CRIME UNDER THE CANOPY:

THE CORRELATION BETWEEN URBAN FORESTS

AND CRIME OCCURRENCE IN OLYMPIA, WASHINGTON

by

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ABSTRACT

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and Crime Occurrence in Olympia, Washington

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As urban populations continue to increase, the corresponding reduction in tree canopy cover demonstrates notable impacts to community and environmental health. To address the need for balance between nature and urbanization, research continues to seek ways to incorporate nature within cities and explore the benefits of robust urban forests. An increasing number of studies began recognizing that urban forests may provide the additional benefit of crime suppression. However, a relatively small number of similar studies have been conducted, and they are geographically localized or temporally limited. Further research is needed to examine this relationship and assess the application in spatial and longitudinal studies.

This research used data from the City of Olympia to focus on validating the relationship between tree canopy cover and crime occurrence in an urban core area. Analysis was conducted using regression, spatial, and temporal analysis at the census block group level with socioeconomic variables as controls. Regression results from two annual datasets demonstrated a significant inverse relationship, where a greater percentage of urban tree canopy cover predicted reduced crime rates in 2008 ($\beta = -13.114$, $p < 0.001$) and in 2014 ($\beta = -7.910$, $p < 0.001$). This study concludes that incorporating high-canopied trees in urban green space is associated with crime suppression. The data supports developing cities to include urban forests and public green spaces as a way to reduce crime and create healthier, happier communities.

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Chapter 1: Introduction

1.1 Introduction

As of 2016, the majority of the human population resides in cities; in America alone, the urban population comprises 80% of all residents (U.N. Population Division, 2016). Not surprisingly, urban areas are expected to increase substantially over the next 50 years. Cities grow to accommodate new arrivals, both in terms of geographic boundaries and in the ways that urban space is utilized to provide residential housing. As a result, urban areas have lost more than 600 million trees to development over the last 30 years, demonstrating a 30% gross decline in tree canopy cover (American Forests, 2015).

To address the need for balance between nature and urbanization, practitioners and scientists continue to seek ways to conserve and create green spaces within cities. Drawing upon research that demonstrates the strong connection between mental health and nature experience, inquiries into urban green space and its impacts on mental health continue to provide evidence in support of incorporating nature as part of metropolitan design. An increasing number of studies began recognizing that urban forests may provide an additional, lesser-known benefit: crime suppression.

Previous studies examined urban tree canopy cover and crime occurrence at varying geographic scales and, correspondingly, with varying methodology. The results hold the potential to provide cities with beneficial and much needed information to garner funding and public support; however, the relatively small number of studies are geographically localized or temporally limited. Further research is needed to examine and assess this potential relationship in spatial studies. Additionally, the analysis techniques need further validation and no studies have been conducted that assess change over time.

The research conducted as part of this thesis seeks to answer the following questions: Is there a relationship between the presence of urban forests and street trees and the occurrence of crime in the City of Olympia? If a relationship exists, has it changed over time? Building off of the established methodology from previous studies and addressing the gaps in spatial and temporal analysis, this analysis addresses the hypothesis that a greater percentage of tree canopy cover in an urban core area has an inverse effect on crime, leading to reduced instances. Secondarily, while the study focuses more on a repeated cross-section of time rather than a long-term time series, there is value in understanding whether research conducted in one area is consistent over time. This may uncover other potential confounding variables, and will speak to the strength of the canopy/crime relationship.

Ultimately, this research aims to positively impact human and environmental health in three ways by addressing the potential crime-reducing benefits of street trees: 1) reducing stress and improving mental states before criminal behavior is induced, 2) improving general feelings of security and well-being as a result of reduced crime, and 3) support building better cities with green spaces as a way to reduce crime and create healthier, happier communities.

1.2 Background

Romanticizing nature is thought to be the result of the benefits that cities provide (Cronon, 1995; Jacobs, 1961), where the freedom from working the land and ease of access to resources allowed people to dream about nature in a new way. The yearning to be away from the "hustle and bustle" of the city led many to seek refuge in the interim suburban areas, not too far from the cities resources but far enough to reach quietude. The potential negative result, however, has been the suburban growth, prevalent in and since the 1950s. This process involves destruction of the very aspect city-escapists were hoping to find in “natural” settings.

Over the last several decades, however, the preference of our increasing population shifted to residing primarily within metropolitan areas. In the last fifteen years, urban populations rose from 46.6% to 54% (of the total world population), and by 2030 this number will likely range near 60% (U.N. Population Division, 2016). This means that cities constitute the major living centers of the world, where humans primarily find social and cultural interaction, where we find joy and sadness, where we live and die.

The process of urbanization involves converting green spaces to impermeable surfaces, such as concrete and asphalt, removing trees and vegetation to make way for human-built infrastructure. As defined by Fields (2002), densely forested urban areas include at least fifty percent tree cover, whereas sparsely forested areas include less than twenty percent tree cover. The urban forest cover of a typical American city in 2002 was approximately thirty percent (Fields). Today, with broader participation in national programs, such as the Arbor Day Tree City USA program, more investment into street trees and maintenance is formalized through participants’ respective urban forestry programs. Tools to quantify, manage, and plan urban forests have developed over the past decade, evolving to online, GIS-based systems. Urban planners can easily access evidence-based methods to develop multi-faceted design approaches that include nature as an essential element (American Planners Association’s (APA) Green Community Center, 2015).

Maintaining a high percentage of urban forest can positively affect a city in several, well-documented ways: stormwater attenuation (Kirnbauer et al., 2013), reductions in air pollutant concentrations (Fields, 2002; McPherson et al., 2005; Kirnbauer et al., 2013), energy savings through mitigation of urban heat-island effects (McPherson et al., 2005; Sydnor et al., 2011), reducing erosion, providing wildlife habitat, and removing carbon dioxide (CO2) (McPherson et al., 2005; Kirnbauer et al., 2013), CO2 sequestration (Livesley et al., 2014), and releasing oxygen into the atmosphere (McPherson et al., 1999; Kirnbauer et al., 2013).

Additionally, substantial research demonstrates the positive impacts on human health and behavior from "green spaces", which may include urban vegetation, trees, and other nature-based infrastructure or installations (Choudhry et al, 2015; Louv, 2012; Velarde et al., 2007). Strong relationships with and continued connections with nature support positive human growth, development, and sustainable human health. Severed connections with nature, typically coupled with an overexposure to modern technology, lead to unbalanced physical and emotional states, e.g., stress, fatigue, inability to focus or complete tasks, and difficulty recalling information (Lohr & Pearson-Simms, 2006; Louv, 2012; Velarde et al., 2007).

To add to this array of benefits, emerging literature assesses the relationship between the presence of nature, specifically trees, and the reduced occurrence of crime (Donovan & Prestemon, 2012; Hayden-Gilstad et al., 2015; Kuo et al., 2008; Kuo et al., 1998; Troy et al., 2012; Wolfe et al., 2012). Although cities may recognize the importance of green spaces on human health (Levitz et al., 2014), little is known about the impacts on human behavior specifically in reference to the motivation to commit or consider committing crimes. Therefore, further research is necessary to examine the potential of this relationship.

An understanding of this research and theoretical basis behind the relationship between mental health, criminally-motivated behavior, and the potential of urban trees to reduce crime could support cities in urban greening efforts, regulatory policies or protocols, and support healthier communities.

Chapter 2: Literature Review

2.1 Introduction

The following review explores the theoretical basis of: 1) nature's influence on psychological and physical health, and 2) criminally motivated behavior. Synthesis of these theories provides a framework for understanding how urban forests have the potential to reduce crime occurrence by alleviating the precursory mental conditions that lead to unlawful behavior. Ultimately, this research proposes that incorporating urban forestry practices into urban infrastructure and design will provide strategies for evidence-based city planning and crime reduction efforts.

2.2 Physiological and Psychological Benefits of Exposure to the Natural Environment

2.2.1 Discussion of Theory

The technological advancements of modern day life are thought to promote a new, widespread societal illness: stress (Bratman, Daily, Levy, & Gross, 2015; Grahn & Stigsdotter, 2003). The outcomes of stress, which may act either as a symptom or a cause, present themselves both physically and psychologically. In the well-known fight or flight theory, the physical process involves the brain receiving messages about the surrounding environment, assessing situations for threat or urgent action, and priming the body to react through a series of hormonal signals. Grahn & Stigsdotter (2003) use the biological basis of the fight or flight theory to articulate the psychological impacts on the body, describing present-day stress as a condition of disharmony between "what we are able to accomplish and what is demanded of or expected from us, [leading] to a feeling of being unable to control our [lives]" (p. 3).

The connection between mind and body explains why the myriad causes demanding attention typically result in mentally fatigued and physically depleted individuals. Mental fatigue affects executive functioning skills, namely: 1) working memory – the ability to mentally hold and manipulate information such as when solving problems or setting goals; 2) cognitive flexibility – the ability to shift rules and switch tasks; and 3) inhibitory control – the ability to resist temptation or delay gratification (A. Diamond, personal communication, February 21, 2013). The negative impacts to executive functioning, also referred to as cognitive processing, present as "thoughtless, tactless, and unstrategic" actions (Kuo & Sullivan, 2001b, p. 546), as well as lack of inhibitory control and impulsive behavior (Kaplan, 1995). Emotionally, individuals experience irritability and then frustration, potentially leading to aggressive behavior if left unchecked (Grahn & Stigsdotter, 2003; Kuo & Sullivan, 2001b).

Stephen Kaplan's Attention Restoration Theory (ART) (1995) provides a well-articulated model of the prevailing theories regarding stress-related physiological impacts and nature. Building upon James' (1892) initial division between voluntary attention (as cited in Berman, Jonides, & Kaplan, 2008, p. 1207), where cognitive processes control attention, and involuntary attention, where engaged attention comes without directed effort, Kaplan introduced the theory that nature allows for restoration because it does not demand our voluntary, or directed, attention. Directed attention requires application of executive functioning skills and, as noted above, without periods of repose individuals will eventually suffer from exhaustion and loss of inhibitory control. Kaplan (1995) refers to the involuntary, non-cognitive capacity as "fascination." His proposal suggests that fascination takes over and provides space for mental restoration in nature settings because this environment mitigates or soothes the demands on our cognitive faculties caused by modern society.

Paralleling the idea of nature's power of restoring attentive and cognitive capacity, Ulrich's (1984) Stress Recovery Theory (SRT) proposes that nature is conducive to mental health because it reduces stress and therefore allows for recovery. The logical basis draws upon the theory of fight or flight stress responses, positing that the brain must quickly assess situations for potential threats. Nature sends messages of safety or absence of threat, creating periodic spaces for restoration and recovery.

