.06%	0.80%	-1.32%	10.41%	-16.54%	11.88%	-2.62%	3.07%	0.04%	0%
Percent Slope	**Mean**	15.60%	-7.14%	0.00%	0.85%	1.69%	-3.33%	3.45%	-3.33%	-1.72%	0.46%	0%
	Median	5.81%	-19.84%	12.18%	-12.98%	1.37%	1.76%	-1.34%	-1.56%	-5.20%	-2.13%	-2%
Age of Structure	**Mean**	-6.77%	-2.59%	13.44%	17.97%	-7.70%	10.46%	19.54%	6.57%	9.22%	7.24%	6%
	Median	-20.00%	-12.50%	171.43%	121.05%	-9.52%	13.16%	18.60%	9.80%	-1.79%	45.00%	19%
Market Value	**Mean**	-41.33%	-8.28%	36.42%	97.26%	4.21%	-47.16%	-6.55%	-12.91%	100.72%	3.03%	3%
	Median	-19.19%	-7.03%	21.44%	2.58%	5.06%	1.62%	-5.50%	-9.71%	-11.64%	-2.47%	-3%

Frequency and Descriptive Analysis of Deforestation Categories

In order to further explore tree removals in Austin, Texas, permitted tree removals and their associated landscape characteristics were aggregated at the U.S. Census block group level. Using Jenks Natural Breaks, block groups were classified into three deforestation categories—low, medium, and high (see Figure 9). The low deforestation category consists of 341 block groups with tree removals ranging from one to 14 per block group. The medium deforestation category consists of 83 block groups with tree removals ranging from 15 to 38 per block group. The high deforestation category consists of 36 block groups with tree removals ranging from 39 to 93 per block group. These categories were explored through frequency and descriptive analysis relative to their corresponding landscape characteristics. The landscape characteristics of tree removals were aggregated to the block group level by taking the median percent slope, median market value, median age of structure, median distance to major roads and hydrologic features, and the mode general land use for each block group. The remaining landscape characteristics—educational attainment, median income, population density, percent white population, and percent owner occupied—were extracted at the block group level from American Community Survey data.

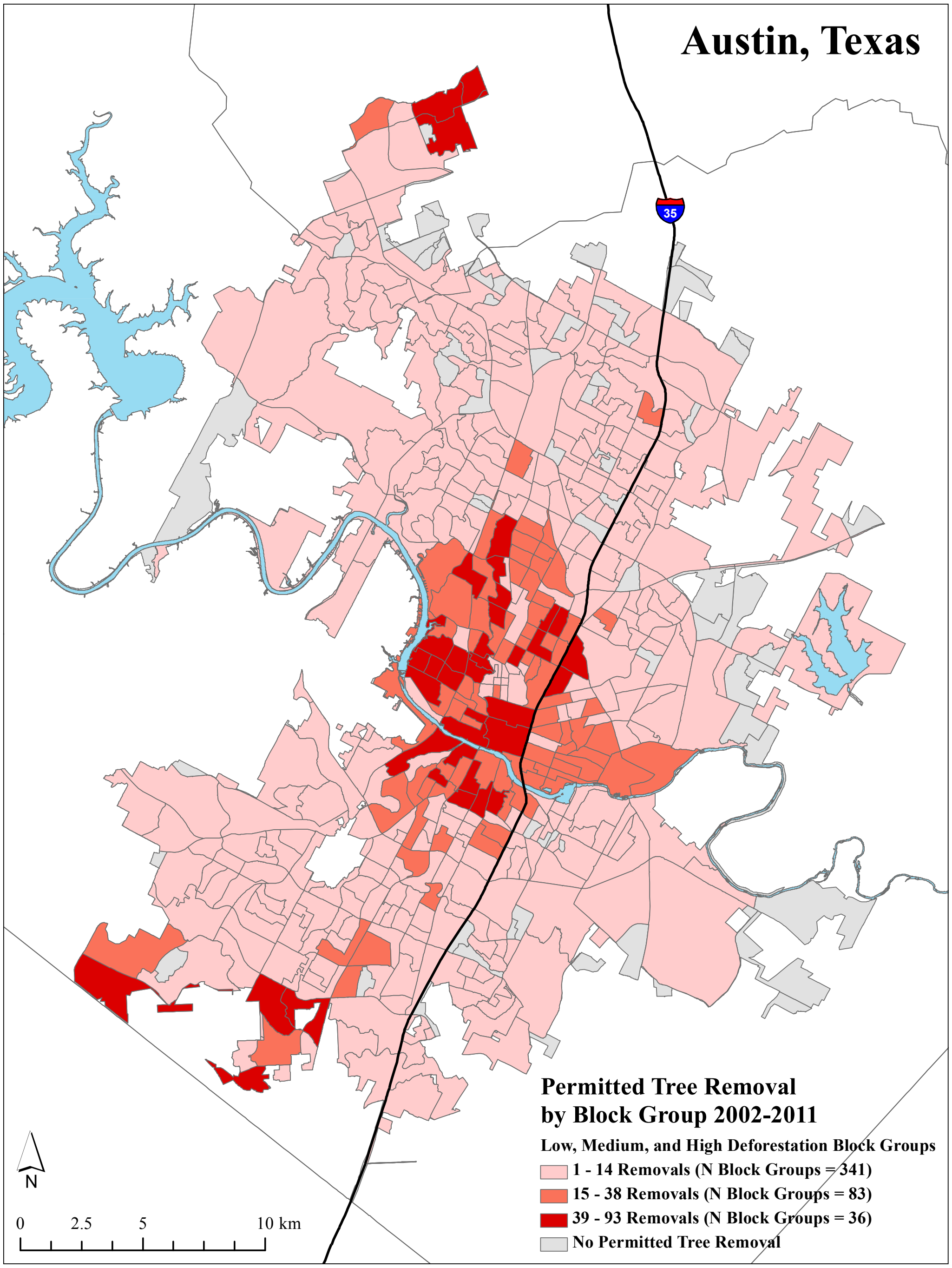


Figure 9. Low, medium, and high deforestation categories.

The results of the descriptive and frequency analysis for each of the deforestation categories are presented in Table 4. General interpretation of the median values of the results indicates that proximity to major roads is greatest for the low deforestation category compared to the high and medium categories. The low deforestation category also has younger structures than the high and medium categories. Median market value decreases from high to low across the categories, as does percent white and percent college graduate. Median income and percent owner occupied is greatest for the high deforestation category, and population density is lowest for the low deforestation category.

Table 4. Results of descriptive and frequency analysis for low, medium, and high deforestation categories at the block group level.

Variable		High	Medium	Low
Block Groups (N)		36	83	341
Residential		30	79	273
Nonresidential		6	4	149
East		2	21	103
West		34	62	238
South		10	24	149
North		26	59	192
Proximity to	**Mean**	173.96	143.50	174.58
Hydrologic Features[1]	**Median**	166.91	120.07	164.39
	Mode	.	.	.
	Range	286.97	502.51	474.90
	Variance	7,548.65	8,345.71	10,190.31
	SD	86.88	91.35	100.95
Percent Slope	**Mean**	1.14%	0.99%	1.21%
	Median	1.10%	0.82%	0.91%
	Mode	.	.	.
	Range	2.27%	3.58%	6.59%
	Variance	0.39%	0.37%	1.15%
	SD	0.62%	0.61%	1.07%
Proximity to	**Mean**	273.46	288.96	366.41
Major Roads[1]	**Median**	232.36	227.75	312.92
	Mode	.	.	.
	Range	580.10	950.18	1,423.18
	Variance	21,242.11	36,024.19	73,596.97
	SD	145.75	189.80	271.29
Age of Structure[2]	**Mean**	56.01	57.98	32.53
	Median	62.00	61.00	33.00
	Mode	70.00	61.00	31.00
	Range	93.00	92.00	104.00
	Variance	682.79	424.23	285.38
	SD	26.13	20.60	16.96
Population Density	**Mean**	81.40	106.41	49.69
	Median	83.01	95.60	32.55
	Mode	.	.	0.00
	Range	209.59	412.58	740.59
	Variance	3,201.95	6,903.79	5,472.22
	SD	56.59	83.09	73.97

Table 4 continued. Results of descriptive and frequency analysis for low, medium, and high deforestation categories at the block group level.

Variable		High	Medium	Low
Percent White	**Mean**	87%	78%	68%
	Median	90%	83%	71%
	Mode	.	.	.
	Range	36%	67%	96%
	Variance	83%	236%	293%
	SD	9%	15%	17%
Percent College Graduate	**Mean**	71%	53%	41%
	Median	71%	56%	40%
	Mode	.	.	0%
	Range	65%	83%	100%
	Variance	221%	477%	589%
	SD	15%	22%	24%
Percent Owner Occupied	**Mean**	62%	49%	49%
	Median	58%	45%	51%
	Mode	82%	.	0%
	Range	82%	92%	98%
	Variance	574%	522%	838%
	SD	24%	23%	29%
Median Income[3]	**Mean**	$86,361	$52,201	$57,634
	Median	$79,900	$45,234	$49,452
	Mode	.	.	.
	Range	$139,644	$241,945	$201,406
	Variance	$1,389,138,282	$1,450,236,333	$1,216,240,992
	SD	$37,271	$38,082	$34,875
Market Value[3]	**Mean**	$498,637	$431,361	$2,291,357
	Median	$359,621	$271,768	$220,652
	Mode	.	.	.
	Range	$1,701,194	$5,525,572	$318,757,342
	Variance	$125,237,639,540	$441,428,528,224	$320,778,346,030,722
	SD	$353,889	$664,401	$17,910,286

[1]Meters; [2]Years; [3]USD

Tests of Difference between Deforestation Categories

This research used the Kruskal-Wallis H Test to determine if a statistically significant difference occurred between the high, medium, and low categories of deforestation at the block group level for each predictor variable. If the Kruskal-Wallis H Test confirmed that there was a statistically significant difference between categories of deforestation, a post-hoc Mann-Whitney U Test was used to conclude between which groups the statistically significant difference occurred. Table 5 displays the results of the Kruskal-Wallis H Tests, and Tables 6, 7, and 8 display the results of the post-hoc Mann-Whitney U Tests.

Physical landscape characteristics

Results of the Kruskal-Wallis H Tests indicate that there is a statistically significant difference between categories of deforestation relative to proximity to hydrologic features ($H(2) = 7.952$, $P = 0.019$), but that there is not a statistically significant difference between categories of deforestation relative to percent slope.

Post-hoc Mann-Whitney U Tests suggest that relative to hydrologic features statistically significant differences occur between the low deforestation group and the medium deforestation group ($U = 11{,}434$, $P = 0.007$), and the medium deforestation group and the high deforestation group ($U = 1{,}855$, $P = 0.037$). A comparison of the mean ranks suggests that tree removals within the medium deforestation group are closer to hydrologic features than tree removals in the low deforestation group, and that tree removals within the medium deforestation group are closer to hydrologic features than tree removals in the high deforestation group.

Urban landscape characteristics

Results of the Kruskal-Wallis H Tests on the urban landscape variables indicate that there is a statistical difference for each variable relative to the low, medium, and high categories of urban deforestation. First, the difference between categories of deforestation relative to median age of structure was statistically significant ($H(2) = 114.68$, $P > 0.001$). The Mann-Whitney U Tests confirmed that statistically significant differences occur between the low deforestation group and the medium deforestation group ($U =$

23,838.50, $P < 0.001$), as well as between the low deforestation group and the high deforestation group ($U = 9{,}807$, $P < 0.001$). A comparison of the mean ranks suggests that tree removals within the low deforestation group are associated with newer structures than tree removals in the medium deforestation group and the high deforestation group.

Second, the results of the Kruskal-Wallis H Test indicate that there is a statistically significant difference between categories of deforestation relative to proximity to major roads ($H(2) = 6.728$, $P = 0.035$). Here, the results of the Mann-Whitney U Tests show that the statistically significant difference occurs between the low deforestation group and the medium deforestation group ($U = 11{,}922$, $P = 0.026$). A comparison of the mean ranks suggests that tree removals within the medium deforestation group are closer to major roads than those within the low deforestation group.

Third, the results of the Kruskal-Wallis H Test for land use indicate that there is a statistically significant difference between deforestation categories ($H(2) = 10.819$, $P = 0.004$). Results of the Mann-Whitney U Tests show that statistically significant differences occur between the low deforestation group and the medium deforestation group ($U = 16{,}291.5$, $P = 0.001$), and the medium deforestation group and the high deforestation group ($U = 1{,}317$, $P = 0.033$). A comparison of the mean ranks suggests that tree removals within the medium deforestation group are associated with greater quantities of residential land use than the low deforestation group and the high deforestation group.

The final urban landscape characteristic is population density. The results of the Kruskal-Wallis H Test for population density indicate that there is a statistically significant difference between the low, medium, and high urban deforestation categories (H(2) = 66.091, $P < 0.001$). Results of the Mann-Whitney U Tests show that statistically significant differences occur between the low deforestation group and the medium deforestation group ($U = 21{,}819$, $P < 0.001$), as well as between the low deforestation group and the high deforestation group ($U = 8{,}473$, $P < 0.001$). A comparison of the mean ranks suggests that tree removals within the low deforestation group are associated with lower population densities than tree removals in the medium deforestation group and the high deforestation group.

Socioeconomic landscape characteristics

Results of the Kruskal-Wallis H Tests for the five socioeconomic landscape characteristics indicate that there are statistically significant differences between the urban deforestation categories for each variable. First, for percent white, the Kruskal Wallis H Test was statistically significant (H(2) = 59.202, $P < 0.001$). Results of the Mann-Whitney U Tests show that statistically significant differences occur between the low deforestation group and the medium deforestation group ($U = 19{,}031.50$, $P < 0.001$), as well as between the low deforestation group and the high deforestation group ($U = 10{,}191.50$, $P < 0.001$), and between the medium deforestation group and the high deforestation group ($U = 2{,}028$, $P = 0.002$). A comparison of the mean ranks suggests that tree removals within the medium deforestation group and the high deforestation group have higher percentages of white population than tree removals in the low deforestation group, and that tree removals in the medium deforestation group have a higher percentage of white population than that of the high deforestation group.

Second, the results of the Kruskal-Wallis H Test for percent owner occupancy indicate that there is a statistically significant difference between categories of urban deforestation (H(2) = 6.646, $P = 0.036$). Results of the Mann-Whitney U Tests show that statistically significant differences occur between the low deforestation group and the high deforestation group ($U = 7{,}657.50$, $P = 0.015$), and the medium deforestation group and the high deforestation group ($U = 1{,}940.50$, $P = 0.010$). A comparison of the mean ranks suggests that tree removals within the high deforestation group are associated with greater percentages of owner occupants than tree removals in the low deforestation group and the medium deforestation group.

