

**SENTINEL CONDITIONS: ESTIMATING RISK OF
RESIDENTIAL BURGLARY VICTIMIZATION USING
SOCIO-ECONOMIC PROXIES**

by

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BA-Honours, University of Saskatchewan 2005

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS

In the
Department of Geography

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SIMON FRASER UNIVERSITY

Fall 2007

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ABSTRACT

Sentinel indicators, regularly applied within the fields of biology, ecology and remote sensing, act as proxies to measure environmental phenomena that are difficult to assess directly. The well-developed sentinel framework can be adapted for use within a crime analysis setting, identifying the relative risk of residential burglary victimization without relying on the crime occurrence data alone. By selecting and combining theory-supported social and economic factors known to relate to the existence of residential burglary, the resulting sentinel layer estimates the geographic patterning of risk of victimization throughout select municipalities in British Columbia. Additional adjustments made to this model expand its geographic applicability, allowing for estimations of relative risk of residential burglary victimization across a wider range of urban areas. In doing so, this methodology increases the understanding of how the relationship between theory-supported socio-economic conditions and residential burglary changes across different urban landscapes.

Keywords: *GIS, proxy mapping, sentinel conditions, socio-economic status.*

DEDICATION

This work is dedicated to Jordan Parente, who has given me endless encouragement and support over the past years. I am so grateful for his patience, companionship, and most of all for his sense of humour. For always finding the lighter side, and for always reminding me what I am working for, I cannot thank him enough.

ACKNOWLEDGEMENTS

I am very grateful for the support and guidance of my supervisory committee, Dr. Nadine Schuurman and Dr. Patricia Brantingham. Your encouragement and leadership have enabled me to explore new and exciting facets of both Geography and Criminology, and I am eager to continue in this pursuit.

Thank you to my lab mates, both in the Geospatial Data Research Lab, and in ICURS. By working with this inspiring, diverse group of individuals, I have been constantly exposed to innovative and refreshing ideas. It has truly been an honour to be a part of these groups.

Special thanks, as well, to both SSHRC (CGS-Masters) and the Institute for Canadian Urban Research Studies, for supporting and funding this research.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Acquiring data can be a problematic aspect of research faced across a variety of disciplinary boundaries. Some phenomena may be too difficult or costly to directly measure (Bortone and Davis 1994; Fitzgerald, Lanno, and Dixon 1999; Gray, Cunjak, and Munkittrick 2004; Regoli et al. 2006); access to other data may be hindered or prevented for ethical, privacy or security reasons (Boulos et al. 2005; Ratcliffe 2004b). Researchers within biology, ecology and remote sensing have responded to this issue by incorporating sentinel data sources into their data collection techniques. Sentinels are proxies, used to acquire information about a phenomenon that cannot be measured directly or easily. By studying and measuring changes in chosen sentinel data, these measurements can then be used to estimate local conditions occurring in the surrounding environment. Such a feature would be a useful addition to crime analysis where individual-level data can be difficult to acquire and may be restricted from public dissemination due to privacy and data security concerns.

1.2 Research Problem

In recent years, law enforcement paradigms have been moving from the traditional, reactive method of control, towards a more proactive style, known as intelligence-led policing (McGarrell, Freilich, and Chermak, 2007; Paulsen 2004;

Ratcliffe and McCullagh 2001). Within this framework, crime analysts focus extensively on data analysis, identifying trends and patterns within crime data, and allowing police resources to focus specifically on recurring problems and crime hotspot locations (Ratcliffe 2004c). Local, area-specific investigation and community-level policing have grown alongside this paradigm, increasing public involvement within law enforcement, (McGarrell, Freilich, and Chermak 2007) while simultaneously requiring an increase in the public dissemination of crime occurrence data (Ratcliffe 2002b). This shift has also resulted in an increase in the use of Geographic Information Systems (GIS) within policing environments, allowing for the quick circulation of up-to-date maps, and depicting trends and patterns in criminal activity (Lodha and Verma 1999, Paulsen 2004).

At the same time, GIS has become an indispensable part of the crime analyst's toolkit, providing accessible, easy-to-understand mapping techniques (Lodha and Verma 1999). A variety of cartographic and GIS methods have been used in policing environments to produce an assortment of maps depicting hotspots of criminal activity (Paulsen 2004, Ratcliffe and McCullagh 1999). While such developments provide indispensable tools for use within policing environments, each method requires crime records or address-level criminal occurrence data as a starting point. This is not a problem for any map intended only for use by security-cleared officers or members, but for privacy reasons, such information may not be publicly disseminated. There are grave privacy and security issues associated with releasing such information to the public (Ratcliffe, 2002b).

As a result of restricted public access to address-level crime records, it is not always possible to develop maps for public display based on individual level data. This data inaccessibility extends to researchers as well. Acquiring sensitive data can require extensive security clearances, and significant challenges are often in place in order to gain the necessary permissions and approvals from ethics and review committees (Boulos et al. 2005). There is a clear public and research-oriented need for both access to crime information, as well as clear constraints to prevent such access. Sentinel conditions are a means of addressing both access and security needs by providing a publicly available, easily accessible proxy to crime data for the purpose of illustrating vulnerability.