2.2.2 Theoretical Synthesis and Application

Synthesizing the SRT and ART models, Hartig et al. (1991) demonstrated that while the ART model focuses on the cognitive response and the SRT model on the emotional response, both contribute to an understanding of how nature supports relief from mental fatigue, facilitating mental restoration. Additionally, both theories agree that a view of nature provides more benefit than other senses, and direct experience provides the next highest benefit. The literature largely supports that the ability to see nature represents the greatest influence over lowering stress levels (Ulrich, 1984; Leather, Pyrgas, Beale, & Lawrence, 1998; Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006), and may subsequently encourage outdoor experience and more visits to natural areas (Grahn & Stigsdotter, 2003; Velarde et al., 2007).

The closeness of nearby nature, such as an urban park or trail, facilitates ease of access and more frequent use; the latter is positively associated with lower stress levels (Grahn & Stigsdotter, 2003) and improved perceptions of overall health (Maas et al., 2006). The argument follows that in urban areas where technology overruns our attentional capacity, including green space (parks, trees, or other vegetation) provides benefit to human health by relieving stress and mental fatigue, and an escape from our modern, day-to-day city life. The well-documented physiological and psychological benefits of including nature via green spaces in cities lead to increases in positive attitudes and higher community satisfaction (Sanesi et al., 2006), improvement in cognitive functioning and positive emotional states (Berman et al., 2008; Bratman et al., 2015; Hartig et al., 1991; Kaplan, 1995), and decreases in stress levels and faster stress recovery times (Grahn & Stigsdotter, 2003; Kaplan, 1995; Ulrich, 1984). Additionally, more green space (by volume and proximity) clearly demonstrates a positive, stress-reducing impact (Maas et al., 2006; Wolfe & Robbins, 2015).

2.3 Criminal Behavior and Motivations in Urban Areas

2.3.1 Discussion of Theory

While researchers and city officials may recognize the importance of green spaces on human health (Levitz et al., 2014), questions remain about the impacts on human behavior, specifically in relation to the motivation to commit or consider committing crime. The literature relating criminal behavior to urban green space references two broadly implemented models – the “Broken Window Theory” and the “Routine Activity Theory” (Donovan & Prestemon, 2012; Cohen & Felson, 1979; Becker, 1968).

The Broken Window Theory proposes that unmaintained areas represent zones of public disorder and are therefore conducive to continued and increased criminal activity (Wilson & Kelling, 1982). Following this model, certain environmental conditions—the presence of litter, gangs of youth, overgrown or unruly vegetation, vandalism, graffiti, publicly intoxicated individuals, homeless individuals, and open drug use--promote a perceived lack or absence of social control. These “smaller” crimes, commonly termed “social incivilities,” set the stage in these areas for larger, more aggressive crimes to occur, such as theft, assault, rape, and murder (Wilson & Kelling, 1982).

Despite receiving some criticism and needing further research-based validation (Center for Evidence-Based Crime Policy, 2015), the Broken Window model continues to serve as a focal point (Sousa & Kelling, 2006) as demonstrated by the past three decades of policing practices and crime prevention strategies. Indeed, Sousa and Kelling (2006) found that law enforcement actions may maintain the public order by increasing arrests for smaller, misdemeanor crimes leading to an associated decrease in larger, felony crimes (as cited in Wilson & Kelling, 2006, p, 171).

The Routine Activity Theory outlines three preliminary criteria that need to be in place for a crime to occur: a potential criminal, victim, and regulatory authority (Cohen & Felson, 1979). Essentially, there must be an opportunity to commit a crime, a benefit to the criminal of some kind, and a sufficient lack of authoritative oversight for a criminal to consider the act. If the surrounding environment is devoid of regulatory enforcement, a criminal with opportunity will have greater incentive to commit an offense. Additionally, a criminal will assess the potential reward, whether pecuniary or not, as well as the consequences before committing a crime (Donovan & Prestemon, 2012).

2.3.2 Factors in Urban Crime

While crime in urban areas results from multiple factors, the Broken Window and Routine Activity theories provide a basis for understanding the geographical occurrence of crime and the general motivations for committing crime: 1) opportunity, 2) intent, 3) rewards, and 4) consequences. Similar to the Broken Window Theory, territoriality (defining ownership and respect of space for protection purposes) and the defense of property (fences, bolts, locks, etc.) play a role in a criminal's target selection process and are linked to reduced crime (Brown & Altman, 1983) by giving cues to the level of owner and neighbor concern and/or vulnerability in an area (Brown & Bentley, 1993).

Studies that assess the relationship between environmental design and nature in urban areas and criminal activity also use census block group data to address population density, racial/ethnic composition, median income, education levels, and vacancies in rental housing (Donovan & Prestemon, 2012; Gilstad-Hayden, 2015; Kuo & Sullivan, 2001a; Troy et al., 2012; Wolfe & Mennis, 2012). In a study of New Haven, Connecticut, Gilstad-Hayden et al. (2015) found that neighborhoods with lower income and education levels did not necessarily equate to higher crime rates, even though increased crime rates are common in disadvantaged neighborhoods.

Other potential factors contributing to the occurrence of crime in metropolitan areas include city size, pecuniary returns, and low arrest rates – all positively associated to higher instances of crime over rural areas (Glaeser & Sacerdote, 1999). Whether lower crime rates in rural areas results from an abundance of and/or easier access to nature is currently an understudied area of research.

2.4 Synthesis: Known Studies Linking Criminal Behavior and Mental States Affected by Nature

2.4.1 Urban Green Space and Crime: The Conflict

The available literature regarding urban nature and crime often describes a dichotomous relationship, where evidence either points to a positive (inducing) or an inverse (reducing) association between the effects of vegetation on crime occurrence (Kuo & Sullivan, 2001a; Troy et al., 2012; Wolfe et al., 2012). The two main views, described in the following section, both specifically assess vegetation or trees in reference to the occurrence of crime; however, the role of the aforementioned green spaces led to debate as to whether that space promoted or reduced criminal activity.

The prevalent positive association (crime-inducing) theory rests on research demonstrating that low-level, dense vegetation provides cover for criminal activity, obstructs or obscures views of potential victims and law enforcement agents, and leads to fear of crime and low perceptions of safety (Donovan & Prestemon 2012; Hur & Nasar, 2014; Jansson et al., 2013). Nasar and Fisher demonstrated that vegetation should be removed or methodically scaled back to reduce potential cover for criminal activity (as cited in Kuo & Sullivan, 2001a, p. 344). Landscaping and maintenance regimes also significantly influence perceptions of safety; this plays a role in the public use of parks, open space, and other urban natural areas where disorderly or dense vegetation leads to fear of crime (Ulrich, 1986; Kuo, Bacaicoa, & Sullivan, 1998; Kuo & Sullivan, 2001a; Nasar, Fisher, & Grannis, 1993). The spacing of trees and surrounding vegetation next to a pathway may obstruct a user's view or line of sight, promoting fear of crime and inhibiting use (Jansson et al., 2013). It may also be that other factors affect public use in closed pathways, such as lighting or time of day.

The opposing research that describes an inverse (crime-reducing) association between vegetation and crime occurrence demonstrates that landscapes designed with open spaces and unobstructed views promote perceptions of safety (Kuo & Sullivan, 2001a; Sreetheran & Van den Bosch, 2014). In fact, greater amounts of vegetation support decreases in total violent and property crimes (Kuo & Sullivan, 2001a); the caveat is that the study focused specifically on the influence of grass and high-canopy trees. The benefit of including green spaces in such a fashion was associated with reduced crime, largely in part because it did not include the dense, tangled, fear-inducing type of vegetation factored into other studies. In an urban setting, Garvin, Cannuscio, and Branas (2013) experimented with vacant lots prone to crime; by greening these areas and transforming them into well-maintained areas by adding vegetation or park-like elements, they found an association with reduced crime occurrences. Although Garvin et al. did not specifically reference or indicate a relationship, their results align well with the Broken Window Theory – a vacant, disorderly lot made orderly by increasing vegetation promoted public, reduced criminal activity and decreased prevalence of social incivility. It seems further application of Broken Window Theory in research using green spaces as a variable would support the proposal that order reduces crime.

2.4.2 Urban Green Space, Mental Fatigue and Crime: Synthesis and the Importance of Trees

Emergent research may not always reference Broken Window Theory specifically; however, using green space as part of the equation in crime reduction solutions continues to gain ground. The feasibility of such a solution builds upon the evidence-based research, where: 1) severe mental fatigue may lead to violent or aggressive behavior, 2) a view of or contact with nature relieves stress and reduces mental fatigue, and 3) altering vegetation maintenance regimes to improve safety perceptions and encourage public use may support crime suppression.

Based on a review of the available literature, the research demonstrating reduced crime due to vegetation as a *primary factor* was initially documented in a series of studies of urban public housing developments in Chicago, Illinois. Kuo & Sullivan (2001b) broadened their exploration of the contributing factors of crime noting that the physical environment is directly associated with violent behavior. By examining the actual occurrence of crime documented in police reports (not just the perception or fear of crime) and the relationship between various levels of vegetation surrounding residential area, the duo produced rather ground-breaking results (2001a). The greenness of the buildings' surroundings showed an <u>inverse</u> relationship to crime occurrence. Growing evidence in the ensuing years continues to show that vegetation can have a positive impact on crime reduction (Wolfe et al., 2012).

The key component, although not identified as such in the research of Kuo and Sullivan, was that *trees and grassy areas* were the vegetation types used in the analysis. Later studies expanded upon this concept, additionally drawing from nature and mental health research, to demonstrate that trees have the potential to reduce levels of negative stress and may ultimately suppress criminal behavior (Donovan & Prestemon, 2012; Hansmann, Hug, & Seeland, 2007; Grahn & Stigsdotter, 2003; Kaplan, 1995; Park et al., 2008; Ulrich, 1976). Consistent with the findings on the type/form of vegetation assessed in previous studies, trees must be well-maintained to provide the intended crime-reducing benefit, and perhaps even of a certain height, crown size, and distance from other trees.

Donovan and Prestemon (2012) studied crime in an urban residential neighborhood in Portland, Oregon, refining the definitive benefit of trees, revisiting the dichotomous argument between vegetation as a fear-inhibitor versus a fear-inducer. Smaller trees block view distance and, when planted closely to residences, actually seem to promote crime occurrence. Alternatively, trees of a certain crown height and distance from buildings (thus non-view-obstructing) support crime suppression, especially when planted in the public right-of-way (Donovan & Prestemon, 2012; Troy et al., 2012). Gilstad-Hayden et al. (2015) conducted the most recent study of trees' impact on crime reduction. With the main focus of validating the results of previous, similar studies, the study's consistent findings demonstrate that greater canopy cover has an inverse association with crime, leading to lower crime rates. As cited earlier, greater amounts of green space in urban areas has a positive association with reduced mental fatigue, supporting the parallel theory that greater canopy supports crime suppression.