Third, the results of the Kruskal-Wallis H Test for percent college graduates indicate that there is a statistically significant difference between urban deforestation categories (H(2) = 55.189, $P < 0.001$). Results of the Mann-Whitney U Tests show that statistically significant differences occur between the low deforestation group and the medium deforestation group ($U = 18{,}218$, $P < 0.001$), the low deforestation group and the high deforestation group ($U = 10{,}238$, $P < 0.001$), and the medium deforestation group and the high deforestation group ($U = 2{,}211$, $P < 0.001$). A comparison of the mean ranks suggests that tree removals within the high deforestation group have a statistically significant greater percentage of college graduates than tree removals in the low deforestation group and the medium deforestation group. Mean rank comparisons also suggest that tree removals within the medium deforestation group have a statistically significant greater percentage of college graduates than tree removals in the low deforestation group.

Fourth, the results of the Kruskal-Wallis H Test for median income indicate that there is a statistically significant difference between the low, medium, and high urban deforestation categories (H(2) = 24.383, $P < 0.001$). Results of the Mann-Whitney U Tests show that statistically significant differences occur between the low deforestation group and the high deforestation group ($U = 9{,}070$, $P < 0.001$), and between the medium deforestation group and the high deforestation group ($U = 2{,}292$, $P < 0.001$). A comparison of the mean ranks suggests that tree removals within the high deforestation group have a statistically significant higher median income than tree removals in the low deforestation group. Mean rank comparisons also suggest that tree removals within the high deforestation group have a statistically significant higher median income than tree removals in the medium deforestation group.

Finally, the results of the Kruskal-Wallis H Test for market value indicate that there is a statistically significant difference between categories of urban deforestation (H(2) = 20.638, $P < 0.001$). Results of the Mann-Whitney U Tests show that statistically significant differences occur between the low deforestation group and the medium deforestation group ($U = 16{,}381$, $P = 0.026$), the low deforestation group and the high deforestation group ($U = 8{,}668$, $P < 0.001$), and the medium deforestation group and the high deforestation group ($U = 2050$, $P = 0.001$). A comparison of the mean ranks suggests that tree removals within the high deforestation group have a statistically significant higher market value than tree removals in the low deforestation group and the medium deforestation group. Mean rank comparisons also suggest that tree removals within the medium deforestation group have a statistically significant higher market value than tree removals in the low deforestation group.

Directional landscape characteristics

The final set of variables this research tested centered on the directional location of tree removals: east or west of Interstate 35 and north or south of the Colorado river system, which runs southwest through Austin. The results of the Kruskal-Wallis H Tests for east/west and north/south indicate that there are statistically significant differences between the low, medium, and high deforestation categories (H(2) = 10.148, $P = 0.006$; H(2) = 8.418, $P = 0.015$, respectively). Results of the Mann-Whitney U Tests for east/west show that statistically significant differences occur between the low deforestation group and the high deforestation group ($U = 4{,}625$, $P = 0.002$), and the medium deforestation group and the high deforestation group ($U = 1{,}191$, $P = 0.013$). A comparison of the mean ranks suggests that tree removals within the high deforestation group and that tree removals within the medium deforestation group have a statistically significant greater probability of being located west of Interstate 35 than tree removals within the low deforestation group.

The results of the Mann-Whitney U Tests for north/south indicate that a statistically significant difference occurs between the low deforestation group and the medium deforestation group ($U = 12{,}060$, $P = 0.014$). A comparison of the mean ranks suggests that tree removals within the low deforestation group have a statistically significant greater probability of being located south of the Colorado River system than tree removals within the medium deforestation group.

Table 5. Results of the Kruskal-Wallis H Tests between low, medium, and high deforestation categories (α = 0.05).

Variable	Chi-Square	df	Asymp. Sig.
Proximity to Hydrologic Features	7.952	2	0.019
Percent Slope	1.528	2	0.466
Proximity to Major Roads	6.728	2	0.035
Age of Structure	114.680	2	< 0.001
Residential/Non-residential	10.819	2	0.004
Population Density	66.091	2	< 0.001
Market Value	20.638	2	< 0.001
Median Income	24.383	2	< 0.001
Percent White	59.202	2	< 0.001
Percent Owner Occupied	6.646	2	0.036
Percent College Graduate	55.190	2	< 0.001
East/West	10.148	2	0.006
North/South	8.418	2	0.015

Grouping Variable: Low, Medium, High Deforestation Block Groups

Table 6. Results of the Mann-Whitney U Tests between the low deforestation group and the medium deforestation group (α = 0.05).

Variable	Mean Rank Low	Mean Rank Medium	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Proximity to Hydrologic Features	220.47	179.76	11434	14920	-2.714	0.007
Percent Slope	214.58	203.96	13443	16929	-0.708	0.479
Proximity to Major Roads	219.04	185.64	11922	15408	-2.227	0.026
Age of Structure	184.09	329.21	23838.50	27324.50	9.676	< 0.001
Residential/Non-residential	206.22	238.28	16291.5	19777.5	3.287	< 0.001
Population Density	190.01	304.88	21819	25305	7.658	< 0.001
Market Value	205.96	239.36	16381	19867	2.227	0.026
Median Income	214.88	202.71	13339	16825	-0.812	0.417
Percent White	198.19	271.3	19031.5	22517.5	4.874	< 0.001
Percent Owner Occupied	213.06	210.19	13960	17446	-0.191	0.848
Percent College Graduate	200.57	261.49	18218	21704	4.062	< 0.001
East/West	214.54	204.14	13457.5	16943.5	-0.88	0.379
North/South	218.63	187.3	12060	15546	-2.454	0.014

Grouping Variable: Low (N = 341) and Medium (N = 83) Deforestation Block Groups

Table 7. Results of the Mann-Whitney U Tests between the low deforestation group and the high deforestation group (α = 0.05).

Variable	Mean Rank Low	Mean Rank High	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Proximity to Hydrologic Features	188.62	192.64	6269	6935	0.211	0.833
Percent Slope	187.47	203.5	6660	7326	0.839	0.401
Proximity to Major Roads	191.96	160.97	5129	5795	-1.623	0.105
Age of Structure	178.24	290.92	9807	10473	5.901	< 0.001
Residential/Non-residential	188.41	194.58	6339	7005	0.47	0.638
Population Density	182.15	253.86	8473	9139	3.755	< 0.001
Market Value	181.58	259.28	8668	9334	4.069	< 0.001
Median Income	180.4	270.44	9070	9736	4.715	< 0.001
Percent White	177.11	301.6	10191.5	10857.5	6.519	< 0.001
Percent Owner Occupied	184.54	231.21	7657.5	8323.5	2.444	0.015
Percent College Graduate	176.49	302.89	10238	10904	6.593	< 0.001
East/West	193.44	146.97	4625	5291	-3.134	0.002
North/South	191.87	161.86	5161	5827	-1.837	0.066

Grouping Variable: Low (N = 341) and High (N = 36) Deforestation Block Groups

Table 8. Results of the Mann-Whitney U Tests between the medium deforestation group and the high deforestation group (α = 0.05).

Variable	Mean Rank Medium	Mean Rank High	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Proximity to Hydrologic Features	55.65	70.03	1855	2521	2.088	0.037
Percent Slope	63.55	51.81	1733	2399	1.383	0.167
Proximity to Major Roads	59.42	61.33	1542	2208	0.278	0.781
Age of Structure	59.34	61.51	1548.5	2214.5	0.315	0.752
Residential/Non-residential	62.13	55.08	1317	1983	-2.131	0.033
Population Density	62.77	53.61	1264	1930	-1.331	0.183
Market Value	53.3	75.44	2050	2716	3.217	< 0.001
Median Income	50.39	82.17	2292	2958	4.616	< 0.001
Percent White	53.57	74.83	2028	2694	3.089	0.002
Percent Owner Occupied	54.62	72.4	1940.5	2606.5	2.583	0.010
Percent College Graduate	51.36	79.92	2211	2877	4.148	< 0.001
East/West	63.55	51.81	1199	1865	-2.495	0.013
North/South	60.2	59.53	1477	2143	-0.126	0.9

Grouping Variable: Medium (N = 83) and High (N = 36) Deforestation Block Groups

Multinomial Logistic Regression Analysis

A forward stepwise multinomial logistic regression analysis was conducted to predict the probability of belonging to one of the deforestation categories—low, medium, or high—for the 460 block groups in this study using the operationalized physical, urban, and socioeconomic landscape characteristics as predictor variables. Each of the 13 predictor variables was entered into the multinomial logistic regression in steps. Predictor variables with significance levels less than 0.05 were allowed in the model and stayed in the model as other variables were entered if their significance levels remained less than 0.10. The final multinomial regression model included the following variables: proximity to major roads, age of structure, percent white, percent college graduates, and east.

A test of the final model against a constant only model was statistically significant, suggesting that the set of predictors reliably distinguished between categories of deforestation (X^2 (10, N = 460) = 187.553, $P < .001$). Moreover, cross validation of the results supported the validity of the full model. The Nagelkerke pseudo R^2 indicated that the model accounted for 43.6 percent of the total variance. Overall prediction success for the cases used in the development of this model was generally high, with an overall prediction success rate of 80.2 percent. The prediction rate for the low deforestation category was 96.5 percent. However, the prediction rates for the medium deforestation category and high deforestation category were lower, 36.1 percent and 27.8 percent, respectively. Table 9 presents the regression coefficients (B), the Wald statistics, significance levels, odds ratio [Exp(B)], and the 95 percent confidence intervals (CI) for odds ratios for each predictor. The reference category for the response variable is the low deforestation group.

The Wald test for the high deforestation group relative to the low deforestation group reports that percent college graduates, percent white, proximity to major roads, and age of structure are statistically significant predictors at the 0.05 alpha level. For the medium deforestation group relative to the low deforestation group, the Wald test reports that east, percent white, and age of structure are statistically significant predictors at the

0.05 alpha level. Proximity to major roads is statistically significant at the 0.10 alpha level for the medium deforestation group relative to the low deforestation group.

Among the statistically significant predictors of the high deforestation group relative to the low deforestation group, the odds ratios for percent college graduate, percent white, and age of structure is greater than one, and the odds ratio for proximity to major roads is less than one. Holding all other variables constant, as percent college graduate increases the less likely it is to belong to the low deforestation group and the more likely it is to belong to the high deforestation group. It can be said, then, as the percentage of college graduates increases the more likely there will be high amounts of tree removals. The same is true for percent white and age of structure. As the percentage white population increases the more likely there will be high amounts of tree removals, and as the age of structure increases the more likely there will be high amounts of tree removals. Also, holding all other variables constant, as the proximity of tree removals to major roads increases the more likely it is to belong to the low deforestation group.

Among the statistically significant predictors for the medium deforestation category relative to the low deforestation category at both the 0.05 and 0.10 alpha levels, the odds ratios for east, percent white, and age of structure are greater than one, and the odds ratio for proximity to major roads is less than one. The east variable is a particularly strong predictor. Block groups east of Interstate 35 are almost four times more likely to be in the medium deforestation group than the low deforestation group, holding all other variables constant. Also, it can be said that as percent white and age of structure increase the more likely there will be medium amounts of tree removals. At the 0.10 alpha level, as the proximity of tree removals to major roads increases the more likely it is to belong to the low deforestation group.

These results suggest that medium and high amounts of tree removals in Austin, Texas, from 2002 to 2011, are significantly explained by urban and socioeconomic landscape characteristics and that physical landscape characteristics do not play a significant role in tree removals over the study period.

Table 9. Results of the multinomial logistic regression between low, medium, and high deforestation categories.

Deforestation Groups[a]		B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B) Lower Bound	Upper Bound
High	Intercept	-11.525	2.119	29.583	1	.000			
	Age of Structure	.039	.011	12.407	1	.000	1.040	1.017	1.062
	Proximity to Major Roads	-.002	.001	5.510	1	.019	.998	.996	1.000
	Percent College Graduate	.038	.014	7.819	1	.005	1.039	1.012	1.067
	Percent White	.075	.027	7.707	1	.005	1.078	1.022	1.137
	East	1.131	.931	1.477	1	.224	3.099	.500	19.202
Medium	Intercept	-7.864	1.203	42.717	1	.000			
	Age of Structure	.063	.009	53.215	1	.000	1.065	1.047	1.083
	Proximity to Major Roads	-.001	.001	3.095	1	.079	.999	.998	1.000
	Percent College Graduate	-.003	.009	.108	1	.743	.997	.979	1.016
	Percent White	.051	.016	9.833	1	.002	1.053	1.019	1.087
	East	1.358	.478	8.065	1	.005	3.888	1.523	9.926

a. The reference category is: Low.

CHAPTER VI

CONCLUSION

Urban forests provide environmental, economic, and social services to urban areas. As such, municipalities have sought to capitalize on these services for the betterment of the entire community. Tree ordinances attempt to protect urban forest structure through a set of regulations that provide guidelines for tree removals. However, a host of characteristics influence the dynamic structure of urban forests. Thus, the purpose of this research was to analyze the spatiotemporal trends and geographic patterns of tree removals in Austin, Texas, between 2002 and 2011 in an effort to understand how neighborhood-scale landscape characteristics influence urban deforestation and affect the overall distribution of Austin's urban forest.

This research used a GIS and statistical analyses to help uncover spatiotemporal trends and geographic patterns associated with urban deforestation. The results indicate that permitted tree removals and their associated characteristics in Austin have varied over the ten-year study period. The results also show that many neighborhood landscape characteristics significantly explain the geographic patterns associated with urban deforestation.

Temporally, permitted tree removals have increased from 2002 to 2011, coinciding with an overall increase in applications submitted for tree removals. This increase may be attributed to a growing awareness by property owners of Austin's tree ordinance. Despite being enacted in 1984, the tree ordinance received little public consideration until the proposal and passage of the heritage tree ordinance in 2010. The heritage tree ordinance garnered much attention in the media as developers and environmental groups sought to ease or strengthen the proposed regulations put forward by the city council regarding the removal of heritage trees. Since its passage, varying applications of the heritage tree ordinance has kept the ordinance in the media spotlight. Thus, media coverage may have helped educate Austin's property owners of the rules and regulations pertaining to heritage trees and protected trees.