1.3 Research Objectives

This thesis proposes and tests a methodology for estimating risks of victimization by using sentinel data sources. A framework is developed to approximate the distribution of risk of crime victimization, by relying on the socio-economic conditions that exist alongside areas of high crime. The methodology draws from sentinel analysis in biology, ecology, and remote sensing research. Recognizing that the features that correlate with one crime are often different from the features associated with another (Brantingham and Brantingham 1993; Eck 2005), residential burglary is chosen as the focus of this study. This research further aims to test the sentinel methodology in a variety of locations, adapting the model in order to better represent spatial distributions of risk of residential burglary victimization across a range of urban settings.

This methodology is a valuable addition to crime analysis for a number of reasons. First, by incorporating sentinel conditions into crime mapping techniques, users will be able to estimate the risk of residential burglary victimization without using individual crime data. This risk surface is created using publicly accessible census information, and thus avoids the challenges of secure data access. Additionally, this methodology can potentially be used in place of actual crime occurrence maps, allowing greater access to approximated risk of victimization patterns at the neighbourhood level, without infringing on individual privacy and data security issues. Furthermore, by shifting the focus off of the crime itself, and onto the social and economic trends occurring alongside the crime, this form of analysis creates a deeper understanding of how such conditions relate to residential burglary patterns, and how this relationship changes across a range of urban landscapes. It should be noted that while sentinel proxy measures rely on *correlated* socio-economic features, this does not imply a *causal* relationship between the sentinels and the crime levels or the risk of victimization.

1.4 Background

1.4.1 Sentinel conditions: setting the scene

Sentinel conditions are widely used within the fields of biology and ecology. They are often termed *sentinel species* or *bioindicators*, referring to the use of one type of organism as a proxy for monitoring changes within an environment (Fitzgerald, Lanno, and Dixon 1999; Regoli et al. 2006). Sentinels are commonly used to assess anthropogenic impacts within a specific area, their reactions to

stressors measured to indirectly indicate levels of environmental degradation (Bortone and Davis 1994; Fitzgerald, Lanno, and Dixon 1999; Gray, Cunjak, and Munkittrick 2004), or to alert humans to the existence of harmful pollutants (Regoli et al. 2006). This area of research has led to the development of a standard framework for the selection of sentinel species, and the description of specific characteristics needed in a successful bioindicator. Such features include a wide species distribution (as the chosen sentinel must exist at all sites being tested), the ability to react and display responses to environmental stressors, limited mobility, and ease of species collection for sampling purposes (Fitzgerald, Lanno, and Dixon 1999; Gray, Cunjak, and Munkittrick 2004; Ruiz et al. 2005). These characteristics are found, in part or in full, throughout the many iterations of sentinel analysis.

Perhaps the most common use of a sentinel species is as an indicator for the presence of contaminants within an environment. In such studies, a specific species living within the areas of interest is selected based on the aforementioned criteria. It is essential for researchers to develop an extensive body of knowledge surrounding the chosen bioindicator, including in-depth background information on the natural behaviour and physical features of the species in an unpolluted environment (Gibbons, Munkittrick, and Taylor 1998). Investigators collect and sample the target species at multiple study sites, compiling information on the population size and characteristics, and often bringing a portion of the sample into a lab setting for dissection and further analysis (Gibbons, Munkittrick, and Taylor 1998; Gray, Cunjak, and Munkittrick

2004). Once researchers have gathered a sufficient amount of information from the sample, they analyze the data to pinpoint discrepancies between normal physical and behavioural characteristics, and those displayed by the sentinel species at the target study sites. Upon detection of inconsistencies between the two datasets, analysts investigate the sample sites, searching for natural or anthropogenic conditions or contaminants that may be responsible for the intra-species variation (Bortone and Davis 1994; Fitzgerald, Lanno, and Dixon 1999; Gibbons, Munkittrick, and Taylor 1998; Gray, Cunjak, and Munkittrick 2004; Ruiz et al. 2005). In this application of sentinel analysis, changes within a well-known species are used as a proxy to indicate the presence of contaminants or other alterations in their surrounding environment, which may negatively affect the species of interest. This ability to measure the existence of one factor, using another, easier-to-acquire feature, is valuable when applied to crime mapping – readily-available sentinel indicators of crime may potentially be used in place of actual crime occurrence data, when such data is inaccessible.

As bioindicators, sentinel species provide a method to locate and measure environmental stressors that may otherwise be problematic to investigate directly. While infrequently applied, this concept can also be valuable when utilized within other fields. A British Columbian study, for example, measured the level of physician compliance with recommended preventative medicine practices by employing several sentinel conditions. The research team selected four prevalent but avoidable types of cancer for use in this study, in order to ensure that all physicians would have experience practicing the preventative measures

associated with each disease (Smith and Herbert 1993). Through a self-evaluation survey, doctors reported their current preventative practices for each sentinel disease. Results were then compared to the standard provincial recommendations, allowing for an assessment of the adherence of physicians to suggested medical practices (Smith and Herbert 1993). This application of sentinel conditions retains some of the original structural elements of bioindicator use, specifically the wide distribution of sentinel disease choice, and the well-developed body of knowledge surrounding the proper preventative measures for each sentinel. Unique to this study is the use of multiple proxies, providing additional layers of data to reinforce and verify the findings. Such methodological additions will be valuable when transferring the concept of sentinels into crime analysis. Because crime is a complex, multifaceted issue, applying several sentinel layers of correlated data will likewise help to provide more reliable estimates of victimization risk.