But why would trees reduce crime, either as a sole factor or a primary factor over other vegetation types? Reasons may include increased safety perceptions from greening urban areas (Garvin et al., 2013), as greater public use provides a form of regulation beyond policing efforts. The informal surveillance resulting from broad community use supports this theory (Coley, Kuo, & Sullivan, 1997; Jacobs, 2008; Troy et al., 2012; Kuo, Bacaicoa, & Sullivan, 1998). Urban green spaces with trees invite broader community use, and the additional mechanism of social regulation deters criminal behavior and contributes to community building by strengthening social relationships and perceptions of safety in public areas.

2.5 Conclusion: Gaps in Research and Advancement of the Field

Of the research available, five studies over fifteen years specifically addressed vegetation as it relates to crime; four of these addressed trees specifically (Donovan & Prestemon, 2012; Gilstad-Hayden et al., 2015; Kuo & Sullivan, 2001a; Troy et al., 2012; Wolfe et al., 2012). Each study consistently noted important confounding factors, including them as control variables when available and as appropriate. Census block group data facilitated control for median income, race/ethnicity, education level, and population density. The most recent study by Gilstad-Hayden et al. (2015) advocated for the use of FBI UCR codes as a basis for further research in order to promote consistency and comparison of results.

In an area of relatively new research, there remains opportunity for further development of concepts and refinement of theory. This thesis research intends to address two noted gaps by examining: 1) a core urban area where crime is concentrated versus a city or county-wide assessment, considering the higher rate of crime in urban versus rural areas; and 2) a longitudinal analysis of crime occurrence over time as it relates to trees (per my own review of existing research, no such analysis has been completed).

Chapter 3: Methods

3.1 Aim and Objectives of Research

The following research focuses on validating the relationship between urban tree canopy cover and crime occurrence, specifically exploring the hypothesis that a greater percentage of tree canopy cover in an urban core area has an inverse effect on crime, leading to reduced instances. To accomplish this main objective, a defined urban space was established as the study area; socioeconomic variables at the census block group level were controlled for and assessed; statistical and Geographic Information System (GIS) analysis was used to examine the potential effect of urban tree canopy cover on crime occurrence; and the inclusion of spatial data and analysis helped to mitigate the impact of surrounding areas on the imposed study area boundary.

Examining a potential temporal relationship between canopy cover and crime instances using a repeated cross-sectional analysis to assess potential change over a seven-year time span will be used to explore the relationship in more depth. This secondary hypothesis proposes that as more trees are planted or as trees grow larger over time, providing a greater urban tree canopy cover, reduced crime occurrence will follow.

Testing both hypotheses involved data collected from third-party sources and data generated through the use of ArcGIS software.

3.2 Study Site Description

The City of Olympia is located in Thurston County, Washington at the southern-most tip of Puget Sound on Budd Inlet. With a population of 49,670 as of 2014, Olympia encompasses approximately 19.72 square miles (City of Olympia, 2015). The police department divides the City of Olympia into six patrol sectors, where sector "B" encompasses the downtown business core, extends up the west and east sides of Budd Inlet, up to and including the State Capitol Campus (see Figure 1). The City of Olympia defines a comparable area, with respect to boundaries, as the "Downtown Strategy Area," although it excludes the Capitol Campus area (see Appendix A).

To meet the intent of this analysis, patrol sector B provides full coverage of the urban area of interest and several bordering, semi-residential areas. Additionally, using the patrol sector as the selected study area serves three purposes:

1) Previous studies focused on broad or varied geographical areas, at single neighborhood, city-wide, and county-wide scales. In order to examine the impacts of urban forest canopy cover specifically on crime occurrence, this study focuses on an urban core and, to account for border effects, the areas closely surrounding that core.
2) Olympia dedicates a significant amount of resources and coordination to providing a comprehensive plan for improving the downtown area in terms of increased safety, greater economic revenue, broader community participation, and support for natural and historic spaces (City of Olympia, 2015). Focusing on patrol sector B supports Olympia's downtown strategic actions and will provide data to inform funding decisions, tree maintenance regimes, and safety regulation protocols.
3) As cities begin to address ways to account for the impacts of climate change, increased urban populations, and the need for accessible open green space, support for urban "greening" methods continues to increase. Further data to

support the inclusion or development of additional green space within cities, specifically trees, can contribute to decisions made that affect overall public health and environmental well-being.

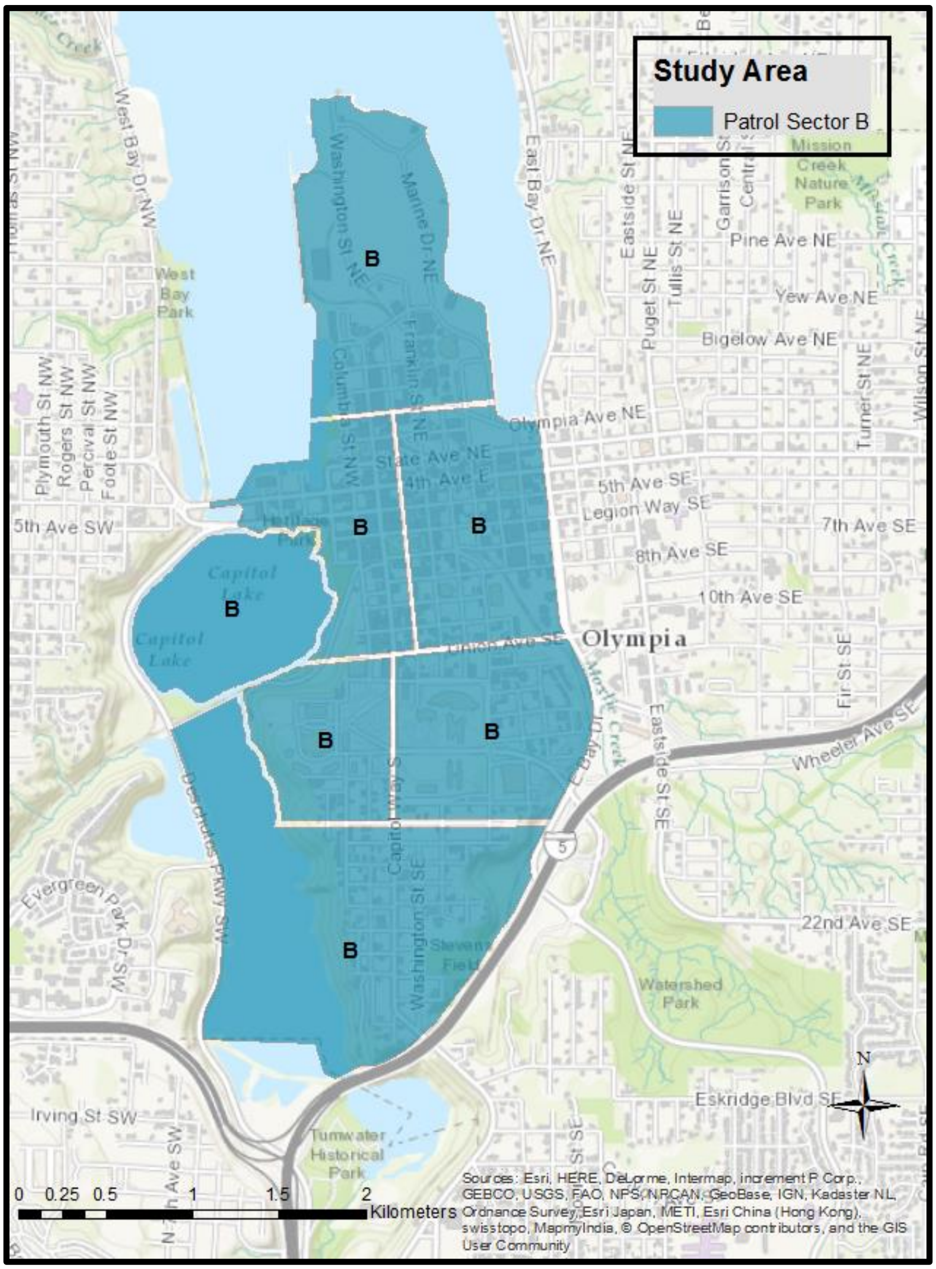

Figure 1. The defined study area based on the City of Olympia Police Department boundaries for patrol sector “B,” depicted over a map of Olympia, Washington.

3.3 Data

3.3.1 Variables

3.3.1.1 Urban Tree Canopy Cover

Canopy cover measures the tree crown diameter combined across all trees in a designated area; some studies cite tree crown radius as an alternate measurement (McPherson et al., 2005). Canopy cover need not be continuous by this definition; rather, the total percentage of coverage accounts for the measurement in the designated area. Percentage of tree canopy cover provides the necessary variable for this analysis, based on research demonstrating that a view of trees over other vegetation, high-canopied trees, and clear, open areas with well-spaced trees provides maximum, positive psychological benefit.

For this study, an urban tree canopy cover dataset was created using Light Detection and Ranging (LiDAR) and orthoimagery (high resolution aerial images with a near-infrared band) data obtained from the City of Olympia. LiDAR is a remote-sensing technique that uses laser light pulses to survey and model the earth's surface, often through aerial methods. The laser pulses reflect on the earth's surface and objects on the earth's surface (buildings, trees, etc.), returning points that can be geographically referenced for analysis.

During 2008 and 2015, the City conducted two LiDAR data collection events. Data for 2015 were collected to "match" the specifications of the 2008 data set, producing comparable results. The City provided raster data for each year in the form of an ArcGIS file geodatabase, using 3.0 Foot Esri Grids (LiDAR Bare Earth and Highest Hit models that reference the lowest and highest laser return points, respectively) and 1.5

Foot GeoTiffs (high-intensity orthoimages). See Appendix B for visuals of the raw datasets.

3.3.1.2 Crime Incident Data

Crime rate figures in both rural and urban areas originate from data tracked voluntarily by many cities, counties, and states. The Uniform Crime Reporting (UCR) Program, managed by the Federal Bureau of Investigation (FBI) since 1930, collects this nationwide crime data for statistical purposes. The most recently published data for the United States demonstrates a rate of 395.7 violent crimes per 100,000 inhabitants in urban areas, as compared to national violent crime rate of 375.7 (Uniform Crime Reports, 2015). The violent crime rates in Washington State and the City of Olympia are 285.2 and 198, respectively (Uniform Crime Reports, 2015). Considering that the this thesis research examines a core urban area, it is additionally useful to note that the national total crime rate outside of metropolitan areas is lower, averaging 168.5 for counties with populations over 25,000, such as Thurston County. Drawing an exact comparison to the City of Olympia presents challenges, as total crime rates are reported per 1000 people, versus 100,000. The Olympia Police Department reported total rime rates of 53.5 in 2008 and 86.3 for 2014 (see 3.4.3 Limitations, Crime Coding Effects for further information about the large gap in reported crime rates).