Over the study period, there has been a shift in the percentages of development- and nondevelopment-related tree removals. At the beginning of the study period, the percentage of tree removals for development reasons was higher than that of tree removals for nondevelopment reasons. At the end of the study period, the percentage of tree removals for nondevelopment reasons had risen markedly. The peak percentage for development-related removals was in 2007, and the peak percentage for nondevelopment related permits was in 2011, suggesting small-scale factors may be at play. The real estate bubble of 2007 coincides with the peak of development-related tree removals. Assuming that nondevelopment-related tree removals are associated with dead or dying trees, increases in nondevelopment-related tree removals over the years 2008 to 2011 may be the result of extreme heat and severe drought.

Spatially, permitted tree removals were found to exhibit distinct geographic patterns. Results of the directional distribution analysis indicate increasing concentration of tree removals in and around the urban core over the years of the study. This concentration could be indicative of a number of factors. After the real estate housing bubble of 2007, new development began to slow along the urban peripheries. At the same time, urban revitalization efforts near to the city core, while diminishing after 2007, were still a focus of the City of Austin and property owners. How these factors translate into tree removals is not known; however, development and renewal projects may necessitate the removal of trees both live and dead.

The results of the hot spot analysis display the significant hot and cold areas of tree removals. As the results indicate, tree removals spatially cluster around the urban core and city peripheries. Moreover, development-related tree removals cluster along the city’s north and south peripheries and the urban core, whereas nondevelopment-related tree removals cluster more around the urban core. As with the directional distribution analysis, possible factors influencing these hot spots might include urban revitalization efforts in the urban core and new development along the urban peripheries. Also, structures in the urban core generally house the oldest structures in a city. As such, trees in the urban core tend to be older than trees elsewhere in the city. The significant cluster of nondevelopment-related tree removals in the urban core could be a result of older, dying or dead trees.

The results of the statistical tests and regression analysis further illuminated the geographic patterns by highlighting statistically significant explanatory landscape characteristics of permitted tree removal in Austin from 2002 to 2011. Results of the Kruskal-Wallis H Tests and post-hoc Mann-Whitney U Tests indicate statistically significant differences between low, medium, and high categories of deforestation relative to neighborhood landscape characteristics. Moreover, results of the multinomial logistic regression analysis indicate that certain neighborhood landscape characteristics significantly explain urban deforestation.

According to the statistical tests of difference between categories, physical, urban, and socioeconomic landscape characteristics differ significantly between low, medium, and high deforestation groups. The high deforestation group has higher percentages of white populations, college graduates, and owner occupants compared to the low deforestation group. The high deforestation group also has higher median incomes and market values compared to the low deforestation category. Greater population density and older structures are found in the high deforestation group compared to the low deforestation group. Comparison of the medium deforestation group to the low deforestation group exhibits some of the same differences. Owner occupied housing and median income are not significant, but proximity to roads and hydrologic features are statistically significant between the low and medium deforestation groups. The tree removals in the medium deforestation group are farther from major roads and hydrologic features than tree removals in the low deforestation group.

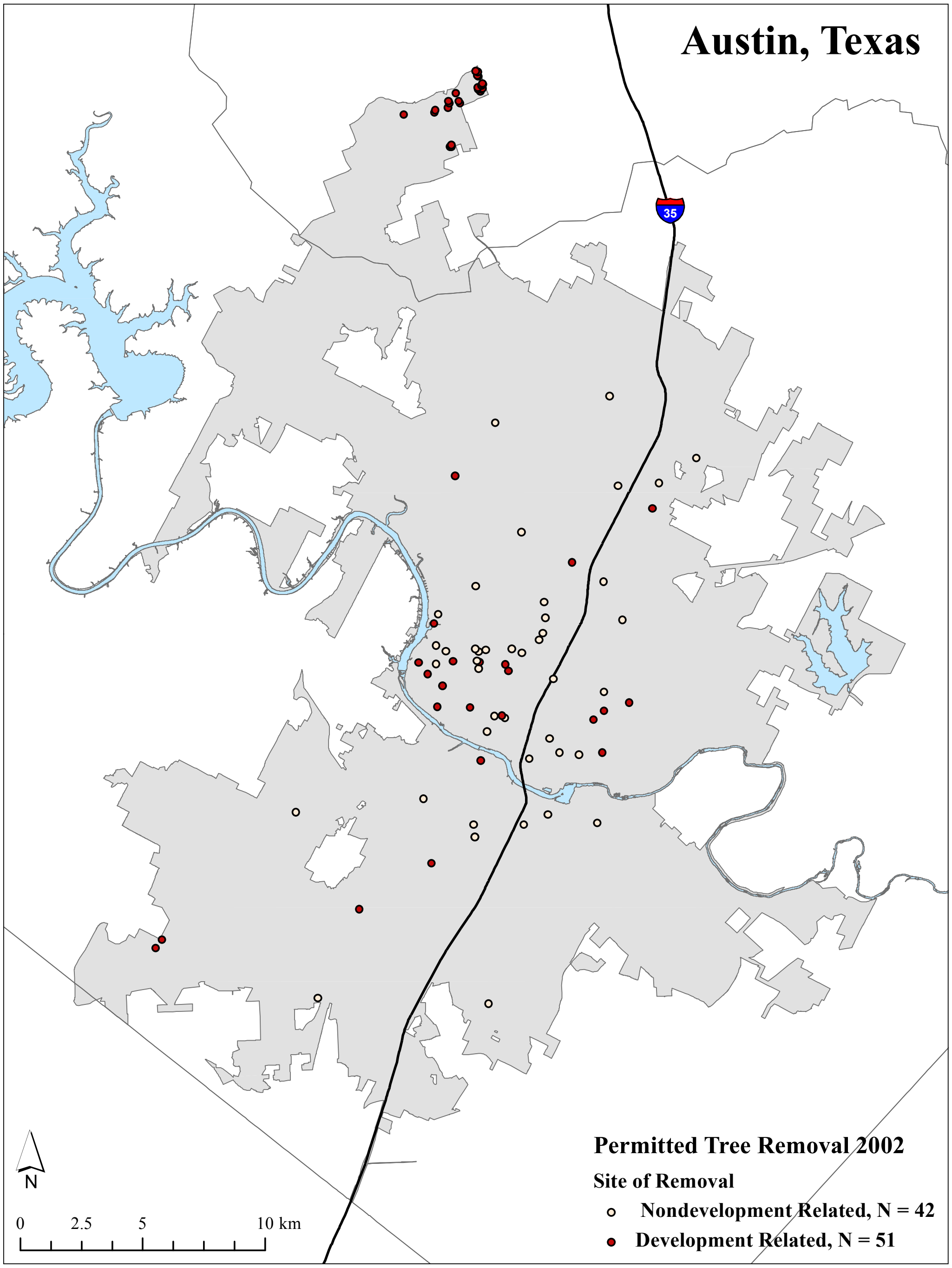
Moreover, the results of the regression analysis indicate that neighborhoods with high percentages of college graduates and white population are most likely to belong to the high deforestation group than the low deforestation group. The results also show that structures are older in the medium and high deforestation groups relative to the low deforestation group, and that tree removals are closer to major roads in the high and medium deforestation groups.

Taken all together, the results of this research suggest that tree removal is a result of the various physical, urban, and socioeconomic landscape characteristics. It shows where, who, and to some extent, why, Austinites are removing protected trees. However, there also seem to be small-scale factors that may influence tree removals in Austin, Texas. Future research into these factors would expand on this research, creating a larger picture of the geography of urban deforestation. Understanding both the large-scale and small-scale factors that affect the distribution of urban forests will continue to be important as urban areas grow.

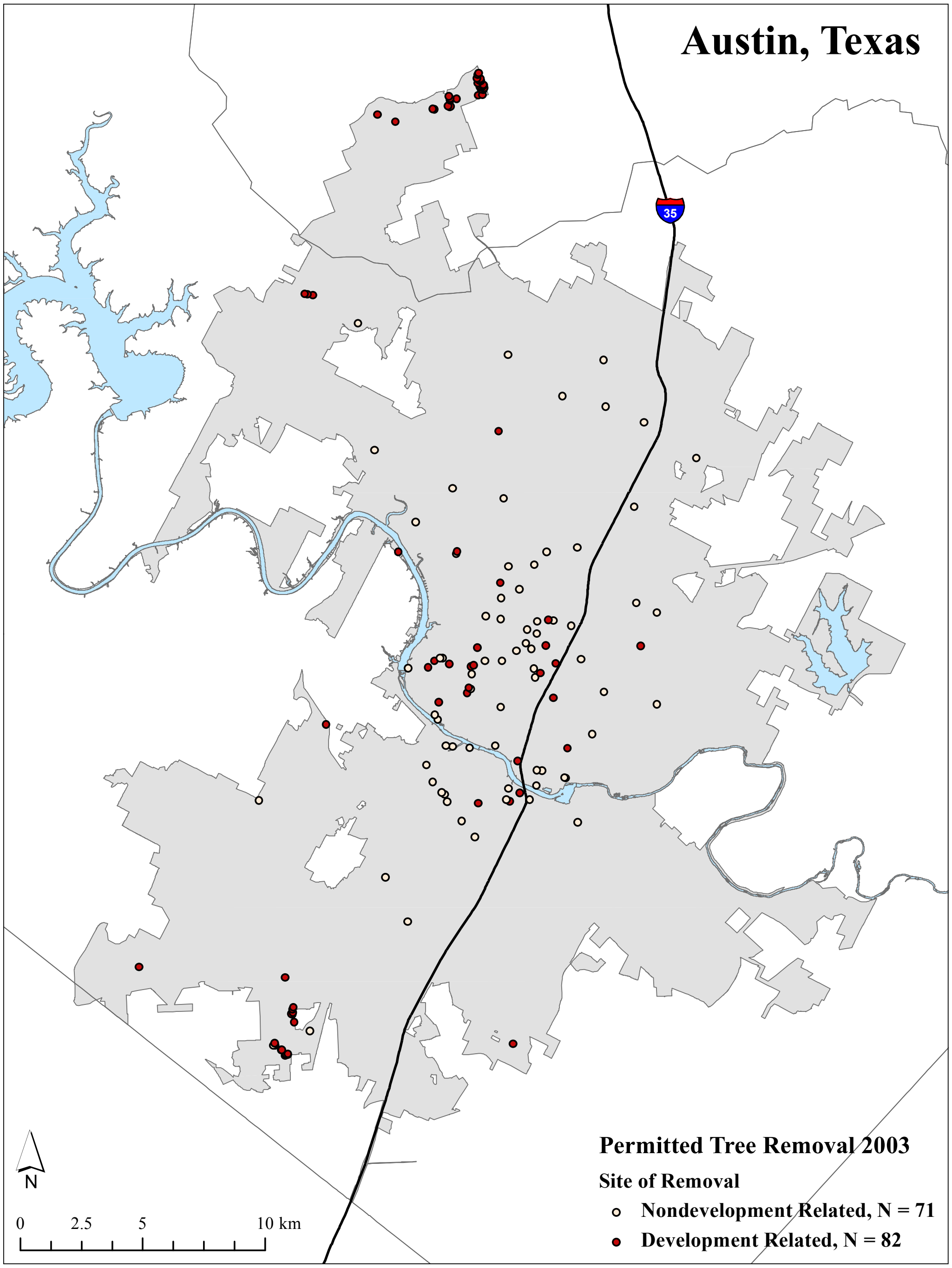
The Austin area is one of the fastest growing areas in the United States. Between 2000 and 2010, the Austin urban area grew 51 percent, and its land area increased by 64 percent (U.S. Census Bureau 2012). In order to the meet the increasing urban growth, continued expansion and development are occurring. As Austin continues to grow, the efforts of citizens, non-profit organizations, and government regulations and programs are essential to protecting urban trees and to maintaining the services they provide. Moreover, urbanization continues across the United States. The results of this research provide urban forest managers in Austin with information on the location and intensity of tree removals, as well as the socioeconomic and urban landscape characteristics that significantly explain tree removals. More broadly, the results of this research provide urban forest researchers and other major metropolitan areas with a geographic understanding of the neighborhood-scale landscape characteristics associated with urban deforestation.

APPENDIX A

MAPS OF PERMITTED TREE REMOVALS, 2002-2011



Austin, Texas
35
Permitted Tree Removal 2002
Site of Removal
Nondevelopment Related, N = 42
Development Related, N = 51
N
0
2.5
5
10 km