Further applications of sentinel indicators extend into the field of remote sensing, where satellite images, used in combination with a variety of other data sources, provide a proxy measure of biodiversity. In such cases, the sentinel layers provide an efficient method to assess the relative biodiversity of large areas, creating an alternative to labour-intensive, small-scale field studies. Several common themes run throughout this body of literature. First, relating to the geographic complexity associated with studying an individual at a community level, remote sensing researchers emphasize the difficulty of accurately measuring biodiversity with small-scale remotely sensed images alone (Tumer et

al. 2003). While technology is constantly advancing, permitting higher-resolution images, the analysis of species density and diversity remains a difficult and imprecise science, often prohibited by exorbitant costs of high-resolution data. Because of this, the majority of remotely sensed assessments of biodiversity levels consist of multiple layers of data, used in combination to increase the accuracy of such proxy measures (Turner et al. 2003). Such methods are often coupled with extensive verification procedures, ensuring that the remotely classified species matches with groundtruthed sites.

A sub-field of remote sensing known as Gap Analysis (GAP) is widely used to identify areas of high biodiversity, in order to evaluate and expand natural protection zones. The goals of Gap Analysis are to locate hotspots of biodiversity, and to determine how well currently delineated nature preserves protect these areas (Strittholt and Boerner 1995). Gap Analysis uses a variety of data sources as sentinels in order to determine the biodiversity of a specific area. Instead of painstakingly sampling and measuring the densities of plant and animal species within select study sites, this program estimates species diversity by compiling data layers and determining the area's suitability as a habitat for both flora and fauna. By correlating certain types of vegetation growth with specific spectral signatures, elevations, climates, and soil types, for example, researchers can create a robust rule-based model from which probable plant species diversity can be determined (Strittholt and Boerner 1995). Researchers use similar combinations of sentinels in order to predict animal distribution patterns. Using the estimated vegetation layer, and coupling this data with habitat

preference information, the land surface is given a measure of suitability, indicating possible vertebrate distribution within each area (Rondinini 2006). Extensive groundtruthing of selected sites within the study area helps to verify results, ensuring that the calculated estimates provide an adequate representation of the species diversity on the ground (Strittholt and Boerner 1995). GAP analysis literature presents an interesting solution to the problems associated with data acquisition. This application reinforces the need for multiple layers of data to add strength to a proxy measurement, and emphasizes the importance of verifying all estimated layers developed using this protocol.

Sentinels have proven to be a valuable tool across a variety of disciplinary boundaries. Sentinel conditions help bridge gaps by providing data where information is otherwise unavailable, and permit a thorough analysis of interactions between multiple variables. These features are valuable in the area of crime analysis, where crime data can be difficult to acquire, and is often of a sensitive nature, therefore in many cases, is simply not available to researchers. In addition to this, traditional use of sentinels is often strengthened by a strong understanding of the features occurring alongside areas under investigation. An extensive areal analysis can also be a valuable addition to crime analysis, providing researchers with a more in-depth understanding of the social and economic framework of locations of interest. Borrowing from the methodologies of previous sentinel applications, we can estimate the relative risk of victimization by studying the socio-economic conditions that exist alongside areas of high crime.

1.4.2 The Canadian census and corresponding concerns

The Canadian census provides researchers with open access to a wide variety of neighbourhood-level socio-economic variables, several of which have been identified in recent literature to relate to the existence of residential burglary (Cromwell, Olson & Wester Avary 1991; Malczewski & Poetz 2005; Bernasco 2003; Brantingham & Brantingham 2000, 1993). The sentinel methodology developed in this thesis is structured around census socio-economic variables. The complex relationship between census variables and actual burglary distributions is first modelled, and then the variables are combined to create a proxy layer that estimates the spatial distribution of the risk of residential burglary victimization. The data employed throughout this research are aggregated to either the Census Tract (CT) or Dissemination Area (DA), the two smallest geographic areas for which the entire Canadian census is available (Statistics Canada 2007a, 2007b). Data at these levels are reported as counts and averages which, when standardized, can be used to compare the socio-economic conditions of one area, with those occurring in another.

Using socio-economic data as sentinels within this framework has the potential to provide an easily accessible alternative to actual crime data. However, the use of census data can often be problematic in itself and must be exercised with care. All individual data aggregated to an area is subject to the modifiable area unit problem (MAUP). The MAUP occurs when trends and results appearing at one spatial scale change when calculated at a different scale (Openshaw 1984). Furthermore, census boundaries are drawn to conform to population limits and street networks, rather than to reflect zones of similar socio-

economic status (Schuurman et al. 2007). With this in mind, one cannot assume that all individuals within a given census area are experiencing the same socio-economic conditions, nor that all occupied private dwellings within a given census area are equally susceptible to residential burglary. In addition, when using neighbourhood-level socio-economic conditions as sentinel indicators of risk of victimization, the underlying socio-economic conditions may appear to be the *cause* of the victimization. However, estimating the risk of victimization at an aggregate level through sentinel use does not support causal inferences. Correlation, in this case, does not imply a causal relationship between socio-economic status and risk of victimization.

1.5 Outline

This thesis is structured into four separate chapters. Chapter one is an introductory section, providing a brief overview of intelligence-led policing and describing the balance between the need for data security, with the requirement for data availability. It explores applications of sentinel conditions within biology, ecology and remote sensing, and introduces the potential for sentinel use within a crime analysis environment.