For this study, the City of Olympia Police Department provided annual crime data for 2008 and 2014 in the format of two Excel spreadsheets[1]. The data included date and time of the crime incident, type of crime, and geo-coordinates based on the North American Datum (NAD) 1983 State Plane for Washington (South FIPS, 4602, US Feet).

[1] The City of Olympia provided the annual crime data in response to a public records request submitted by the author.

This commonly used projected coordinate system supports best-practice with highly-localized, georeferenced data and provides detailed accuracy (with errors less than 1:10,000).

3.3.1.3 Socio-demographic Data

Following the methodology established for control variables in correlation studies between trees and crime (Gilstad-Hayden et al., 2015; Troy et al., 2012; Wolfe & Mennis, 2012), socio-demographic data was sourced from the U.S. Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) database, using shapefiles prejoined with Amercan Community Survey (ACS) demographic data tables at the census block group level. The selected ACS shapefiles included the five-year detailed estimates for the 2008-2012 and 2010-2014 surveys to most closely align with the available LiDAR/orthoimagery and corresponding crime data in this study.

The socio-demographic variables utilized for this study included a subset of the controls selected in previous studies (noted in preceding paragraph), namely median income (median household income in the past twelve months based on 2012 and 2014 inflation-adjusted dollars, respectively), education level (percentage of the area population without at least a high school diploma), and race/ethnicity (percentages of the area population identifying as Hispanic/Latino and as Non-Hispanic/Latino and African American/Black), and total population per block group within the study area.

3.3.1.4 Spatial Data

Census block group boundaries provided the necessary geographical parameters for spatial referencing and analysis of the established dependent and independent variables. Census tracts are divided statistically into block groups, which are designated to contain approximately 600 to 3000 people (United States Census Bureau, 2012). Block group data were sourced from the U.S. Census Bureau’s TIGER database, using the same selection as described for the socio-demographic data. The data has been transformed by Esri into ArcGIS compatible shapefiles, available for download and direct import into ArcMap 10.3 (see Figure 2).

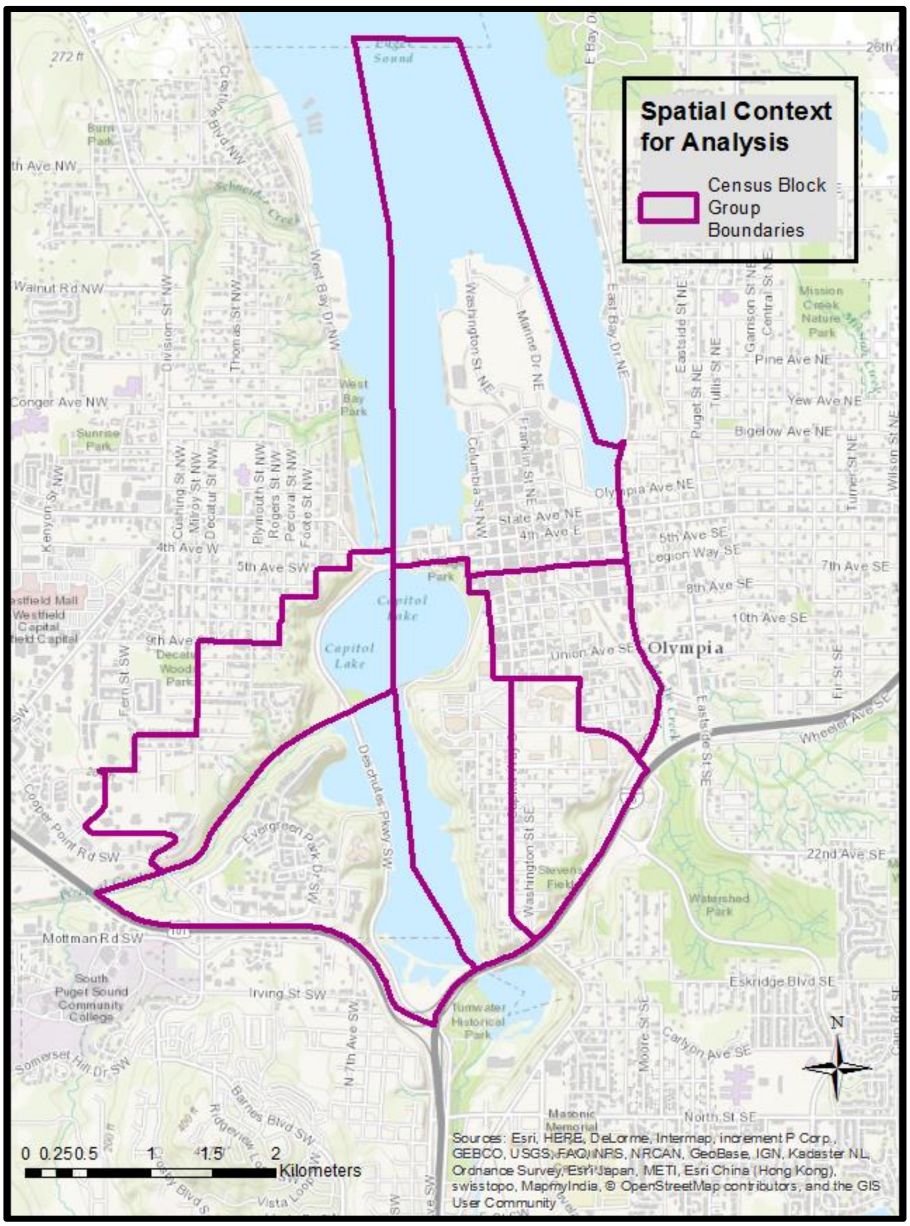

Figure 2. Census block group boundaries overlaying the downtown core of Olympia, Washington. Block group boundaries from the 2008-2012 dataset are depicted, although the 2010-2014 dataset had identical boundaries.

3.3.2 Data Preparation

Preparation of each data component – urban tree canopy cover, crime, and socioeconomic factors – involved some initial refinement using Microsoft Excel 2010 and JMP Pro 12.1.0. However, the majority of the data preparation involved curation via Geographic Information Systems (GIS) by either creating the datasets within, or importing them into, the ArcGIS software suite and compiling a spatial database. Using ArcCatalog and ArcMap 10.3 for refinement of each variable contributed to alignment of all data at the census block group level within the study area.

To derive percentages of urban tree canopy cover, the LiDAR and GeoTiff orthoimagery 2008 and 2015 datasets were imported into ArcMap 10.3 and clipped to cover the designated study area. Exploratory analysis was performed using the bare earth (BE) and highest hit (HH) LiDAR data to create a shaded relief (also called hillshade) map of the study area, assessing for general elevation differences and potential basins of vegetation that would not be defined as canopy cover. This method assessed vegetation levels above five feet in height and within the highest return point range: HH - (BE + 5 feet). Next, two urban tree canopy layers were digitized and edited using the orthoimagery for each year. The editing process involved drawing polygons over the orthoimagery, each of which constituted a unique feature in the GIS layers' attribute tables (see Figures 3 and 4). Data from each feature was summed and organized by census block group boundaries overlaying the study area. The boundaries provided the parameters for determining the percentages of urban tree canopy coverage, calculated from the attribute table for each year's layer.

Figure 3. Tree canopy layer created using ArcMap 10.3 from 2008 orthoimagery.

Figure 4. Tree canopy layer created using ArcMap 10.3 from 2015 orthoimagery.

From the Excel spreadsheets for each year, crime data was coded according to the National Incident-Based Reporting System (NIBRS), managed by the Federal Bureau of Investigation (FBI) Uniform Crime Reporting (UCR) Program. However, due to discrepancies between crime data reporting methods for 2008 and 2014 (discussed in 3.4.3 Limitations, Crime Coding Effects), the variables calculated for analysis included total crime counts (per incident), crime density, and total crime rates versus categorization by crime type. Each crime dataset was geocoded and imported into ArcMap 10.3 and variables were calculated within the census block group boundaries that overlaid the study area.

Socioeconomic data, coming in geographically-referenced tables for all of Washington State, were first narrowed to the relevant census block groups covering the study area using ArcMap 10.3. Using Excel, percentages were calculated for the selected control variables: median income, race/ethnicity, educational attainment, and population density. Since the census block group is a relatively small geographic area, the calculation for population density used square kilometers instead of square miles. All control variable calculations were spatially joined to the corresponding block group.

3.4 Limitations

3.4.1 LiDAR data

While the LiDAR data collection events for 2008 and 2015 covered the same geographic area (the City of Olympia), the exact time of year that the aerial flight took place does not appear to perfectly align. The 2015 aerial flight took place in late May. The month during which the 2008 flight took place is unknown; however, based on observational assessments of Capital Lake in the GeoTiff files, and the presence of algal blooms which typically occur from May through October, it appears the flight took place later in the summer. Similar algal blooms do not appear to be present in the 2015 orthoimagery dataset. The trees in both datasets appear to be in full leaf-out stage, lending support to the conclusion that the time discrepancy likely will not significantly affect the calculations of percent tree canopy coverage for respective years.

Additionally, there were some challenges in discerning the boundary of tree crowns when densely surrounded by vegetation. Assessing shaded relief maps using the BE and HH datasets provided some mitigation of error, and the infra-red band of the orthoimagery supported further clarity in discerning shadows, vegetation, and taller shrubbery from tree canopy. Based on these methods, the error in identifying tree canopy is estimated to be minimal.

Finally, analysis for this research began in mid-2015, as the most recent LiDAR event occurred. To secure corresponding crime and socio-demographic data at an annual scale, 2014 was selected as the most recent, full year for data analysis. Since primary tree growth occurs during the winter, the time delay will likely not have a large impact in this analysis.

3.4.2 Variable Boundaries

The main study area boundary was provided by the Olympia Police Department's patrol sector "B"; however, the two of the census block groups' boundaries partially extend into patrol sector "A." Since crime data was not sourced for sector "A," the crime density variable for this block group is expected to be lower when using only sector "B" crime data. Considering the relatively low incident rate (see Appendix C, map legend inset) and that canopy coverage is identified only within patrol sector "B," it may actually be improve the accuracy of the analysis to isolate the B sector crimes; including additional crime data would likely inflate the results and lead to incorrect inferences.