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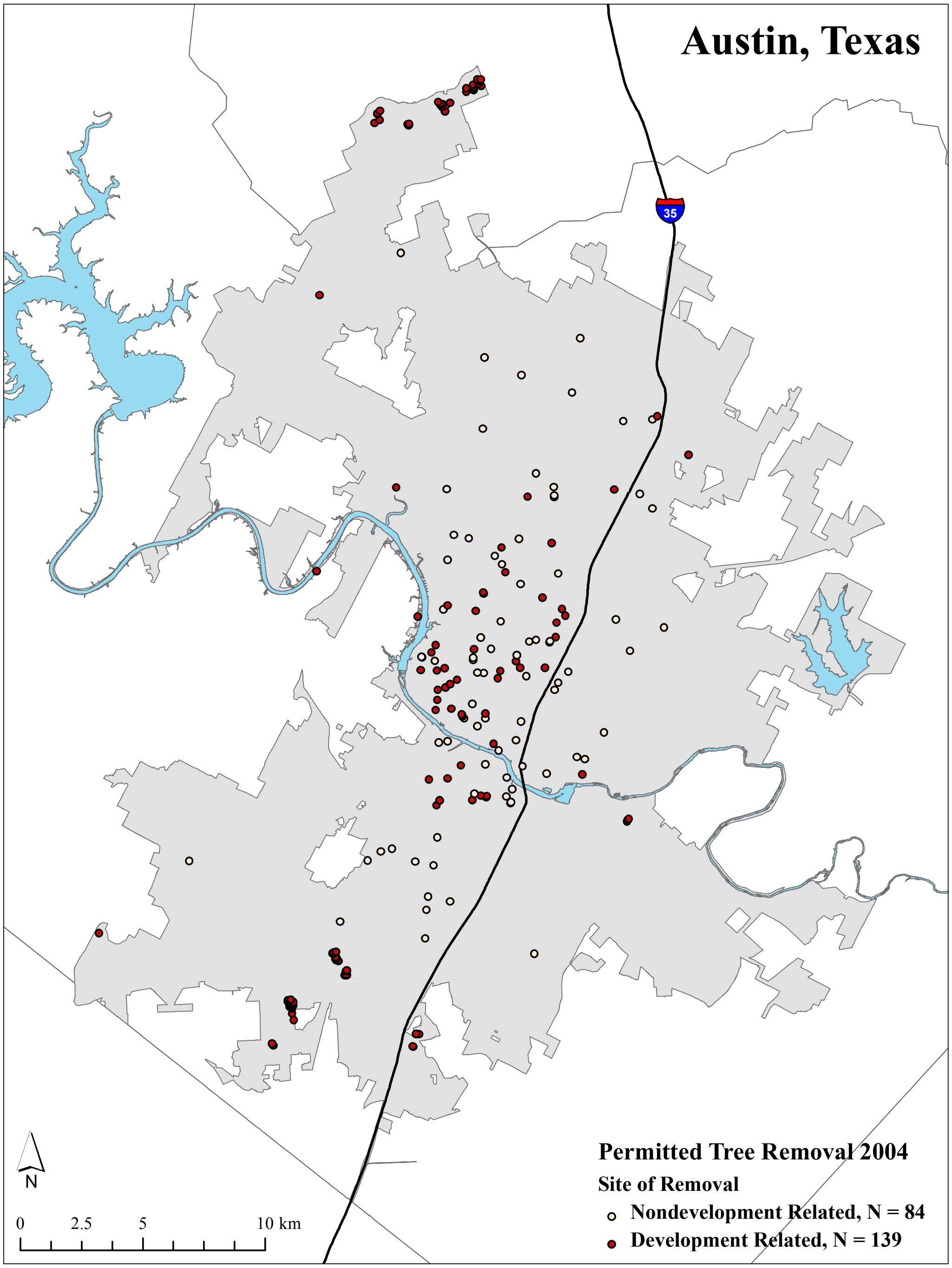
35
Permitted Tree Removal 2003
Site of Removal
Nondevelopment Related, N = 71
Development Related, N = 82
N
0
2.5
5
10 km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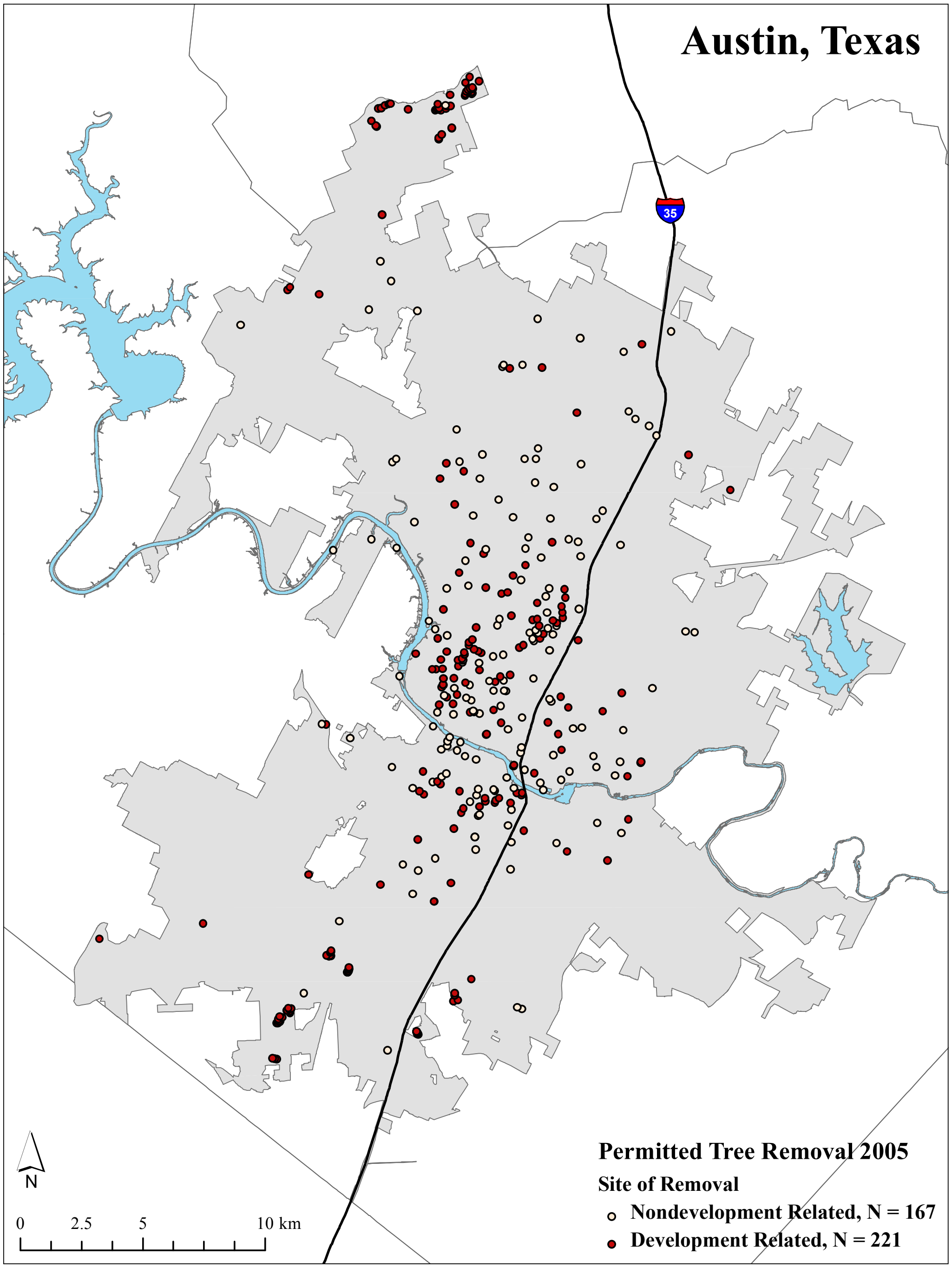
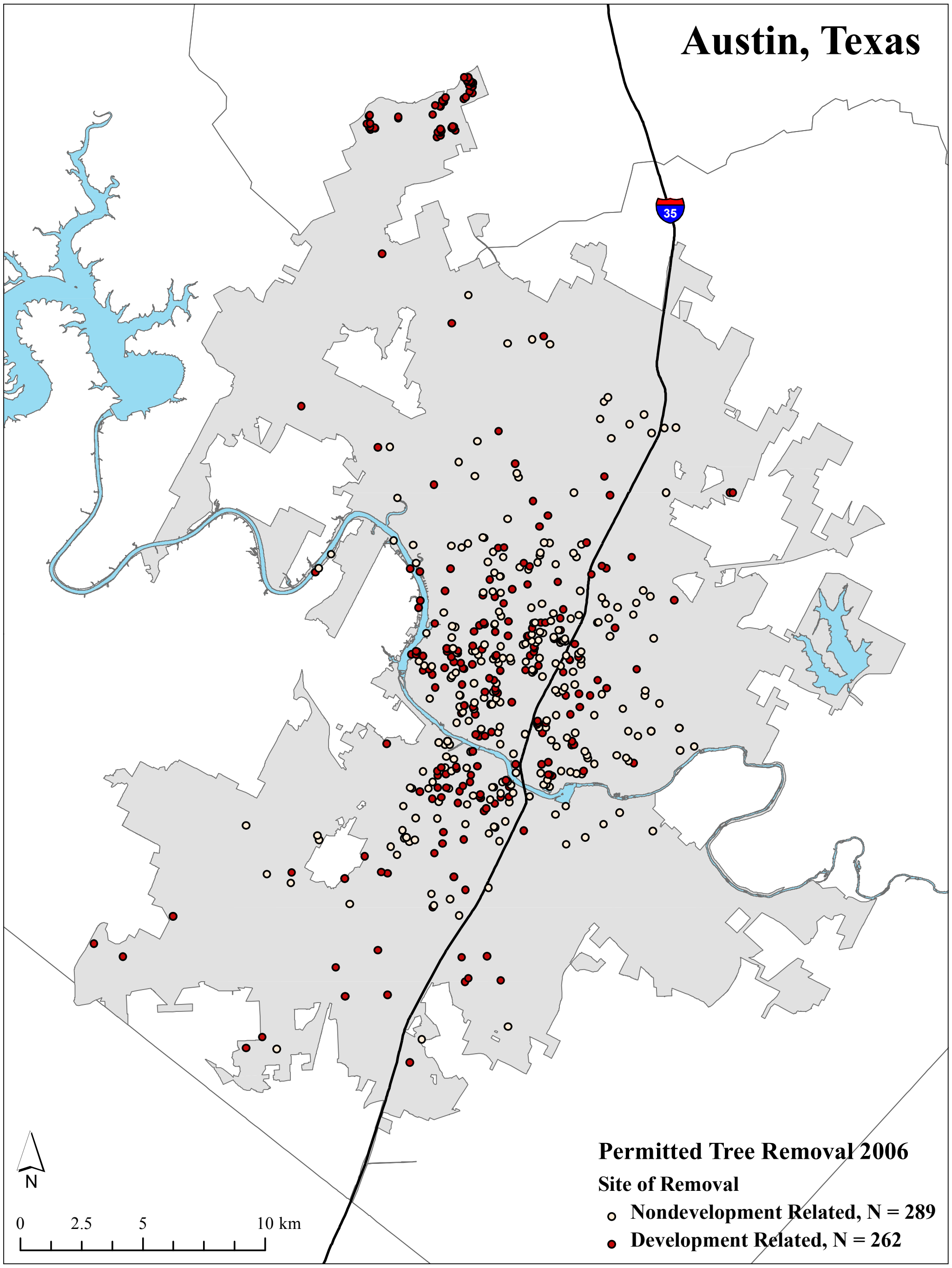
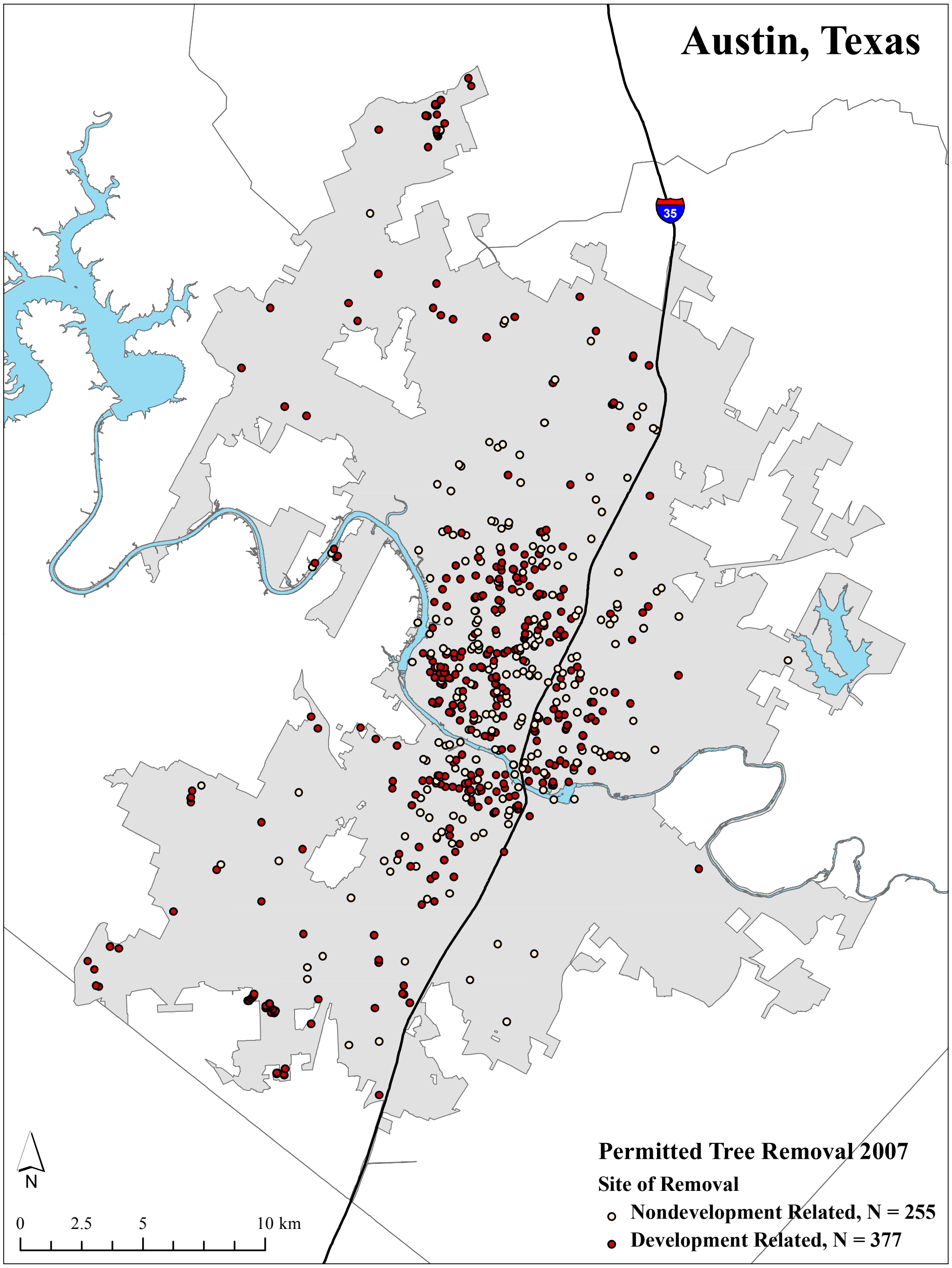
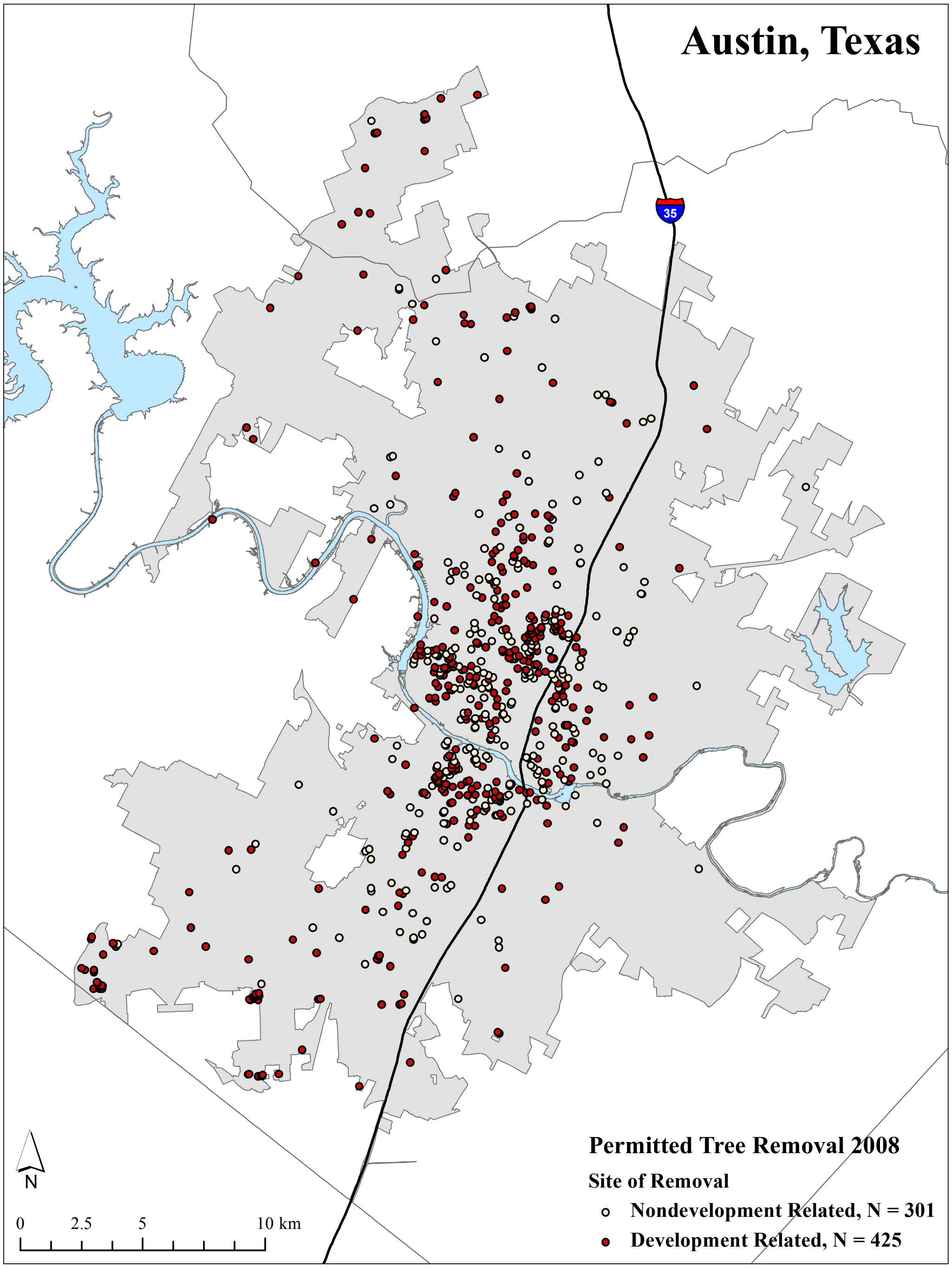
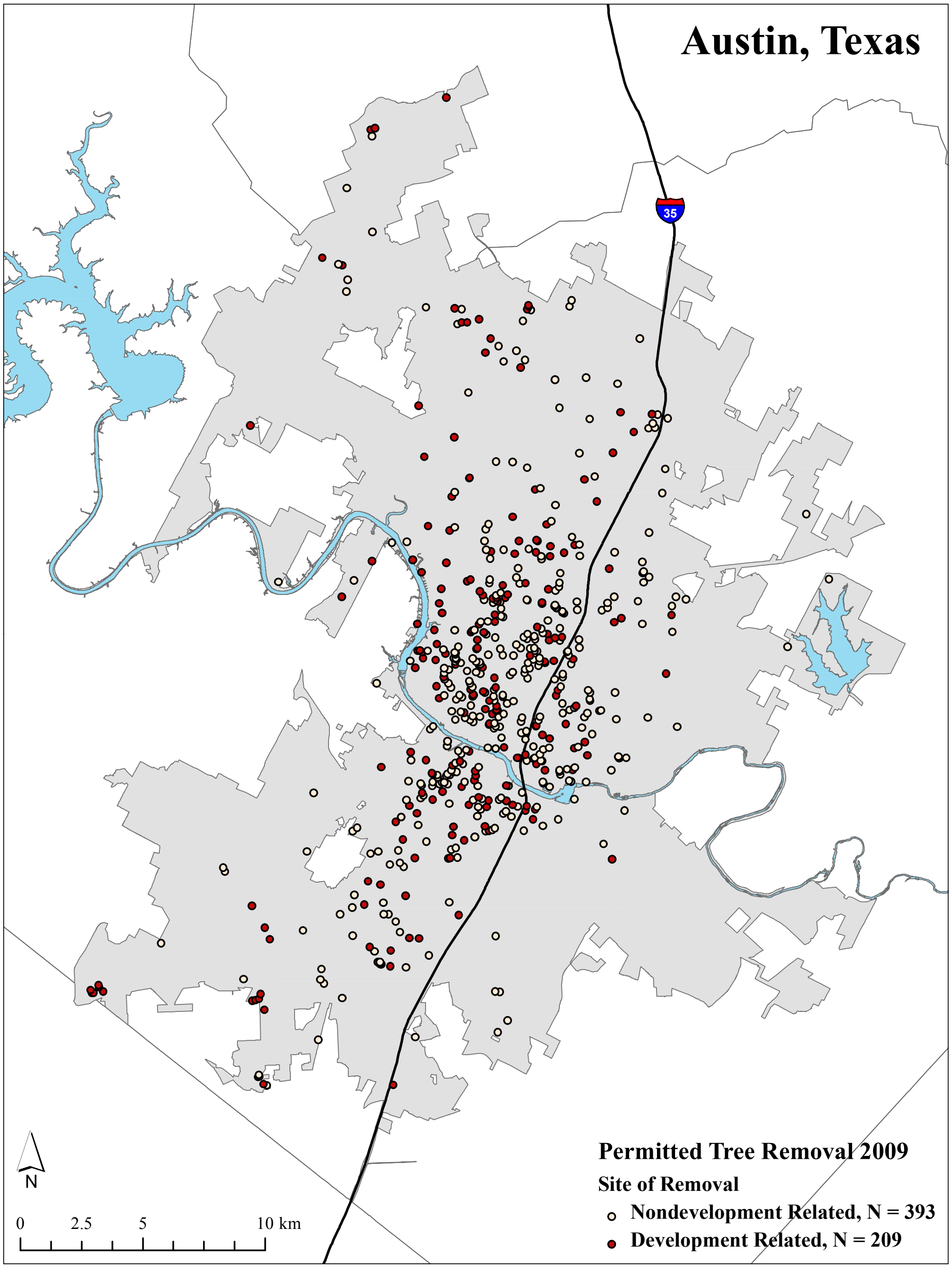
35
Permitted Tree Removal 2004
Site of Removal
Nondevelopment Related, N = 84
Development Related, N = 139
N
0
2.5
5
10 km