Following the format of Simon Fraser University's journal article style thesis, chapters two and three are designed to be read as independent papers. Chapter two introduces a methodology for the application of the sentinel framework within a crime analysis setting. Using frameworks established within biology, ecology and remote sensing, this chapter identifies key socio-economic conditions that can be used as sentinel proxies for residential burglary. It creates

a model of the risk of residential burglary victimization within a selected test municipality within British Columbia, using actual crime data and the chosen socio-economic sentinels. This research then applies the model to predict the relative risk of burglary victimization across an extended urban region, thereby creating a sentinel layer that does not require actual crime data input.

Chapter three expands and adapts the original sentinel model, in order to account for different socio-economic and crime patterns within British Columbia's mid-sized cities. Recognizing that local phenomenon is best represented by locally designed models (Bell, Schuurman and Hayes 2007; Fiedler, Schuurman and Hyndman 2006a, 2006b), the sentinel methodology is re-designed to better reflect the relationships between socio-economic conditions and the risk of residential burglary victimization in these unique urban settings. This paper further explores how the relationship between theoretically relevant sentinel conditions, and actual residential burglary rates, change across different urban landscapes.

Chapter four concludes the thesis by discussing key contributions and challenges faced throughout this research. It emphasizes the need and direction for future research.

CHAPTER 2: SENTINEL CONDITIONS: MAPPING RISK OF VICTIMIZATION THROUGH PROXY DATA¹

2.1 Abstract

Sentinel conditions are proxies for primary measurement of spatial phenomena. They have been applied across disciplines to provide estimates where direct analysis of a feature is impractical or problematic. Commonly used within ecology, biology and remote sensing, sentinels can assist in locating environmental stressors, and can estimate species diversity and habitat degradation. Borrowing from these areas of literature, a similar framework is developed for use within crime analysis. By pinpointing theoretically relevant socio-economic conditions that correlate with hotspots of residential burglary in a British Columbian municipality, a sentinel crime layer is created, which is used to approximate the risk of burglary victimization.

2.2 Introduction

Data acquisition issues affect researchers across many disciplinary boundaries. Some data are too difficult to measure directly, while others are prevented from public release due to their sensitive nature. This cross-disciplinary issue has been tackled within the fields of biology, ecology, and remote sensing, where sentinels, or proxy indicators are employed if the direct

¹ This chapter has been submitted to *The Professional Geographer* with co-authorship of Dr. Nadine Schuurman, and Dr. Patricia Brantingham.

measurement of an environmental phenomenon is difficult or impossible. Sentinel analysis involves measuring levels of (or changes within) a chosen proxy, and using these measurements to determine the condition of the surrounding environment. This methodology can be transferred into crime studies, where access to crime related data is often hindered by security and privacy issues. Carefully chosen sentinel indicators can provide an estimate of the relative risk of crime victimization when direct access to this data is restricted. Selecting theoretically relevant socio-economic indicators that correlate with areas of high criminal activity will produce a sentinel layer that depicts relative victimization risk within a study area, without relying on the crime event data itself.

2.3 Background

2.3.1 Crime mapping and hotspot analysis

Maps have played an essential role within the field of criminology for more than one hundred and eighty years, by providing a method to organize and visually present crime occurrence data (Ratcliffe 2004a; Brantingham, Dyreson, and Brantingham 1976). Criminal activity occurs as a result of the intersection of four essential features – an offender, a target, law and place (Brantingham and Brantingham 1993, 1981). With advancing technologies, crime analysts are better able to depict this complex interaction as it occurs across space. Maps have developed from simple, static visual representations of crime, into robust analytical tools that assist in the understanding of spatial patterns of criminal activity. Geographic information systems (GIS) are increasingly becoming a

staple within the law enforcement setting, providing the capabilities to digitally create such spatial representations (Lodha and Verma 1999; Paulsen 2004).