3.4.3 Crime Coding Effects

Between the 2008 and 2014, the years of selected crime data for this study, the State of Washington (and therefore the City of Olympia) changed the way such data are collected and reported. In 2008, the State used the Washington Uniform Crime Reporting (UCR) Program, based on guidelines and a national UCR program established by the Federal Bureau of Investigation (FBI). Due to program inefficiencies and lack of sufficient detail in the Summary UCR data collected, the State opted to transition to the National Incident-Based Reporting System (NIBRS) which collects more in-depth data on individual crime occurrences (Washington Association of Sheriffs and Police Chiefs, 2008). The 2014 data represents the third year in which the State captured crime occurrence using the NIBRS coding guidelines.

For this study, the impact of the change from Summary UCR to NIBRS methods means that the crime count for 2014 may be slightly inflated, giving the appearance of more crimes having occurred, or may appear to have a more significant increase over 2008 occurrences than is warranted. Multiple "incidents" may be reported for each crime and coded separately in NIBRS, reflecting the difference in how crimes are categorized. To mitigate this impact, the study's analysis used total crime, crime rate, and crime density calculations versus previously established variables for distinguishing violent or property crimes, as categorized under the Summary UCR guidelines.

3.5 Statistical Analysis

Analysis began by assessing the characteristics of the crime, urban tree canopy cover, and socio-demographic data, using descriptive statistics of the mean, standard deviation, and range for each variable. In ArcGIS 10.3, an exploratory analysis was conducted to examine the spatial distributions of crime and identify potential patterns or clustering. This method of data visualization used crime heat maps and an underlying choropleth layer shaded by tree canopy distribution.

The first hypothesis, examining urban tree canopy cover and crime occurrence, was tested using Ordinary Least Squares regression, which can be expressed as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_{2\,+\,\dots}\,\beta_n X_n + \varepsilon$$

Initial regression models included the variables total crime count, crime rate, and crime density and urban tree canopy cover, but not the control variables. Due to theoretical considerations (based on subsequent spatial regression analysis described later) and regression assumptions not being met using crime count or density calculations, a fitted regression model using crime rate as the sole outcome variable was selected for each year. For this model, histograms and residual error plots demonstrated more normally distributed error terms and reductions in heteroscedasticity, respectively. To incorporate the four control variables, the sample data aggregated at the block group level (n=6) was bootstrapped (n=6000) to meet regression assumptions. Variance inflation factors were persistently high when incorporating race and ethnicity (VIF > 4), indicating multicollinearity. Ethnicity proved a better fit than race, based on model fit assumptions and a lower VIF factor. Similar results occurred with median income and educational attainment (VIF > 41), however, due to model over-fitting, these variables were also removed.

Following OLS regression for each year, Global Moran's I tests were carried out on the residuals to assess for spatial dependency; each resultant statistic demonstrated significant spatial autocorrelation. This effect results from block groups sharing physical boundaries with other block groups and city zones, affecting the assumed independent nature of the data. As a result, the independent variables and error terms cannot be assumed to be uncorrelated and the inferences may be overestimated if not accounting for spatial dependency, i.e., crime is affected by variables in neighboring block groups. Crime occurrence tends to be relatively the same in neighboring block groups versus those further away due to spillover effects (Gilstad-Hayden et al., 2015; Troy et al., 2012; Wolfe & Mennis, 2012).

To address the effects of spatially dependent data, spatial analysis takes into account arbitrary boundaries and effects of near-boundary incidents. A spatial weights matrix was constructed, specifically a k-nearest neighbors matrix which places weights on each variable according to the distance between a value and the number (k) of nearest neighbor values. The block group shapefiles joined with explanatory variables were imported into ArcGIS 10.3 to create the matrix and. Including the spatial weights matrix as part of the Global Moran's I test allows for measurement of the linear relationship between a variable and the weighted average of its neighbors, using a model that can be expressed as:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2}$$

where *i* and *j* represent features (values of observations), *n* is the total number of features, z_i and z_j denote the deviation from the mean of a feature, $w_{i,j}$ denotes the weighted value between two features (*i* and *j*) of the row-standardized matrix, and S_0 is the sum of all weights ($w_{i,j}$) in the matrix. Using this model, with an incorporated spatial weights matrix, Global Moran's I tests were re-run on the OLS residuals.

The second hypothesis, assessing the change in tree canopy cover compared to crime occurrence over time, was tested using a repeated cross-sectional analysis. The same percentages of block group canopy cover and crime rate calculations were organized by year and imported into ArcGIS 10.3 to assess mean change over time and examine spatial differences.

Chapter 4: Results

4.1 Descriptive Statistics

Table 1 provides the descriptive characteristics of each regression variable, summarized by block group and year of analysis. The dependent variable (crime rate) and independent variables (tree canopy, socio-demographic factors) demonstrated clear variability across block groups. Total crime and total population are included as reference for the calculations of other variables. Averages for Total crimes and Crime rate were 225 and 385.35 in 2008 and 178.33 and 249.61 in 2014, respectively[2]. Tree canopy coverage for both years remained fairly steady at approximately 13%, with a slight (less than 1%) increase in 2015. The average median income for household block groups decreased in 2014, although it was interesting to note the shift in range maximum by approximately $12,000. Total populations within block groups varied slightly each year, but percentages of non-Hispanic African-American/Black and Hispanic-Latino remained relatively the same.

Examination of heat and choropleth maps revealed strong clustering of crime in less densely canopied areas for both years, suggesting that block groups with less urban tree canopy cover experience less total crime occurrence (see Figure 5).

[2] Crime rates appear inflated over those reported by the Olympia Police Department due to calculations conducted on population levels under 1000. For consistency in results, the numbers were calculated similar to standard reporting protocols.

Table 1. Descriptive statistics for study area block groups in Olympia, Washington.

Variable	Mean	Std. Dev.	Minimum	Maximum
2008 (*n* = 6)				
Total crimes	225.00	424.33	0.00	1071.00
Crime rate (per 1000 people)	385.35	806.43	0.00	2020.75
Tree canopy cover (%)	13.07	14.24	0.44	25.45
Median Income	58648.17	35345.84	14884.00	98228.00
Educational attainment (% with less than high school diploma)	1.97	2.59	0.00	6.79
Hispanic-Latino (%)	5.25	5.71	0.00	16.01
Non-Hispanic, African-American/Black (%)	1.83	3.54	0.00	8.85
Total population	924.17	370.25	530.00	1605.00
Population Density (1000 people/sq km)	429.70	239.90	95.67	724.26
2014 (*n* = 6)				
Total crimes	178.33	313.60	1.00	802.00
Crime rate (per 1000 people)	249.61	473.85	0.66	1206.02
Tree canopy cover (%)	13.50	14.23	0.58	33.50
Median Income	52964.50	27444.10	16591.00	86161.00
Educational attainment (% with less than high school diploma)	1.40	1.37	0.00	3.46
Hispanic-Latino (%)	5.65	5.06	0.00	14.01
Non-Hispanic, African-American/Black (%)	1.85	2.31	0.00	5.38
Total population	912.00	328.13	640.00	1523.00
Population Density (1000 people/sq km)	420.91	233.03	120.04	724.26

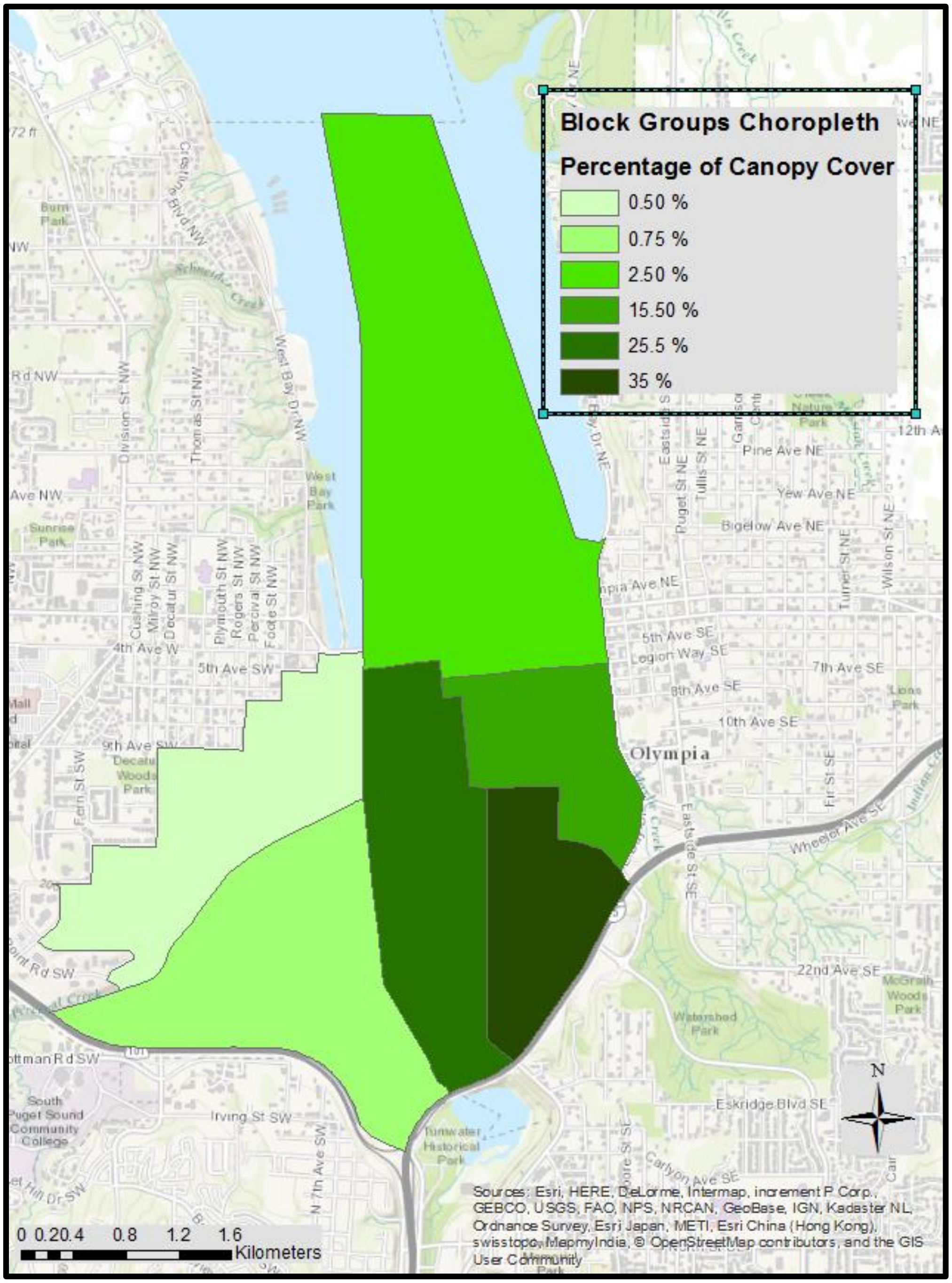

Figure 5. Choropleth map of 2008 block groups shaded by percent canopy cover. 2015 choropleth maps demonstrated similar results.