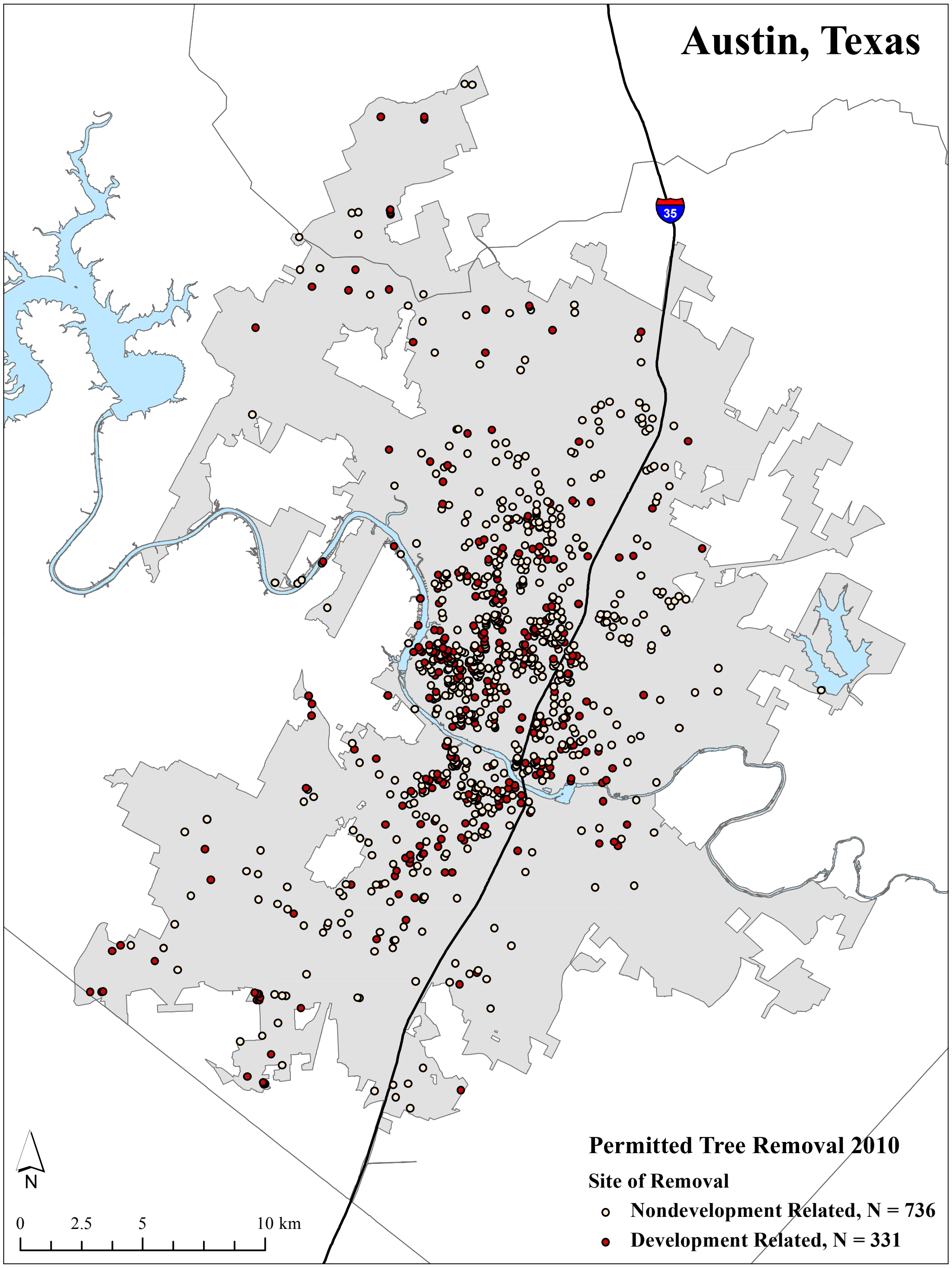

Austin, Texas
35
Permitted Tree Removal 2005
Site of Removal
Nondevelopment Related, N = 167
Development Related, N = 221
N
0
2.5
5
10 km

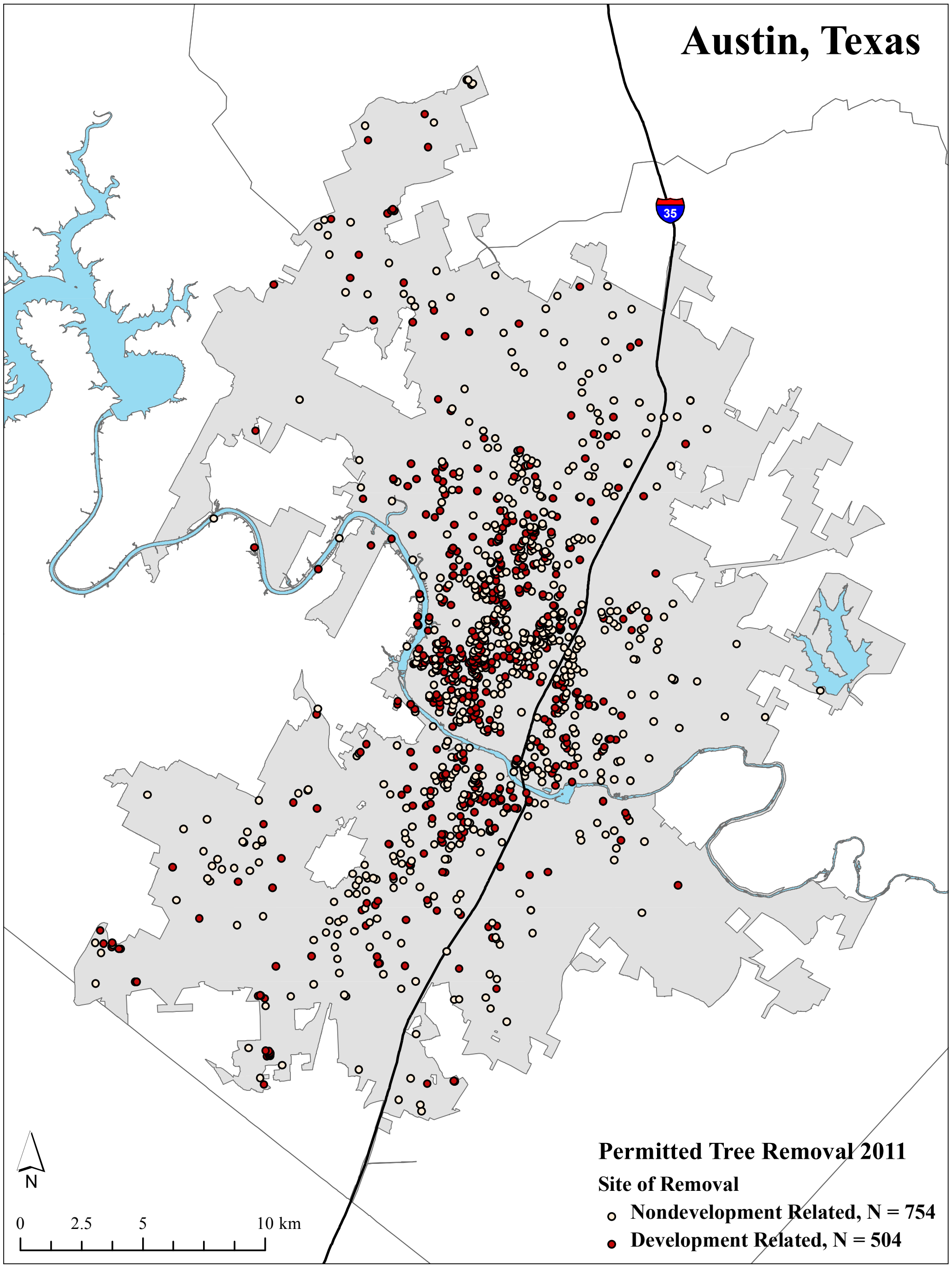

Austin, Texas
35
N
0
2.5
5
10 km
Permitted Tree Removal 2006
Site of Removal
Nondevelopment Related, N = 289
Development Related, N = 262


Austin, Texas
35
N
0
2.5
5
10 km
Permitted Tree Removal 2007
Site of Removal
Nondevelopment Related, N = 255
Development Related, N = 377