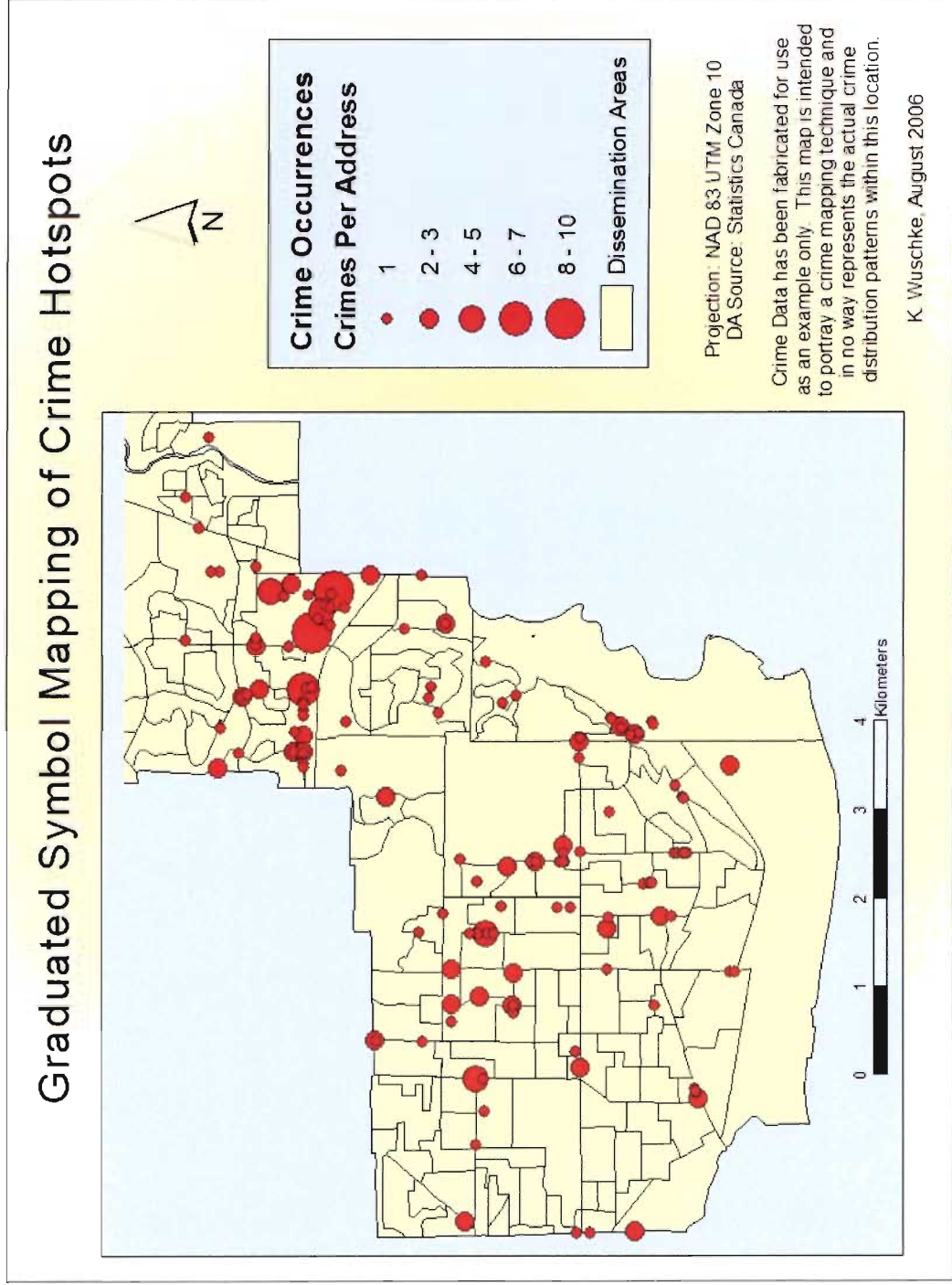
In recent years, policing paradigms have been shifting “towards a more decentralized, proactive style” of law enforcement, known as intelligence-led policing (Ratcliffe and McCullagh 2001). Policing is based primarily upon crime analysis, with a strong focus on gathering, analyzing, and acting on community-specific information (McGarrell, Freilich, and Chermak 2007). This shift has resulted in the increased importance of crime mapping. Within the area of intelligence-led policing, maps provide officers and analysts with the tools to better understand local patterns of crime. They allow for the appropriate allocation of limited police resources by identifying areas that are most in need of intervention (Ratcliffe 2004c). Crime maps also assist in the evaluation of crime prevention initiatives by providing a visual measure of changes in criminal patterns over both space and time (Paulsen 2004).

As mapping technologies continue to advance, a growing focus has been placed on the representation and analysis of hotspots of criminal activity. Areas with high or low numbers of criminal events form across the landscape, because crime is not evenly distributed across space or time (Ratcliffe 2002a). Hotspots are generally defined as areas that have higher than average rates of criminal events, and maps depicting such hotspots are increasingly being used to develop crime prevention strategies (Lodha and Verma 1999; Ratcliffe and McCullagh 2001; Ratcliffe 2004c). Within the field of criminology, several techniques are commonly used to portray these clusters of crime. The type of map selected for

hotspot analysis depends on the type of crime, the amount and type of available data, and the type of area under investigation. Three common examples of hotspot mapping techniques include graduated symbol, choropleth, and kernel density maps.

Graduated symbol maps are most appropriately used to depict crimes when address-level data are available. Clusters of points on the map represent hotspots of criminal activity, with larger symbols being used to portray addresses with multiple crime occurrences (see Figure 2-1). While this technique can be a powerful way to represent criminal activity, the mapped results are open to interpretation, with different users identifying different clusters of points as hotspots (Chainey 2005). This mapping technique can also be confusing as the amount of crime data increases (Ratcliffe and McCullagh 2001), with points overlapping and obstructing the map image itself.

Figure 2-1: Example of a graduated symbol hotspot map



Choropleth mapping techniques provide another method of hotspot analysis. Most appropriate for representing aggregated crime data, this form of mapping generalizes point occurrences by evenly distributing them throughout an area of analysis (see Figure 2-2). This method is generally easy to interpret by map users, with darker-coloured areas representing hotspots of crime, but is not without weaknesses. Such maps imply uniformity within, and sharp contrasts between areas, while actual crime and socio-economic patterns rarely reflect this trend (Schuurman et al. 2006). Any point data generalized to an area is subject to the Modifiable Area Unit Problem (MAUP) as well. Because the areal units of analysis are arbitrarily chosen and delineated, any mapped results are only valid for this single level of aggregation, and will change should the original point data be generalized to different spatial units (Openshaw 1984). Furthermore, aggregating address-level crime occurrences to an areal level limits possible analyses that can be performed with such data. Crimes mapped at one level may only be compared to other occurrences or conditions measured at this same level of aggregation (Brantingham, Dyreson, and Brantingham 1976).