4.2 Statistical Analysis Results

Table 2 provides the results from the Ordinary Least Squares regression analysis assessing the explanatory power of urban tree canopy cover and socio-demographic variables on total crime rate for both 2008 and 2014-15 datasets. Urban tree canopy cover had a statistically significant relationship with crime rate in 2008 (β = -13.114, $p < 0.001$) and in 2014 (β = -7.910, $p < 0.001$).

Table 2. Results from Ordinary Least Squares regression models.

	Crime Rate (per 1000 people)		
Variable	β	SE	Pr > |t|
2008 (*n* = 6000)			
Tree canopy cover (%)	-13.114	0.591	< 0.001
Median Income	n.s.	n.s.	n.s.
Educational attainment (% with less than high school diploma)	n.s.	n.s.	n.s.
Hispanic-Latino (%)	-63.009	1.282	< 0.001
Non-Hispanic, African-American/Black (%)	n.s.	n.s.	n.s.
Population Density (1000 people/sq mile	-2.001	0.033	< 0.001
Intercept	1746.414	16.417	< 0.001
Adjusted R-Squared	0.57		
2014 (*n* = 6000)			
Tree canopy cover (%)	-7.910	0.302	< 0.001
Median Income	n.s.	n.s.	n.s.
Educational attainment (% with less than high school diploma)	n.s.	n.s.	n.s.
Hispanic-Latino (%)	-51.242	0.811	< 0.001
Non-Hispanic, African-American/Black (%)	n.s.	n.s.	n.s.
Population Density (1000 people/sq mile	-0.663	0.019	< 0.001
Intercept	924.644	8.639	< 0.001
Adjusted R-Squared	0.58		

OLS regression using ArcGIS 10.3 provides a geographically symbolized map of the standardized residuals (see Figures 6 and 7). Following OLS regression for each year, a Global Moran's I test on the residuals from both 2008 and 2014 regression models demonstrated significant spatial autocorrelation ($I = 1$, $p < 0.0001$). The Moran's I statistic is measured between -1 and 1, where values closer to positive 1 represent greater spatial clustering and values are autocorrelated. After constructing a spatial weights matrix, a second Global Moran's I test was carried out on the residuals. The resulting Moran's statistic demonstrated only slight reductions in the effect of spatial autocorrelation ($I = 0.998$, $p < 0.0001$) for both years.

While the Moran's I test examines the potential neighboring influences of spatial data, the Koenker (BP) Statistic describes the consistency of the relationship between the modeled dependent variable and explanatory variables in both geographic space and data space. With consistent relationships in the geographic space, the data are said to be stationary. The parallel in data space is minimizing heteroscedasticity in the regression model, where the size of the error terms varies significantly across the explanatory variables' values.

Further examination of the results after including the Moran's I statistic revealed a significant BP statistic (5772.245, $df = 3$, $p < 0.05$), demonstrating statistically significant regional variation (non-stationarity) in the geographic properties of the explanatory variables data. The significant BP values for both 2008 and 2014 supported using robust standard errors over regular standard errors, as well as using the Wald Statistic (6093.281, $df = 3$, $p < 0.01$) to assess good over-all regression model fit for analysis.

Cross-sectional time analysis involved spatial exploration and comparison of the mean differences between the change in crime rate and the change in percentage canopy cover between 2008 and 2014. While there was a relatively large decrease in the crime rate over 7 years, the analysis demonstrated a non-significant relationship in the reduction of crime occurrence and the approximate 0.5% increase in tree canopy cover.

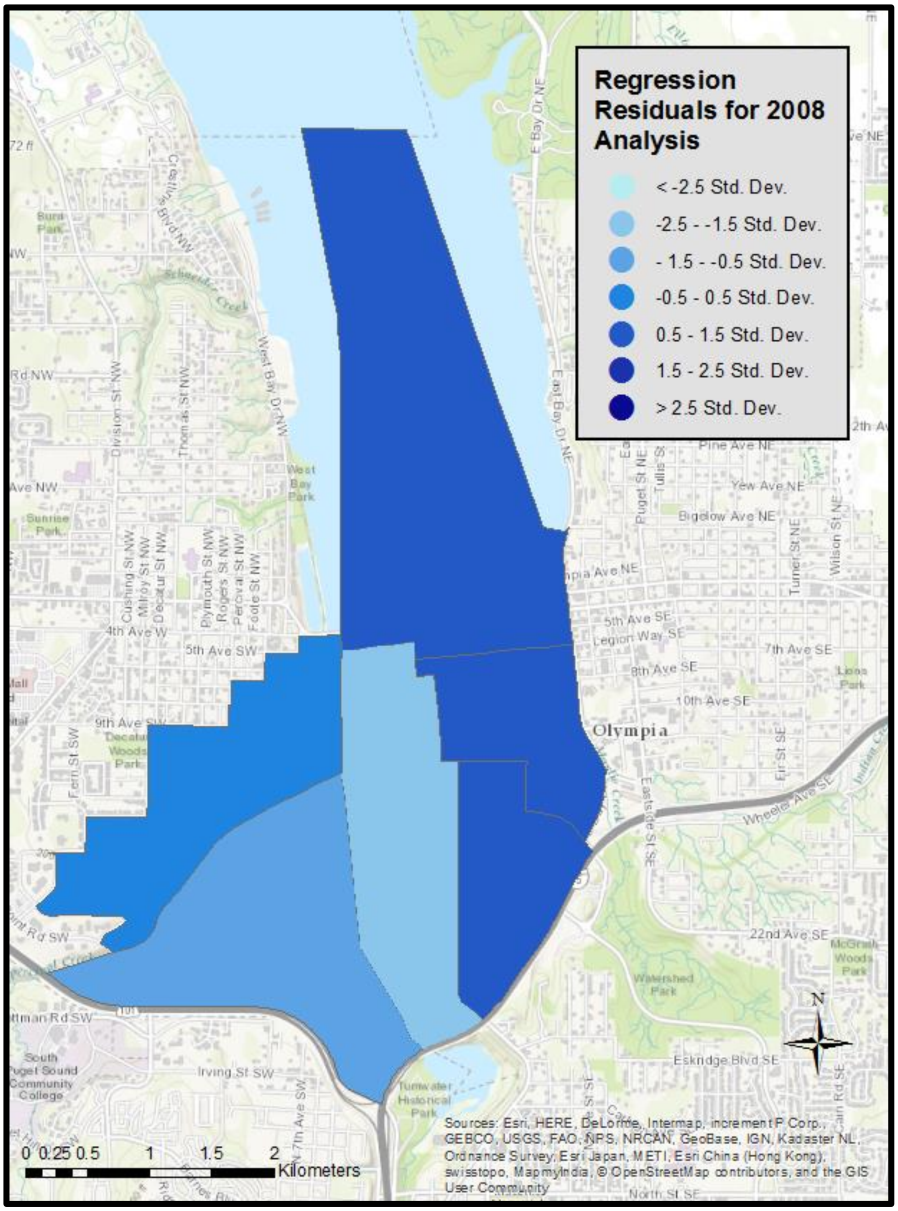

Figure 6. Geographically symbolized map of residuals for 2008 analysis. Created with ArcMap 10.3.

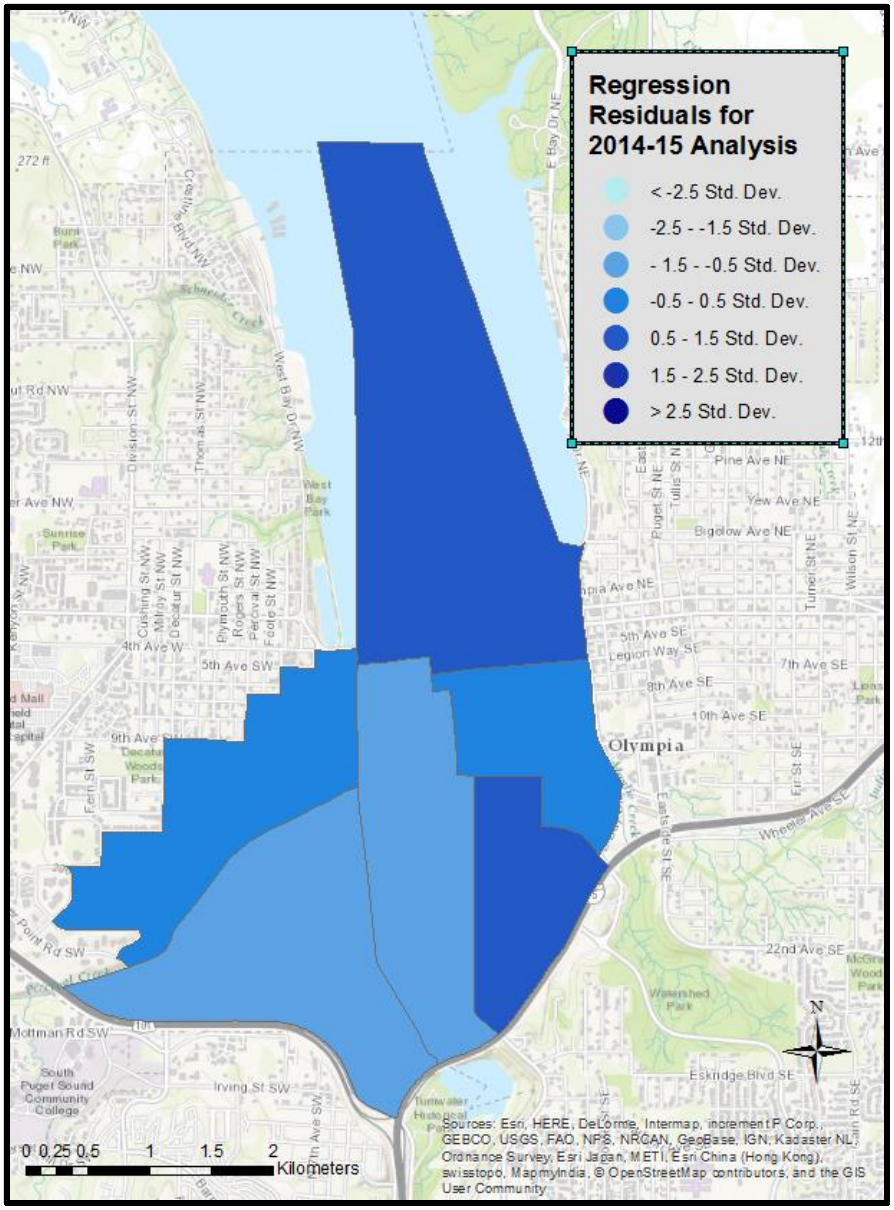

Figure 7. Geographically symbolized map of residuals for 2014-15 analysis. Created with ArcMap 10.3.