Austin, Texas
35
N
0
2.5
5
10 km
Permitted Tree Removal 2008
Site of Removal
Nondevelopment Related, N = 301
Development Related, N = 425

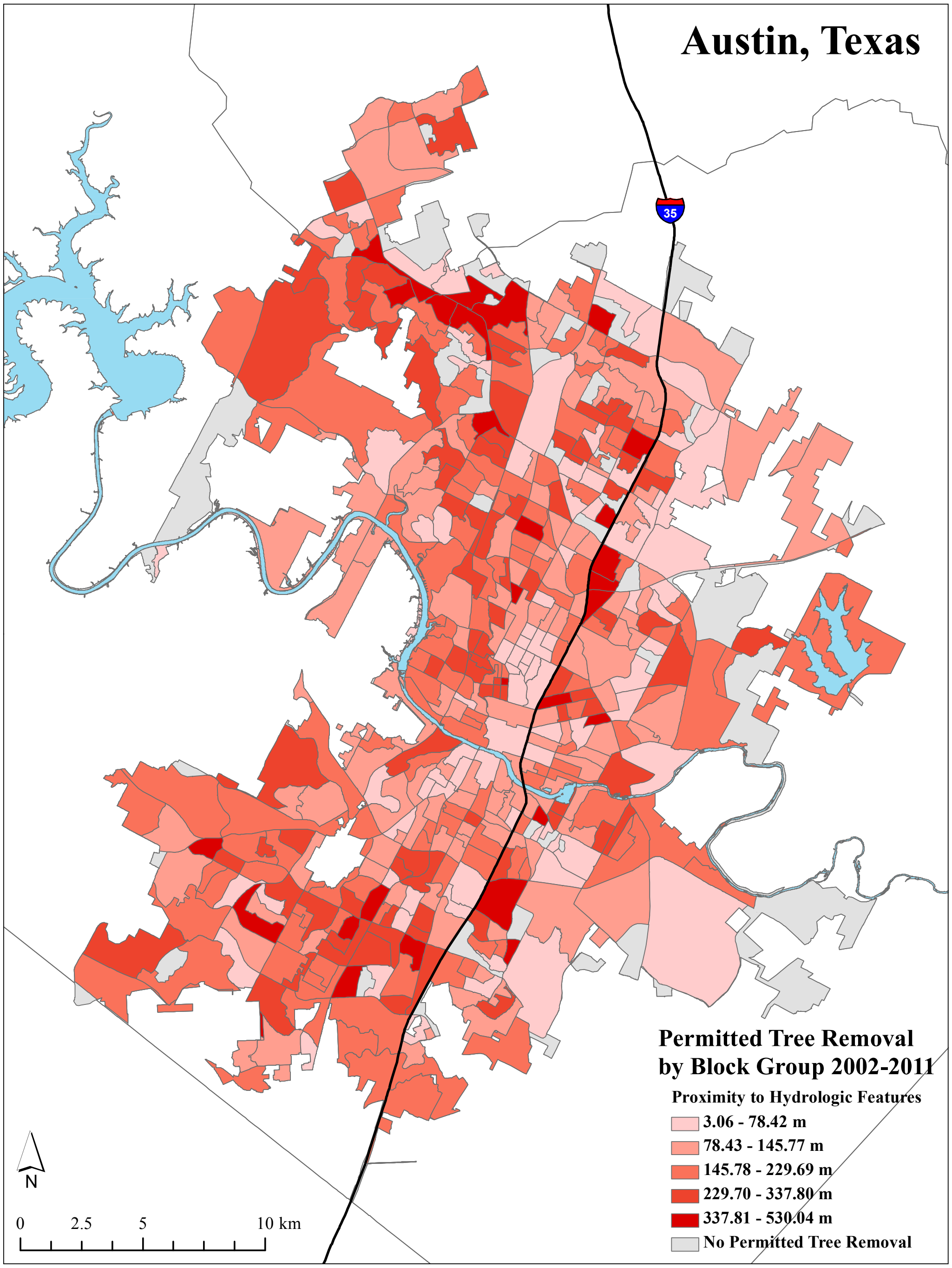

Austin, Texas
35
N
0 2.5 5 10 km
Permitted Tree Removal 2009
Site of Removal
Nondevelopment Related, N = 393
Development Related, N = 209

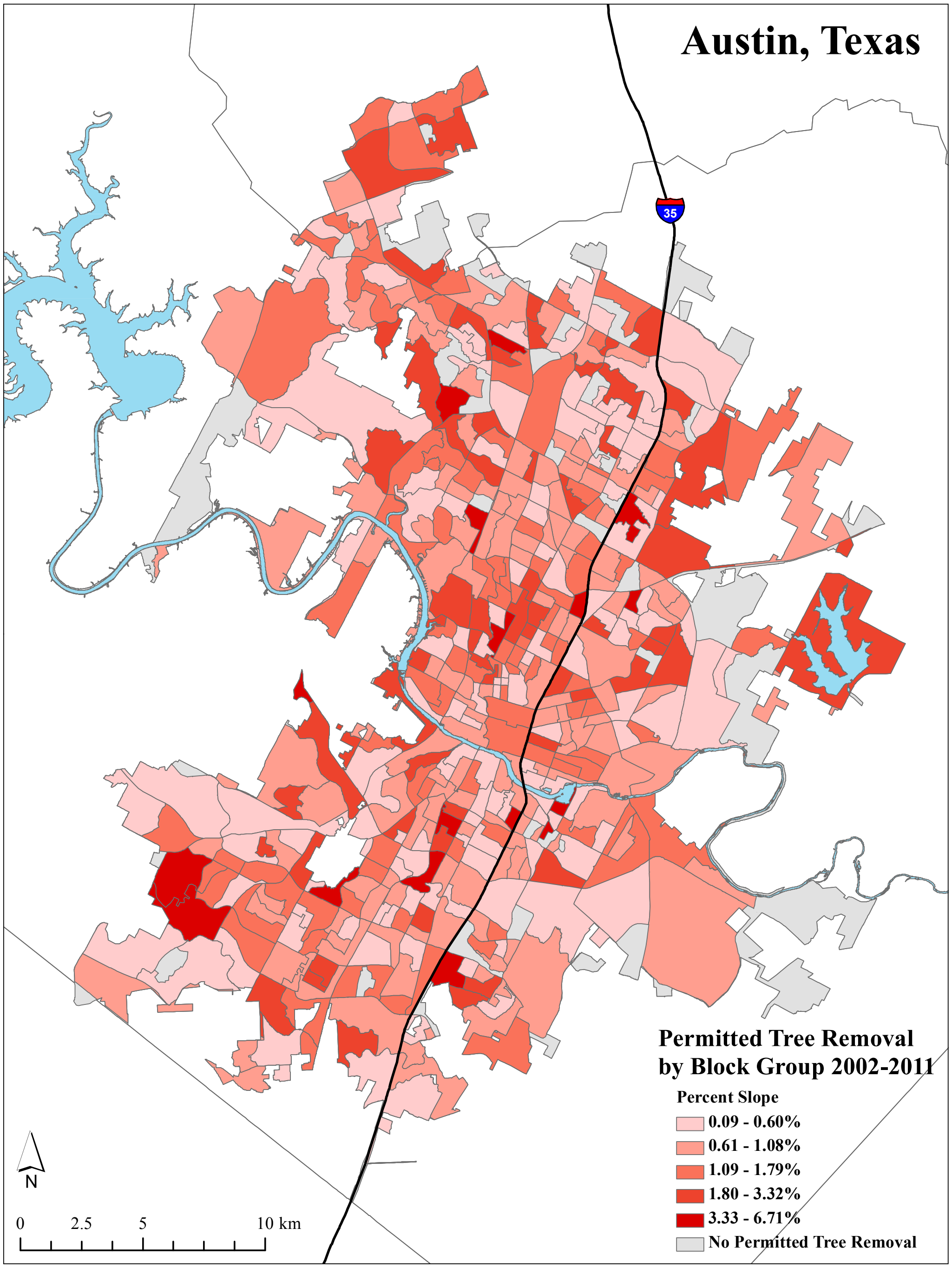

Austin, Texas
35
N
0
2.5
5
10 km
Permitted Tree Removal 2010
Site of Removal
Nondevelopment Related, N = 736
Development Related, N = 331

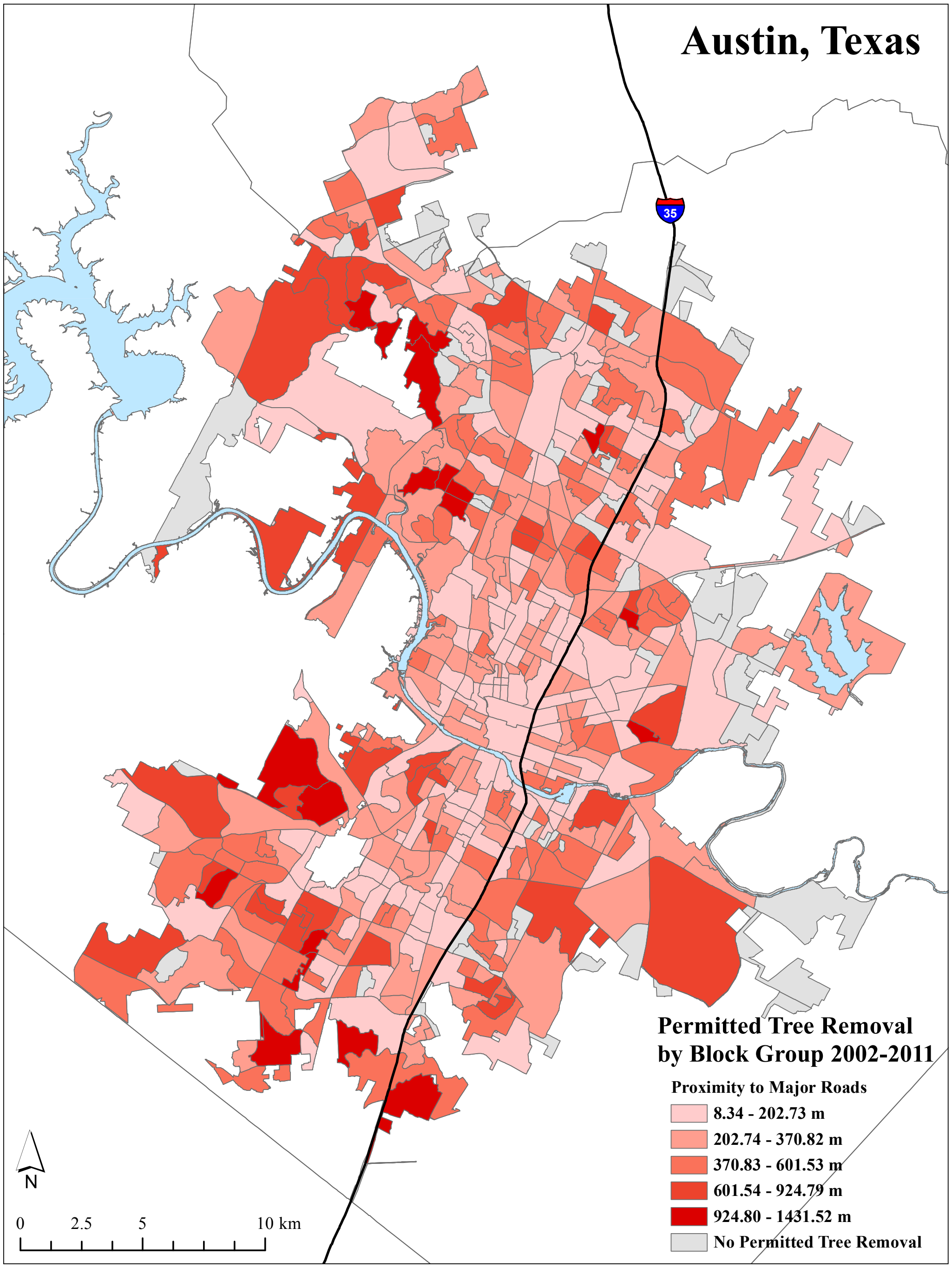

Austin, Texas
35
Permitted Tree Removal 2011
Site of Removal
Nondevelopment Related, N = 754
Development Related, N = 504
N
0
2.5
5
10 km