Kernel Density mapping has gained popularity as a method of representing hotspots of crime. Created as a raster overlay, kernel density maps are displayed as a layer of grid cells, with each cell given a value calculated as a function of the number of crime occurrences within its surrounding area (Ratcliffe 2004c, 33-34). It provides the ease of hotspot identification found in choropleth mapping, without aggregating crime to predetermined areas and falsely implying sharp boundaries (see Figure 2-3). By smoothing crime occurrences across areas, kernel density

shows increased detail, emphasizing gradual changes in crime levels over space (Cameron and Leitner 2005). It still generalizes data, therefore providing a method to deal with large numbers of points that would otherwise be difficult to interpret by a map user. Moreover, the level of generalization effectively masks individual-level data. However, this popular technique has been criticized for its output variability – identical data can be mapped in drastically different ways, depending on the cell size and other specific user inputs (Chainey 2005). Additionally, because this method aggregates data, spreading grouped point occurrences across potentially impermeable boundaries (coastlines or rivers, for example), this method may depict crime in areas that are, in reality, unaffected.

Figure 2-2: Example of a choropleth hotspot map

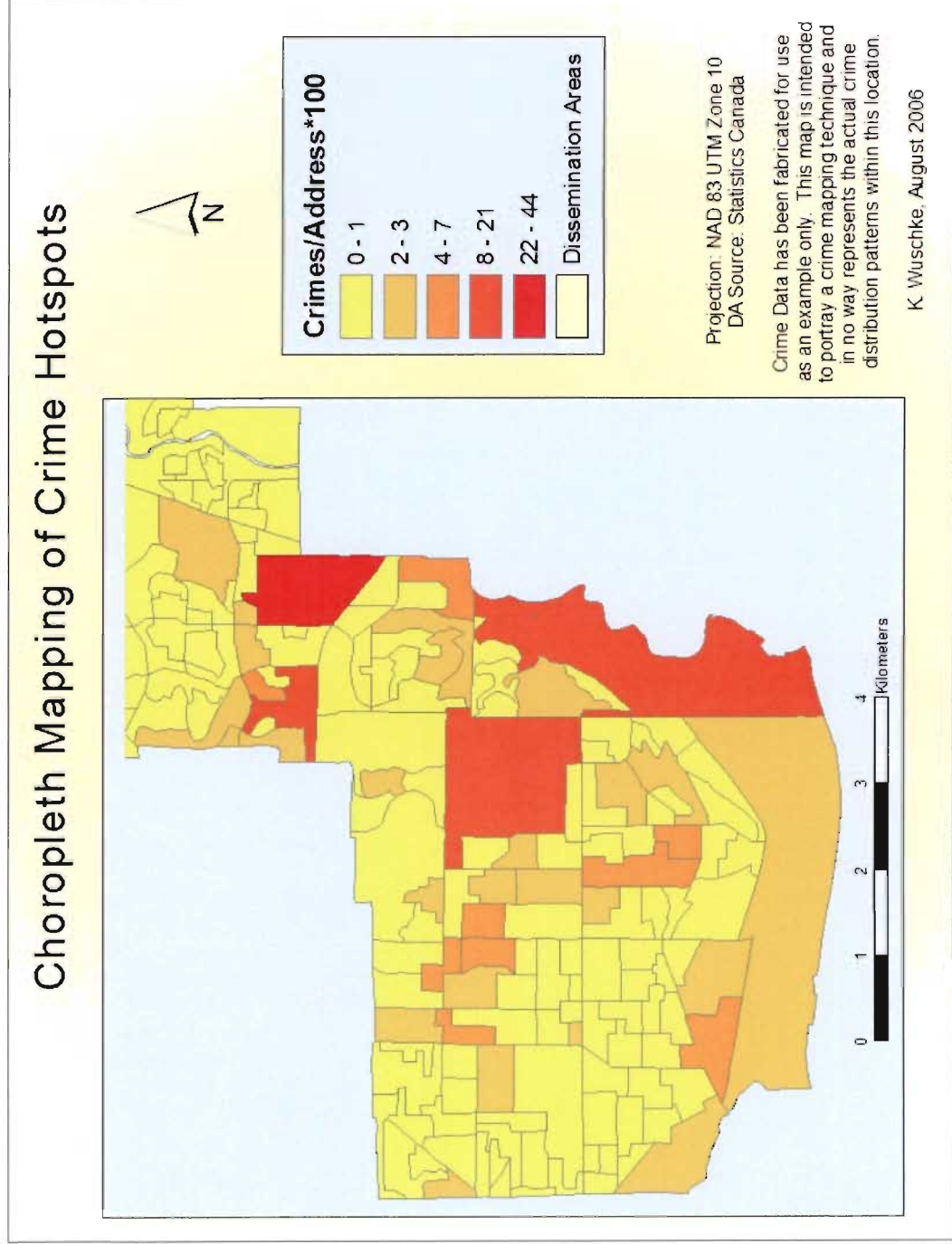
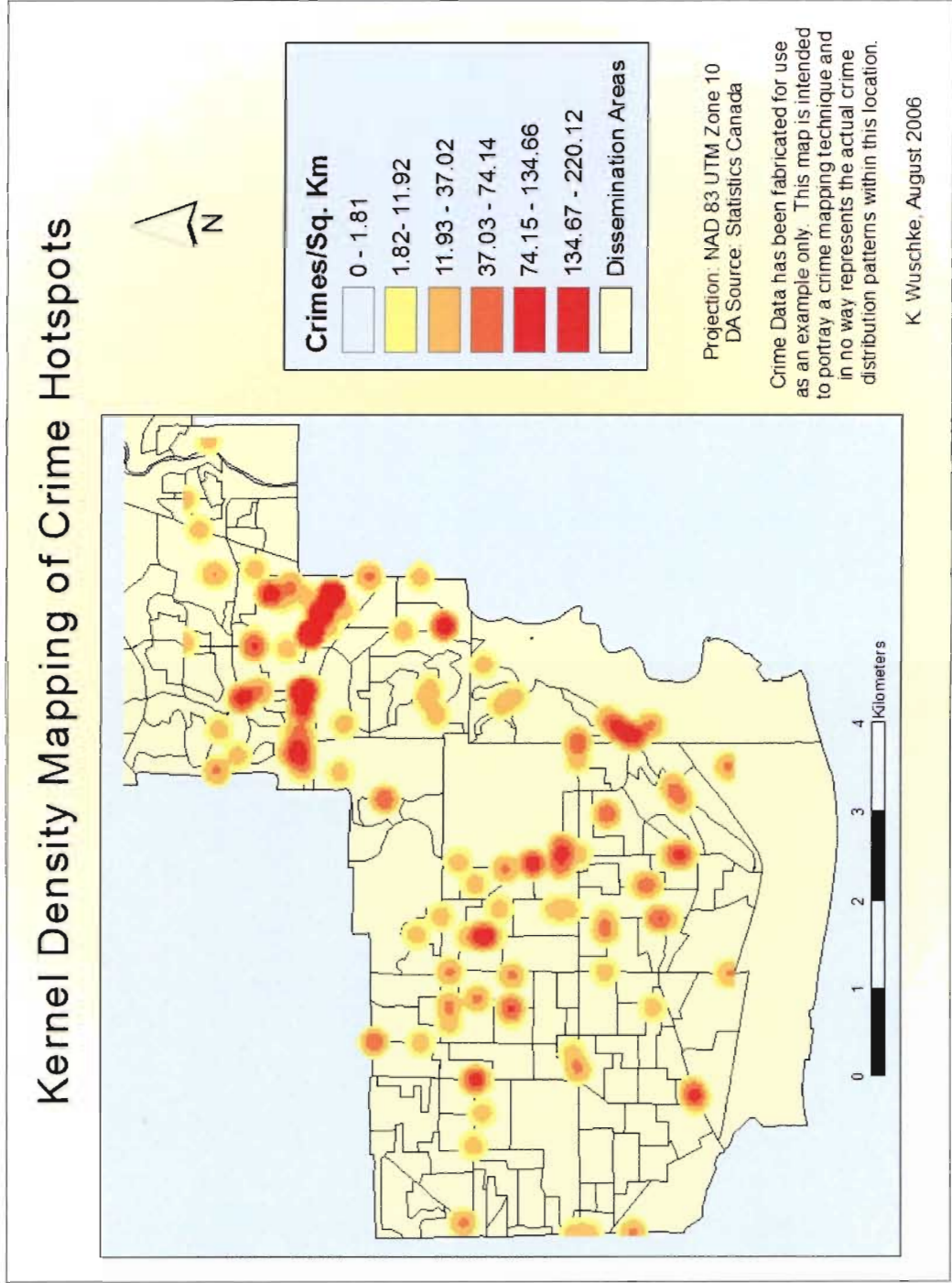