4.3 Discussion

The City of Olympia's urban core served as a study area to examine the relationship between urban tree canopy cover and the occurrence of crime. The small scale provided the opportunity to assess and validate whether greater tree canopy cover supports crime suppression in primarily non-residential areas. The study area encompassed six census block groups for which data were compiled and examined.

Regression analysis of the relationship between urban tree canopy cover and crime occurrence, independent of socio-demographic controls, demonstrated that areas with higher percentages of canopy cover are associated with reduced instances of crime. The inclusion of socio-demographic controls further supported the validated inverse relationship between canopy cover and crime occurrence by providing a mechanism to measure potentially confounding factors in the analysis. The results support the associated findings of other studies concerning tree canopy cover and crime suppression at various geographic scales (Donovan & Prestemon, 2012; Gilstad-Hayden et al., 2015; Kuo & Sullivan, 2001a; Troy et al., 2012; Wolfe et al., 2012).

While the resulting regression analysis of trees and crime agreed with the hypothesized relationship, the limitation of certain control factors in this study warrants further consideration. Although block groups with higher population density demonstrated reduced crime occurrence, this may be due to the urban nature of the study design which includes a limited population residing in the more urban census block groups of Olympia's defined downtown zone. This may also explain why the expected relationships between median income and educational attainment with crime occurrence were not significant. Without sufficient data, due to low population counts, these variables had negligible effects and instead served to over-fit the regression model.

Upon close analysis of Olympia's downtown, one can find a lack of open green space and several notable areas where no trees are present for several blocks. The argument follows that if a view of nature positively supports mental health, and positive mental health leads to reduced crime occurrences, then the areas lacking trees should have inversely higher crime rates. The results from this study align with the theoretical basis for selecting of tree canopy cover as a variable in crime suppression studies, versus vegetation or green spaces in general, mainly because it is not the mere presence of trees or a specific count of trees, but the overall percentage of coverage in a given area. The ability to view nature is enhanced specifically by trees due to the inherent nature of height – those trees that can tower above buildings, lots, or other urban spaces are easier to see and contribute to the greening of the visual landscape.

Chapter 5: Conclusion

5.1 Research Conclusions

Increasing residential populations in cities continue to accentuate the importance of incorporating green space within urban areas. Losses in tree canopy cover contribute to the shortfall of several beneficial factors, including the provision of mental health benefits and suppression of crime. This study provided an opportunity to examine urban trees at a small geographic scale, in the urban core of a moderately sized city. While additional scaled models could provide further validation, the results from this research demonstrate that maintaining higher percentages of tree canopy cover can support reduced crime occurrences.

As cities balance economic and social demands, funding shifts generally have a negative impact on park enhancement or maintenance priorities. The effects of reduced availability or quality of green space may not understood or immediately prevalent. However, research continues to demonstrate the importance of nature to mental health. Providing data to support availability, access, and abundance of trees supports these findings and may encourage cities to invest further in planting and care regimes.

> "Never say there is nothing beautiful in the world anymore. There is always something to make you wonder in the shape of a tree, the trembling of a leaf."
> Albert Schweitzer (Theologian, Surgeon, Nobel Peace Prize Winner)

5.2 Recommendations for Further Research

There are opportunities to enhance the research conducted in this study. First, a deeper understanding of the NIBRS coding system could support categorizing crimes by type and understanding their specific relationship to urban tree canopy cover. For example, since more businesses are present in a downtown setting there may be a relatively higher rate of property crimes such as theft or vandalism. Alternatively, drawing a greater number of people into the space for shopping may increase the violent crime rate due to the increased chances for robbery or assault.

A second opportunity for further analysis is the examination of longitudinal effects. A temporal component was attempted in this study following research by Gilstad-Hayden et al. (2015). However, due to the discrepancies in crime coding and the potential for false inflation of the crime rates, it was not conclusive to assess the rates of change over the seven-year span in this study. Further attempts to assess whether tree canopy cover has a long-term relationship with crime suppression could provide insight into urban greening methods and provide support for consistent funding and maintenance regimes.

Additional considerations include the informal regulatory power of more citizens utilizing open green space. Utilization of a park layer and statistics on community use for a given area may provide insights into the relationship between open space and reduced mental stress, as hypothesized by Kuo (2001a). The phrase “more police on the beat, more crimes on the street” refers to the increased prevalence of arrest when more officers are on duty. If green spaces draw in more residents, would there be a lower need for more formal regulation and policing? And would this result in fewer arrests because officers are not present (though not a reduction in crime), or in fewer crime incidents because of the larger population influence? These questions and more could be analyzed using a more in-depth study design that incorporates crime coding and a geographically weighted regression analysis that allows for regional variation.

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Appendix A

The City of Olympia defined a downtown strategic area in order to implement a comprehensive plan for increased safety, greater economic revenue, broader community participation, and support for natural and historic spaces (City of Olympia, 2015).

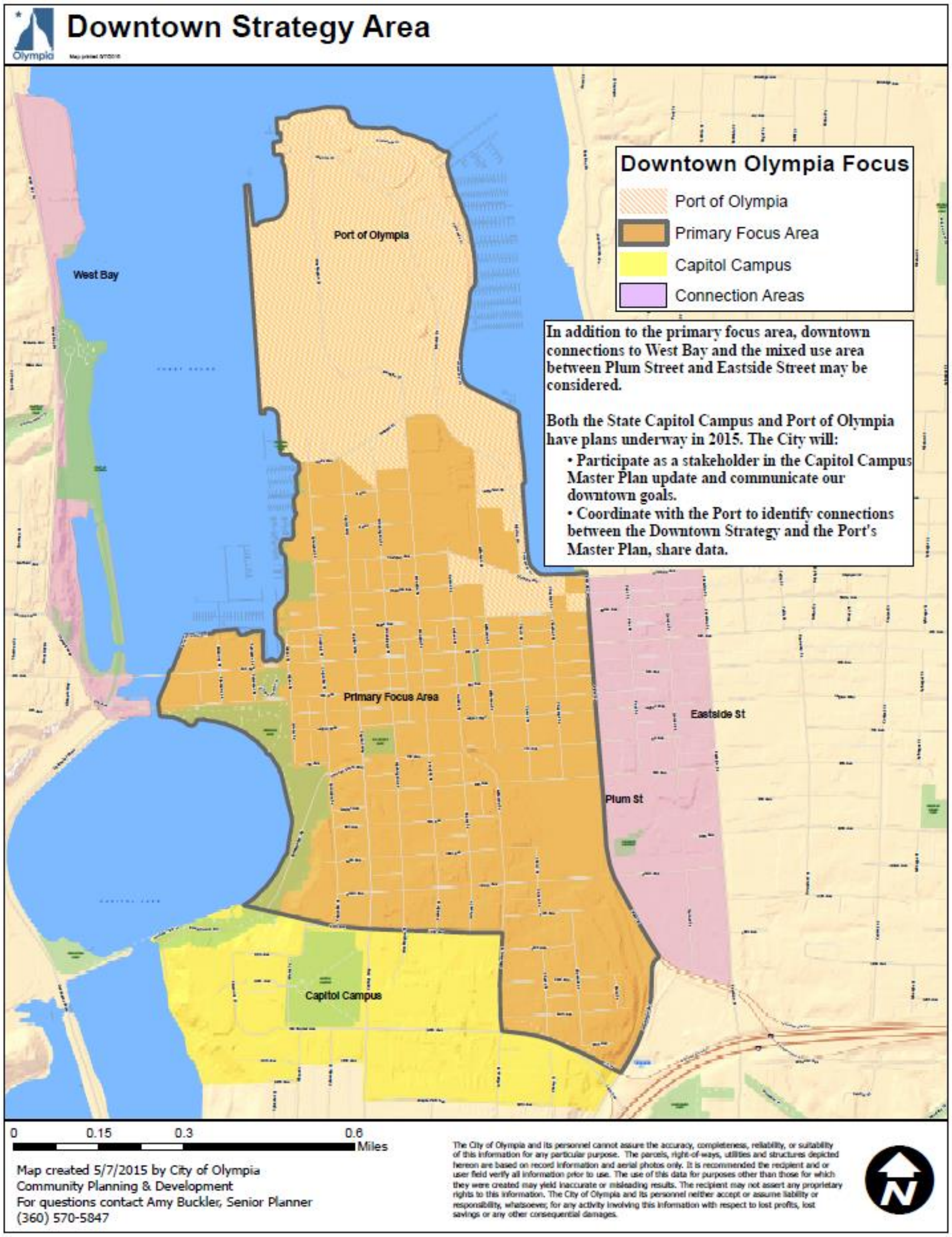

Figure 8. City of Olympia Downtown Strategy Area.

Appendix B

During 2008 and 2015, the City conducted two LiDAR data collection events. The following figures display the 2008 dataset's 3.0 Foot Esri Grids for the LiDAR Bare Earth and Highest Hit models that reference the lowest and highest laser return points, respectively, and the 1.5 Foot GeoTiffs (high-intensity orthoimages) for both 2008 and 2015.