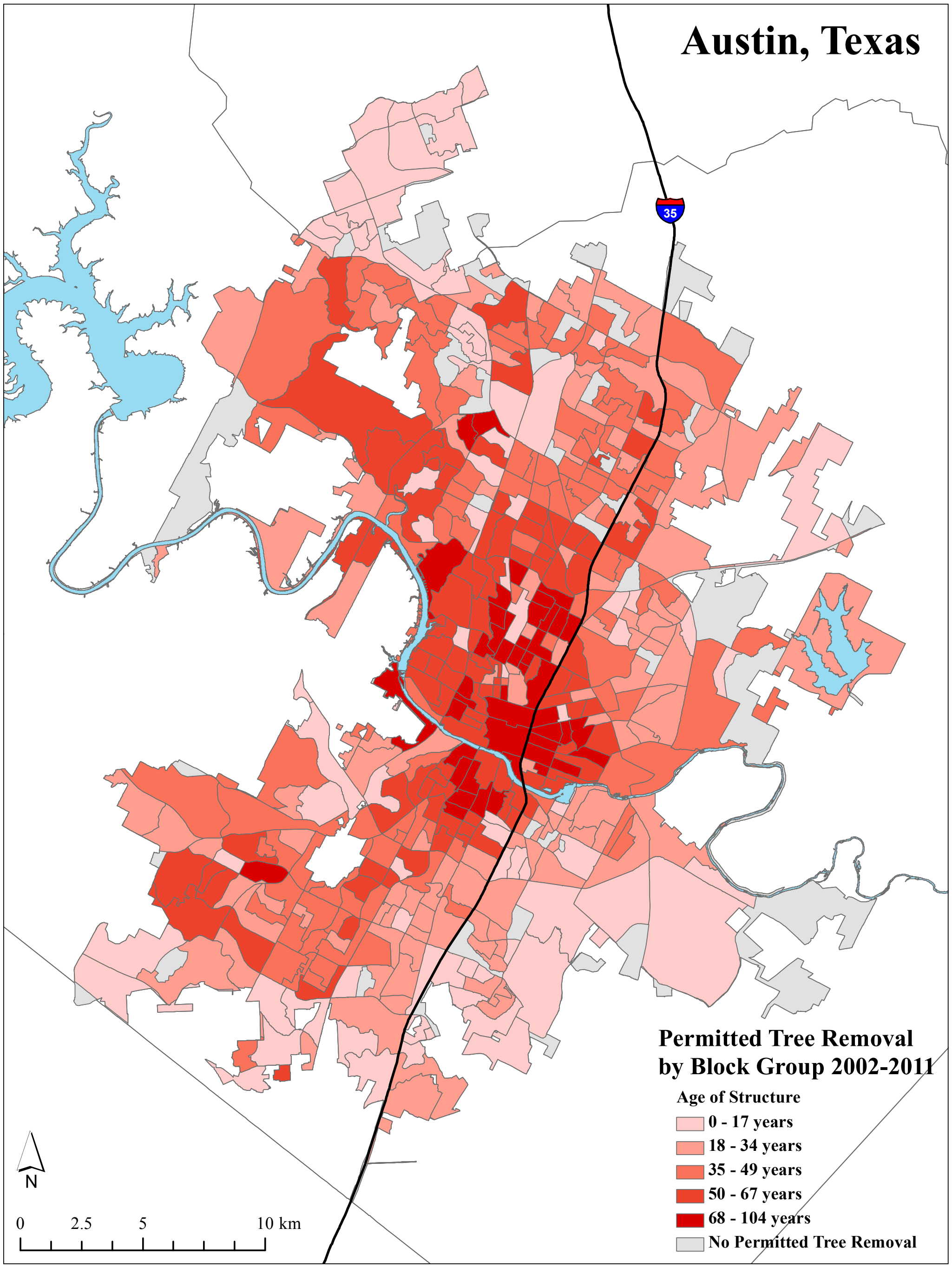
APPENDIX B

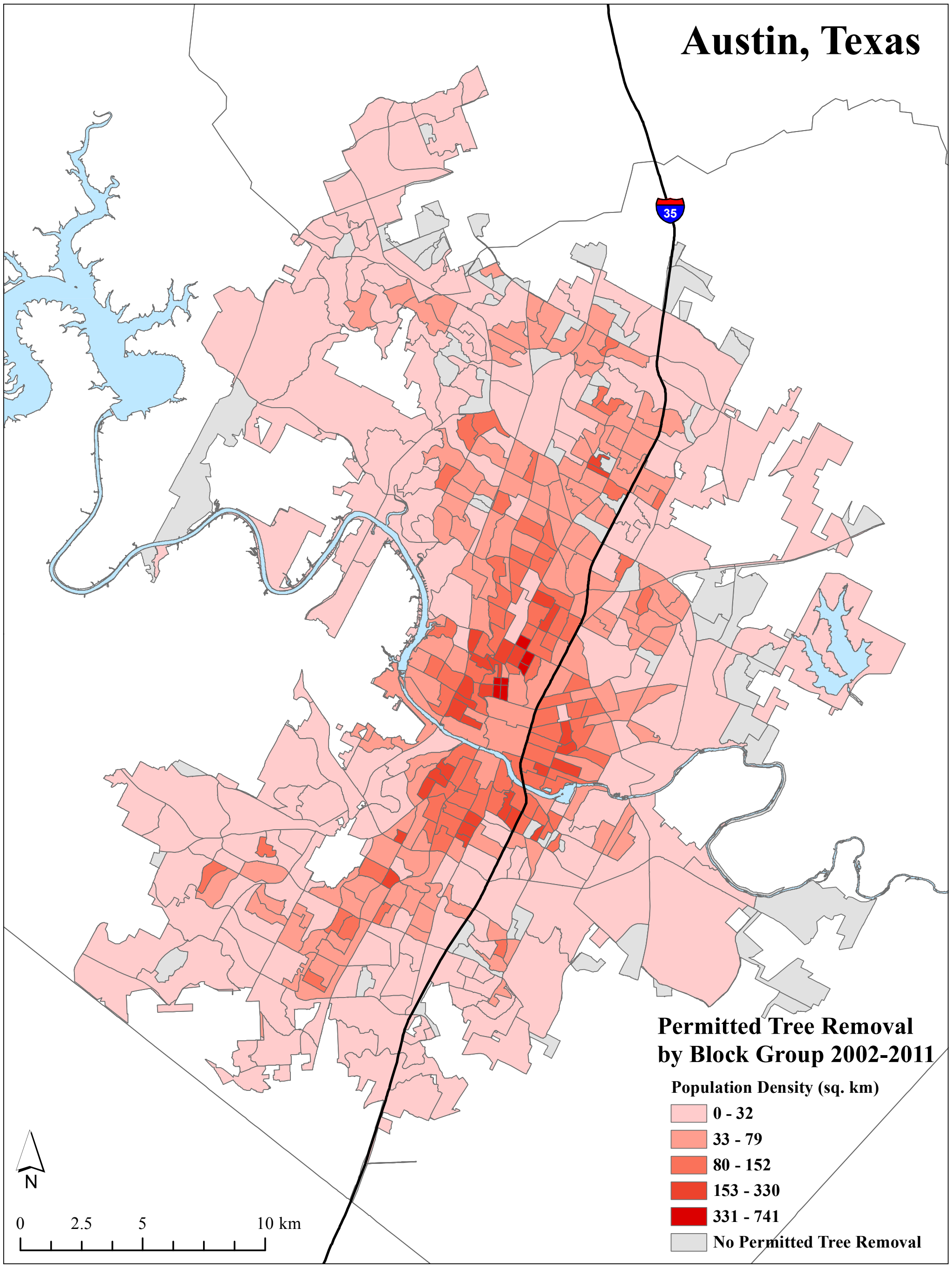
MAPS OF DEFORESTATION BLOCK GROUPS BY PREDICTOR VARIABLES

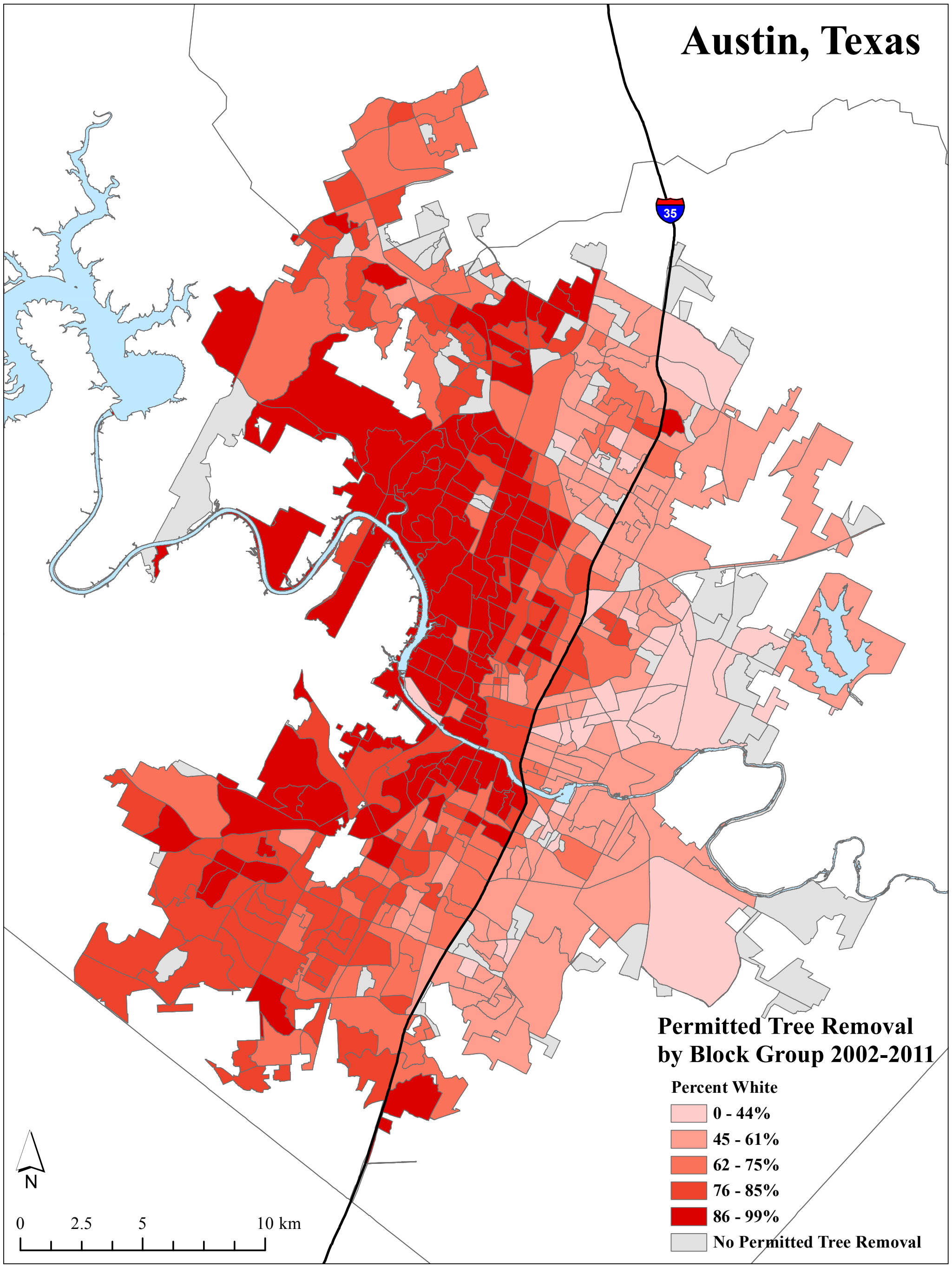

Austin, Texas
35
Permitted Tree Removal
by Block Group 2002-2011
Proximity to Hydrologic Features
3.06 - 78.42 m
78.43 - 145.77 m
145.78 - 229.69 m
229.70 - 337.80 m
337.81 - 530.04 m
No Permitted Tree Removal
N
0
2.5
5
10 km


Austin, Texas
35
Permitted Tree Removal
by Block Group 2002-2011
Percent Slope
0.09 - 0.60%
0.61 - 1.08%
1.09 - 1.79%
1.80 - 3.32%
3.33 - 6.71%
No Permitted Tree Removal
N
0
2.5
5
10 km

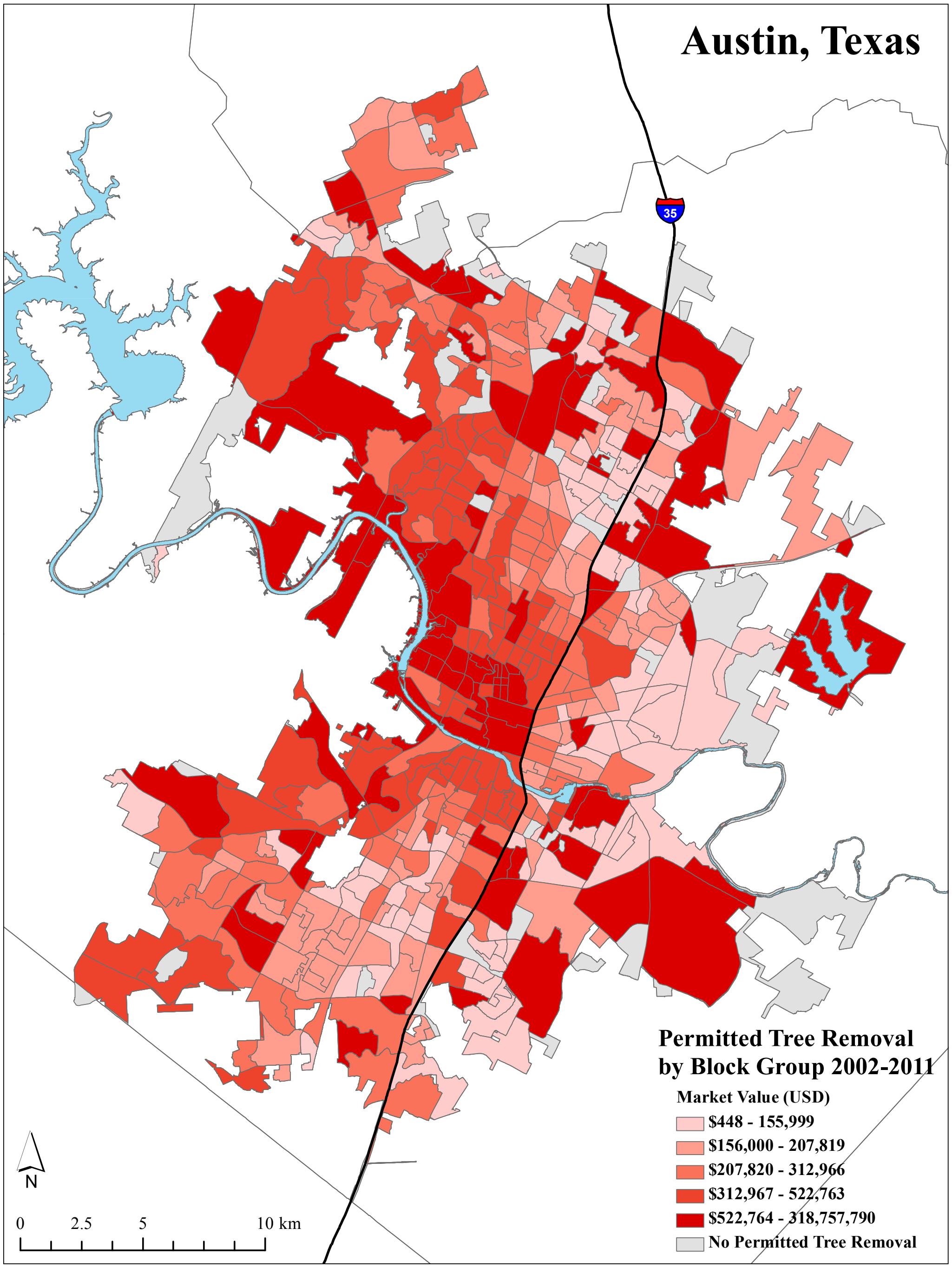

Austin, Texas
35
Permitted Tree Removal
by Block Group 2002-2011
Proximity to Major Roads
8.34 - 202.73 m
202.74 - 370.82 m
370.83 - 601.53 m
601.54 - 924.79 m
924.80 - 1431.52 m
No Permitted Tree Removal
N
0
2.5
5
10 km