Figure 2-3: Example of a kernel density hotspot map



Each method of hotspot analysis has its strengths and weaknesses. While such maps are useful analytical tools when crime data are readily available, these data are not always easily accessible. When available, they are often in the form of raw addresses, requiring cleaning and geocoding before being visually displayed. With regularly growing and changing street networks, and incorrect or vague crime address data, geocoding is often a problematic task, which can introduce errors into the map (Ratcliffe 2002b). Acquiring complete access to criminal occurrences can also prove to be a difficult undertaking for researchers. Crime data are sensitive in nature, and as such, often requires security clearances, special permissions, and dissemination restrictions in order to acquire the appropriate ethics approvals (Boulos et al. 2005). This limits the use of hotspot mapping techniques to police forces, researchers and other government agencies with special access, and restricts how results can be publicly released. Finally, each of these mapping methods focus primarily on patterns of the crime with limited representation of the social and economic trends associated with the areas of victimization.

There is a need for crime hotspot data to be available to researchers and citizens alike. However, there a competing requirement that the privacy of the victims of criminal activity be protected (Ratcliffe 2002b), therefore necessitating that access to address-level crime data remain limited. By borrowing from sentinel methodologies, it is possible to estimate the spatial patterns of risk of victimization by looking at the social conditions that exist alongside areas of high crime. Sentinel indicators have been successfully employed within a wide range

of studies, and can be of benefit within criminology, helping to identify the relative risk of victimization when actual crime occurrence data is restricted or difficult to acquire.

2.3.2 Applying sentinel conditions

Sentinel conditions, used primarily within biology, ecology, and remote sensing research, act as proxies to aid in the study of features that are difficult to measure directly. Each of these areas of research applies sentinel analysis in slightly different ways. Biological and ecological applications of sentinel indicators stress the importance of extensive analysis of the features occurring alongside the phenomena under investigation (Gibbons, Munkittrick, and Taylor 1998). The chosen sentinels are carefully selected features, naturally occurring in the surrounding environment, and are studied in place of the subject of interest. Chosen proxies must exist across a wide geographic area, must relate and respond to the phenomenon under investigation, and must be readily available and easy to sample (Fitzgerald, Lanno, and Dixon 1999; Gray, Cunjak, and Munkittrick 2004; Ruiz et al. 2005). Remote sensing and GAP analysis literature have expanded the sentinel methodology to better measure complex environmental features. Here, multiple sentinels, used in combination with one another, provide a better representation of the phenomenon under investigation (Turner et al., 2003). In addition, extensive groundtruthing is a required component of sentinel analyses, needed in order to verify predicted results (Strittholt and Boerner, 1995). These traits can be harnessed for use within crime

analysis, where crime occurrence data is often classified in nature and can be difficult to acquire.