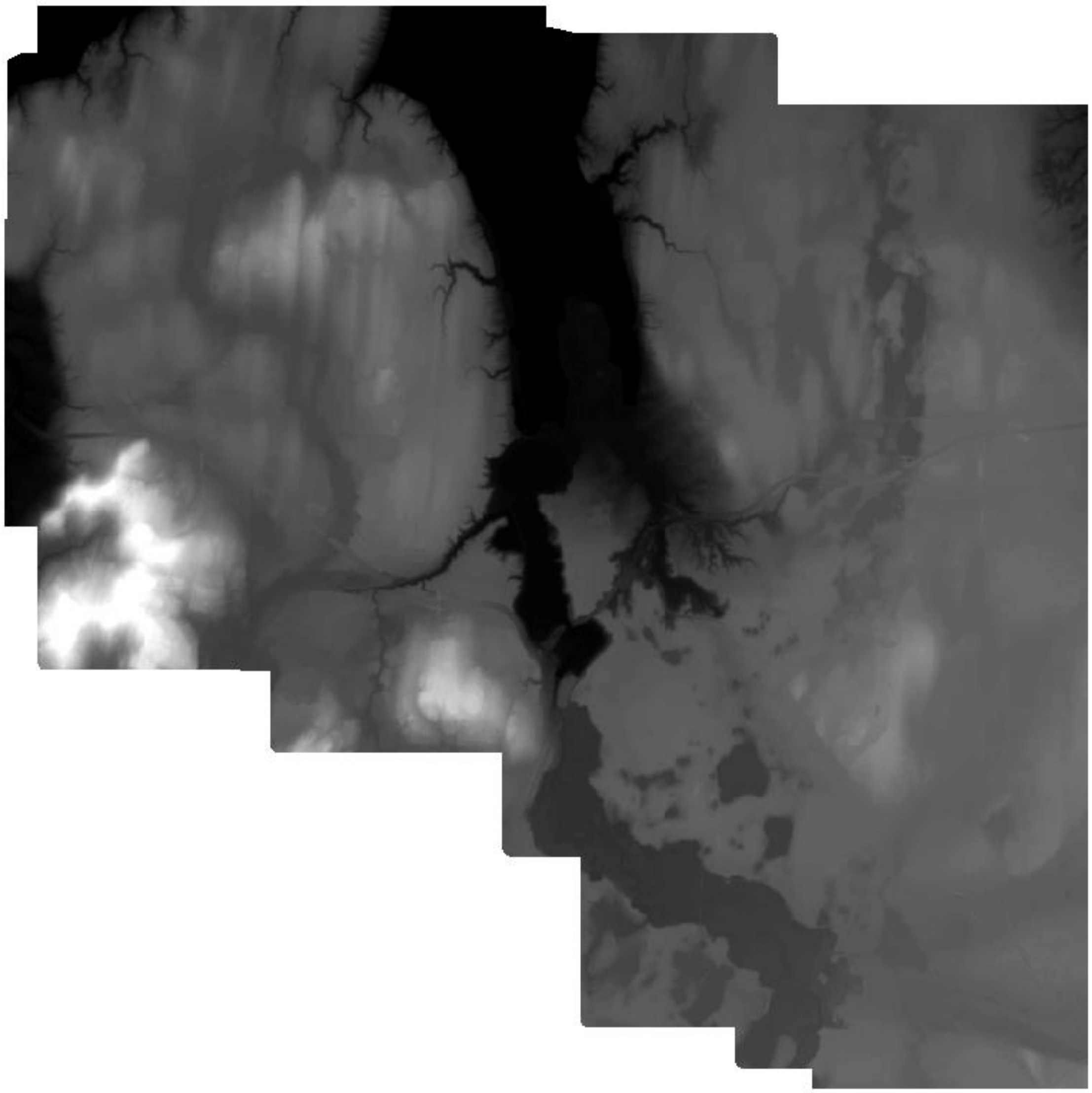

Figure 9. 2008 LiDAR Bare Earth return, 3.0 Foot Esri Grids, Horizontal Datum NAD83 (HARN), Vertical Datum NAVD88 (GEOID03).

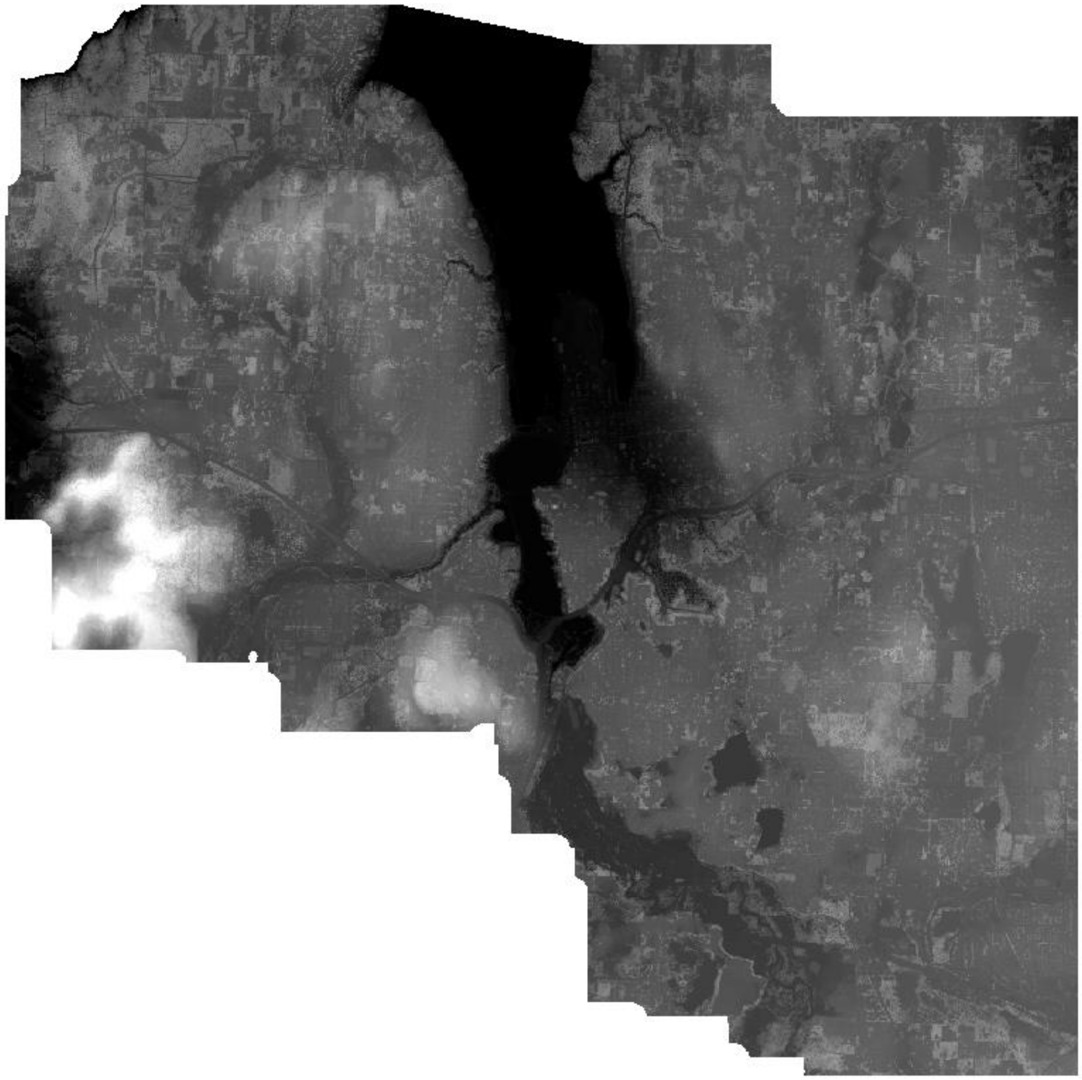

Figure 10. 2008 LiDAR Highest Hit return, 3.0 Foot Esri Grids, Horizontal Datum NAD83 (HARN), Vertical Datum NAVD88 (GEOID03).

Figure 11. 2008 high-intensity orthoimagery, 1.5 Foot GeoTiffs, Datum NAD1983. Inset example demonstrates magnification capability for analysis.

Figure 12. 2015 high-intensity orthoimagery, 1.5 Foot GeoTiffs, Datum NAD1983. Inset example demonstrates magnification capability for analysis.

Appendix C

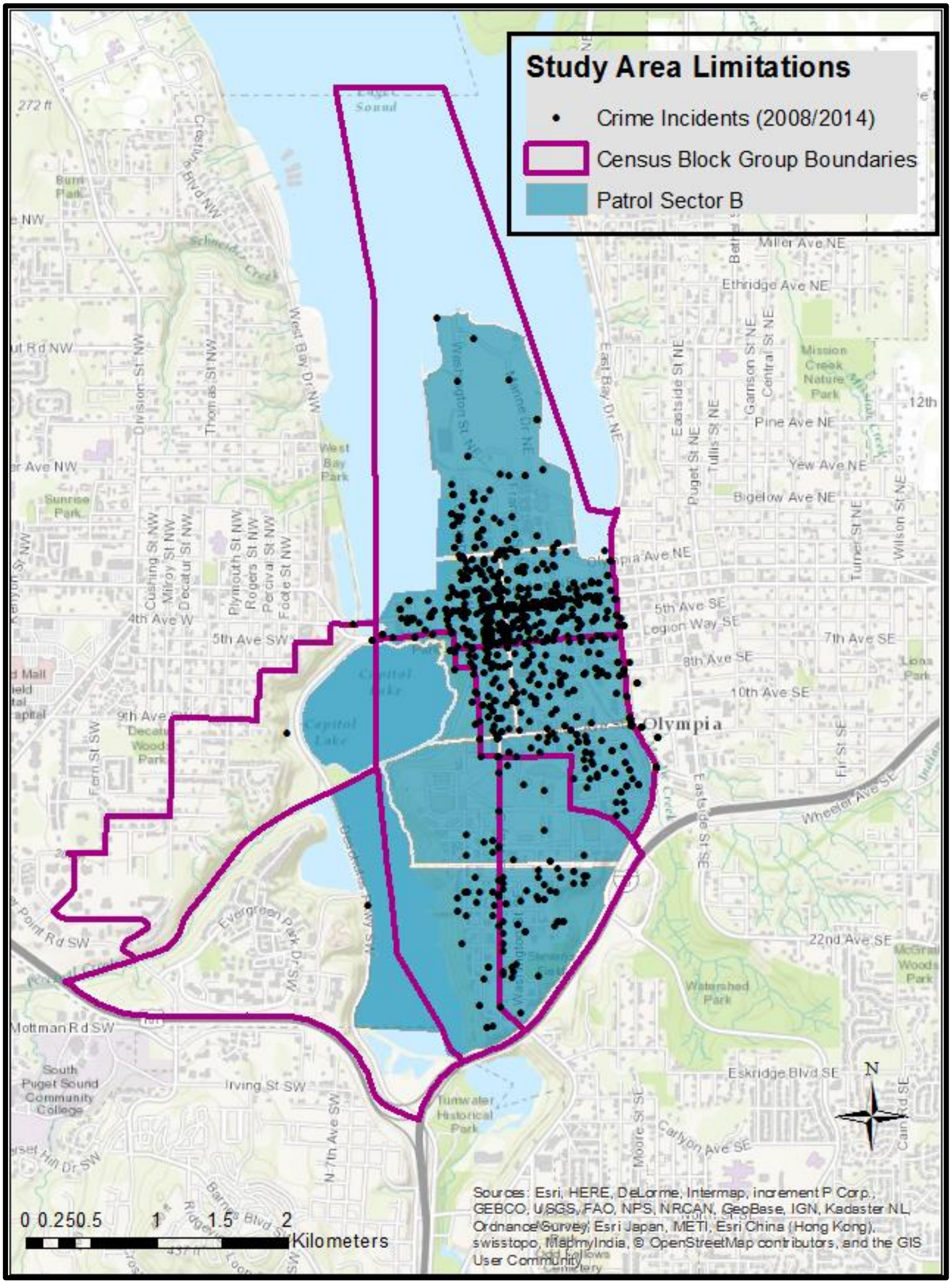

Figure 13. Limitations due to inconsistent boundaries between census block groups and patrol sector "B."