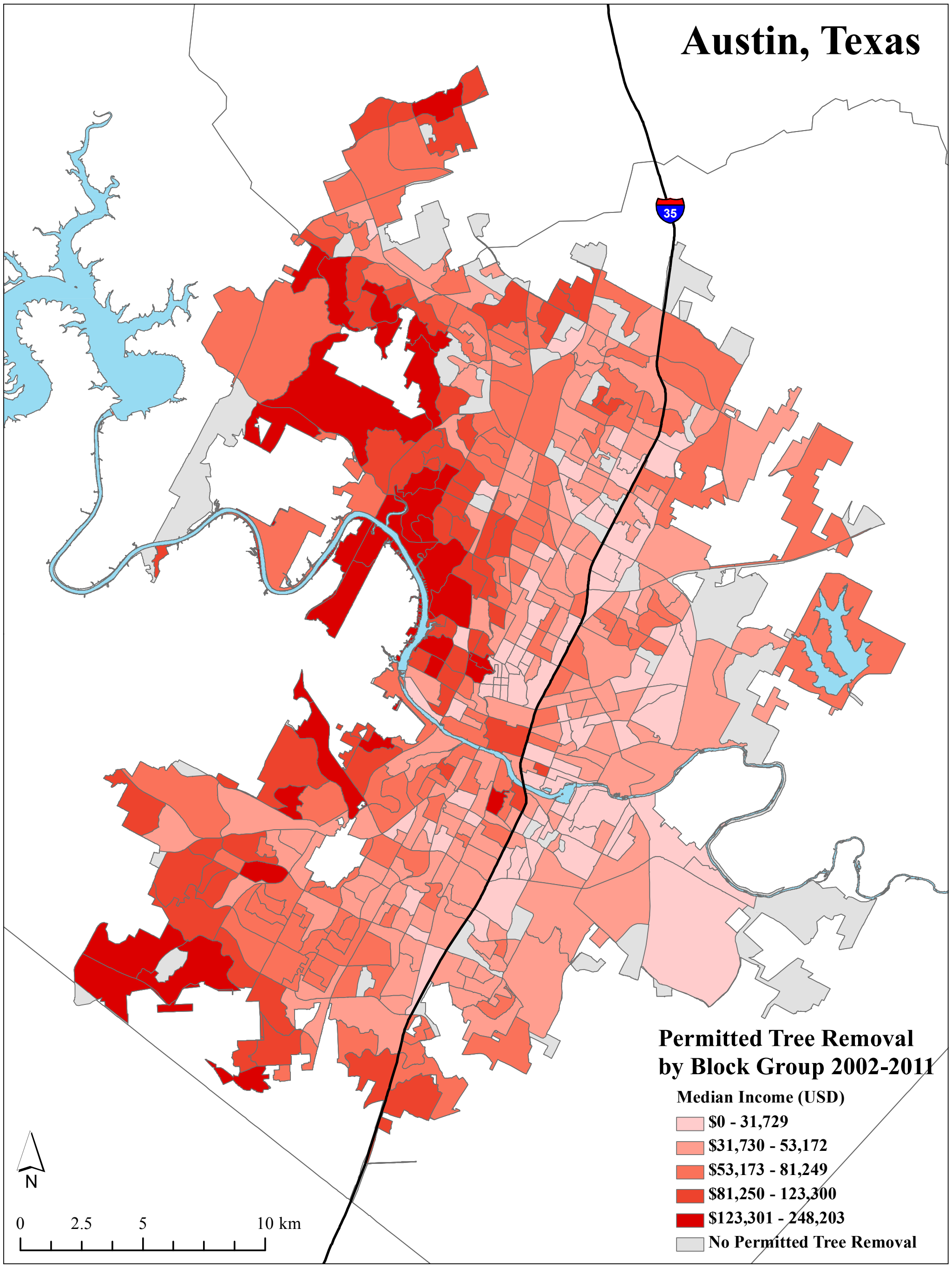

Austin, Texas
35
Permitted Tree Removal
by Block Group 2002-2011
Age of Structure
0 - 17 years
18 - 34 years
35 - 49 years
50 - 67 years
68 - 104 years
No Permitted Tree Removal
N
0
2.5
5
10 km

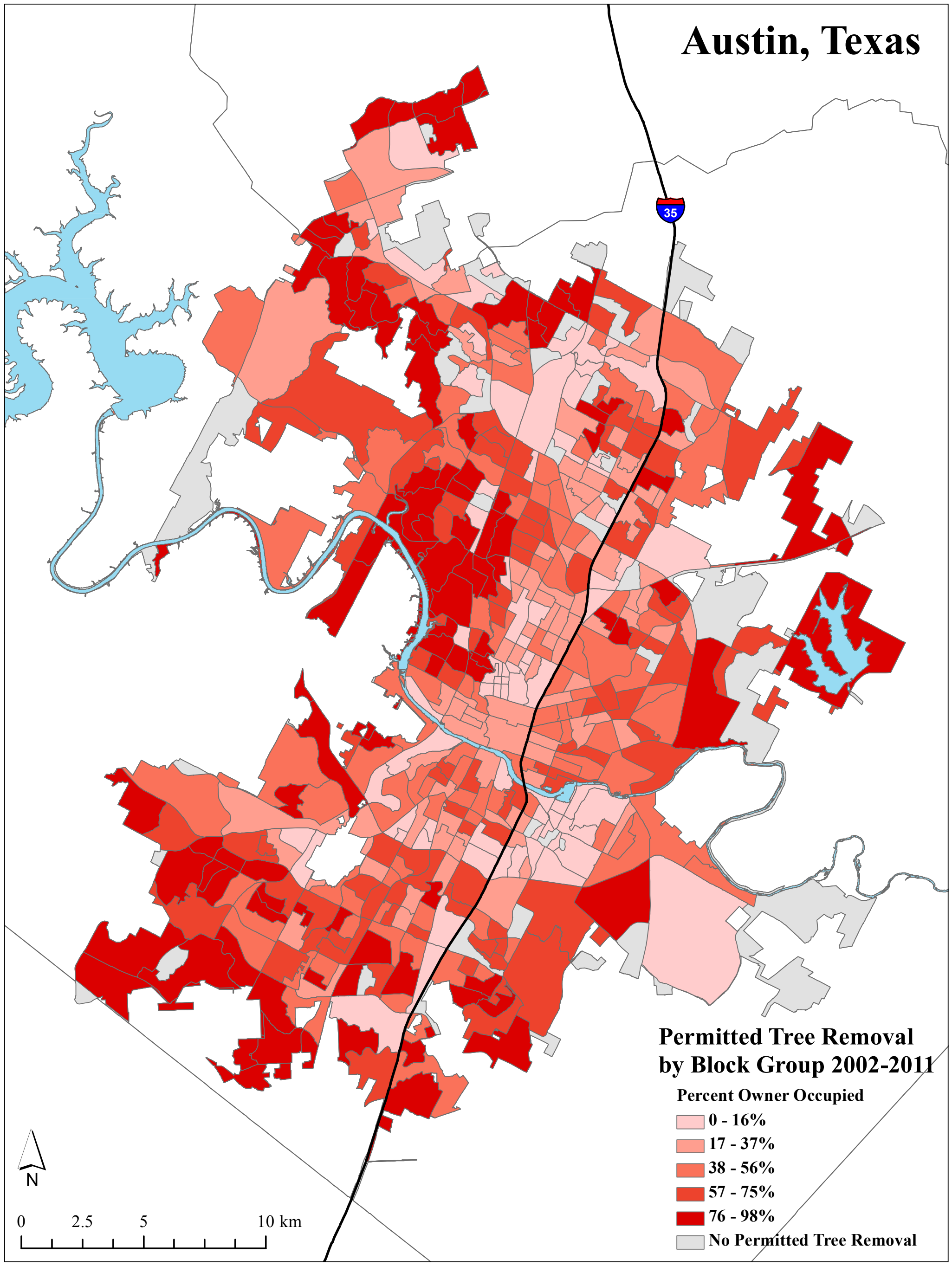

Austin, Texas
35
Permitted Tree Removal
by Block Group 2002-2011
Population Density (sq. km)
0 - 32
33 - 79
80 - 152
153 - 330
331 - 741
No Permitted Tree Removal
N
0
2.5
5
10 km



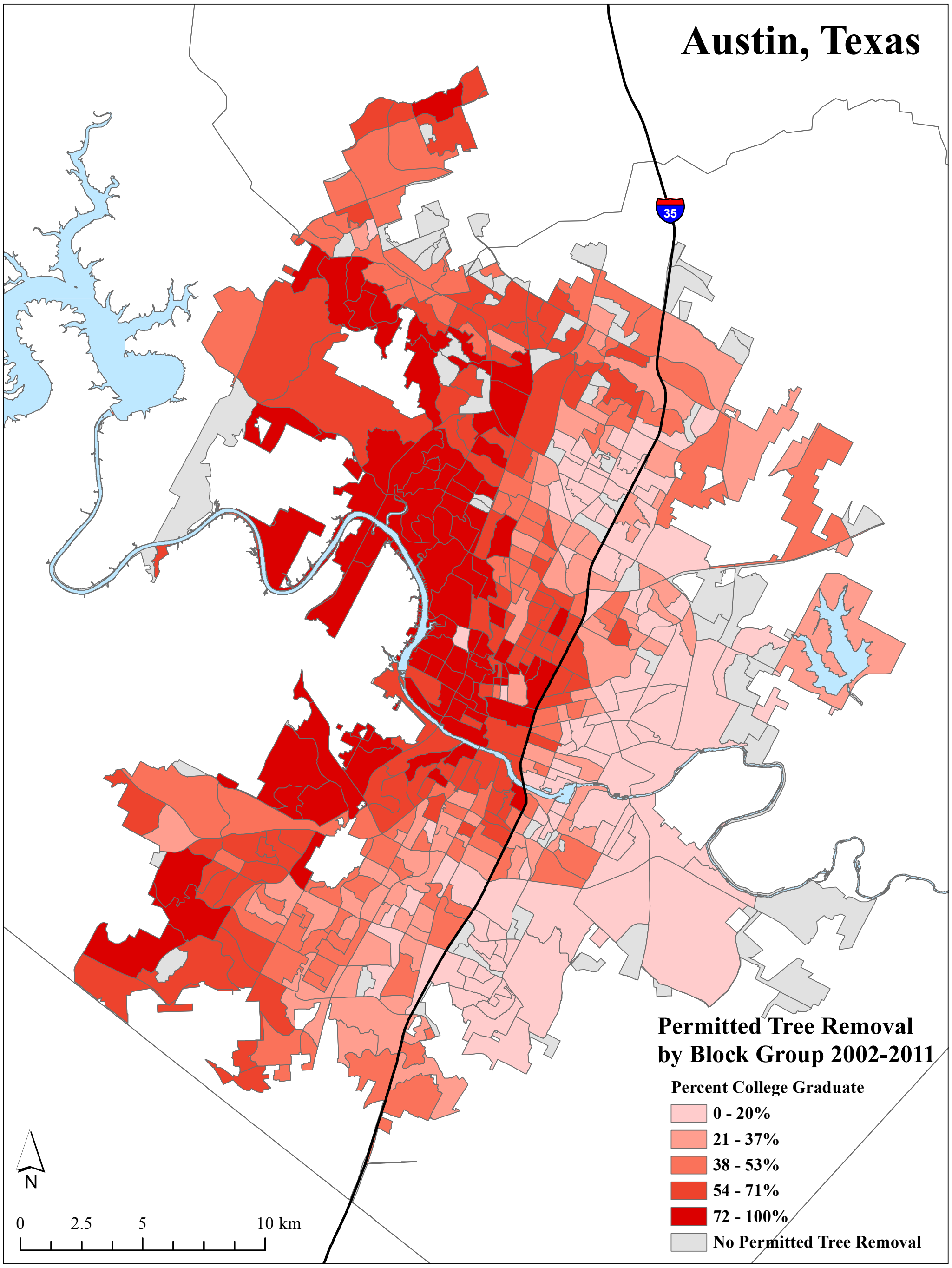
Austin, Texas
35
Permitted Tree Removal
by Block Group 2002-2011
Percent White
0 - 44%
45 - 61%
62 - 75%
76 - 85%
86 - 99%
No Permitted Tree Removal
N
0
2.5
5
10 km


Austin, Texas
35
Permitted Tree Removal
by Block Group 2002-2011
Market Value (USD)
$448 - 155,999
$156,000 - 207,819
$207,820 - 312,966
$312,967 - 522,763
$522,764 - 318,757,790
No Permitted Tree Removal
N
0
2.5
5
10 km


Austin, Texas
35
Permitted Tree Removal
by Block Group 2002-2011
Median Income (USD)
$0 - 31,729
$31,730 - 53,172
$53,173 - 81,249
$81,250 - 123,300
$123,301 - 248,203
No Permitted Tree Removal
N
0 2.5 5 10 km



Austin, Texas
35
Permitted Tree Removal
by Block Group 2002-2011
Percent Owner Occupied
0 - 16%
17 - 37%
38 - 56%
57 - 75%
76 - 98%
No Permitted Tree Removal
N
0
2.5
5
10 km



Austin, Texas
35
Permitted Tree Removal
by Block Group 2002-2011
Percent College Graduate
0 - 20%
21 - 37%
38 - 53%
54 - 71%
72 - 100%
No Permitted Tree Removal
N
0
2.5
5
10 km

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VITA

Brendan Lavy enrolled in the graduate college at Texas State University-San Marcos in the fall of 2010 to pursue a Master of Science in geography. His research focuses on uncovering and analyzing the patterns and outcomes of policy-based and publically implemented environmental conservation and preservation practices and on identifying and proposing practical solutions for the equal distribution of environmental amenities and harms.

From 2009 to 2011, Lavy served as the personal assistant to the Deputy Secretary of State at the U. S. Department of State. As the primary contact for the Deputy Secretary, he coordinated the Deputy Secretary's activities in the department and interagency and managed the day-to-day operations and administration of the Deputy Secretary's office. Before his appointment at the State Department, Lavy was the chief of staff at the Lyndon B. Johnson School of Public Affairs at the University of Texas at Austin, where he managed the engagements of the school's dean, provided professional assistance to the dean, and supervised office staff. Lavy also managed outreach and Internet communications for the Foreign Policy Studies program at the Brookings Institution. He has worked in a variety of managerial roles, and most recently, he served as a consultant and program coordinator for the McComb's School of Business's Subiendo Academy for Rising Leaders at the University of Texas at Austin.

A native of Wichita Falls, Texas, Lavy received a Bachelor of Arts in anthropology from the University of North Texas in 1998. He is the recipient of several professional and academic awards, including the U.S. Department of State's Superior Honor Award, Texas State's Department of Geography John Wiley Graduate Award for Excellence in Geography, Texas State's Graduate College Scholarship, and the Society for Applied Anthropology's Environmental Fellowship. He is a member of the Association of American Geographers, the Alpha Chi National College Honor Society, and the Golden Key International Honour Society.

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