When applying the sentinel methodology to estimate the risk of crime victimization, several key features become important. Using a combination of sentinel indicators, each correlated with a specific crime type, will potentially strengthen this proxy measurement. The chosen sentinel conditions must exist across all locations under investigation, in order to ensure that this method may be tested and applied across a variety of geographic areas. Perhaps the most important feature, present across wide range of sentinel literature, is the necessity to verify results. As emphasized in the GAP analysis literature, determining conditions on ground by using data generalized to an area is a complex task (Strittholt and Boerner, 1995). Groundtruthed test areas assess the accuracy of the proxy measurements, helping to guide researchers to the most valuable sentinel features. When shifting this concept to crime mapping, the *groundtruthing* will involve comparing estimated risk of victimization with actual recorded crime data for specific areas.

2.3.3 Research contribution

This research fills a gap left by current crime mapping techniques by developing an alternative methodology for estimating the risk of victimization. Instead of focusing primarily on crime occurrence data, this framework aims to approximate the relative risk of victimization using sentinel conditions. By relying largely on non-criminal data sources as proxies, this methodology reduces the need for accurately geocoded crime data, and allows researchers to focus on the

social and economic conditions that exist alongside areas of high crime. These conditions will not only help to estimate risk patterns in the absence of more accurate crime event data, but will also allow for increased understanding of the existing social framework of the study area. In doing so, this research will investigate the relationship between the socio-economic variables found to be correlated to specific criminal activities within previous literature, and will discover if (and how) this relationship transforms across urban settings. While any correlations between such socio-economic data and areas of high (or low) crime certainly do not imply a causal relationship between the features, developing a more complete neighbourhood representation can be a valuable addition to research at this geographical level. Socio-economic data is widely available, and is aggregated to the Census Tract (CT) level – a small census area that encompasses between 2500 and 8000 people (Statistics Canada 2007a). In using pre-aggregated variables, the resulting proxy layer depicting estimated hotspots of criminal activity will necessarily be generalized to this areal unit. This presents data at a level of detail that is focused enough to provide insight into the patterns of crime, but simplified enough to avoid pinpointing single locations, which would imply more accuracy than such a proxy measurement can provide.

2.4 Methodology

Locating hotspots of criminal activity within an area can be an important addition to a variety of research topics, allowing for a more thorough understanding of the patterns and trends that affect the region. However, accessing crime occurrence data can be a problematic task, due to the sensitivity

associated with such information. Applying techniques borrowed from sentinel analysis within the fields of biology, ecology, and remote sensing, the relative risk of victimization can be estimated by focusing on the socio-economic conditions that are occurring alongside areas of crime. In addition to this, such research also builds a broader understanding of the social and economic trends that affect the study area.

2.4.1 Choosing the crime

The factors that give rise to a cluster of one type of crime are not necessarily related to the factors correlated with another (Brantingham and Brantingham 1993; Eck 2005). Therefore, it is essential to focus on locating sentinel indicators for a single crime type at a time, as these conditions will differ greatly depending on the offense. Residential burglary is well suited for such an analysis. It is one of the most prevalent crimes in Canada (Fedorowycz 2004), affecting every province and territory, and as such, has been the focus of extensive analysis. Its geographical range is emphasized by Rengert and Wasilchick, who state that, “[n]o matter what local changes are occurring, the general condition of burglary as a common event remains” (1985, 3). Because the precise location of each reported burglary event is known, mapping errors associated with vague or incomplete address data are greatly reduced when investigating this crime. Burglary also opens the door to a wide variety of possible sentinel conditions, as data about the household (describing the *victims* of such burglary), the physical structure of the residence and the neighbourhood are publicly available through the Canadian census.

2.4.2 Identifying sentinel layers

Due to the wide geographic distribution and extensive impact of residential burglary, significant effort has been placed upon understanding the socio-economic factors associated with this crime (Rengert and Wasilchick 1985). Researchers have studied extensively the household compositions that are commonly targeted, the types of neighbourhoods that are chosen, and built environments that are favoured by offenders (Cromwell, Olson, and Wester Avary 1991). Such studies have indicated that an overwhelming majority of burglars will only enter a home that they believe to be unoccupied (Ibid). This principal builds off Cohen and Felson's theory, which states that in order for a crime to occur, three minimal features must be present: a willing and able offender, a suitable target, and the *absence of a guardian* (1979). Households with fewer residents and adults who are employed in the workforce are more likely to leave their home unguarded during the daytime hours, thus are at greater risk of being burgled (Cohen and Felson 1979; Rengert and Wasilchick 1985). In addition to this, homes in disrepair tend to give the impression of the lack of a caretaker or guardian, and therefore may be attractive targets (Brantingham and Brantingham 1993).

Further research has indicated that neighbourhoods with unstable residential populations are at higher risk of victimization (Brantingham and Brantingham 1993; Smith and Jarjoura 1989). This can include neighbourhoods with higher unemployment rates (Cohen and Felson 1979), large proportions of separated and divorced individuals, single-parent households (Smith and Jarjoura 1989), areas with lower household income and locations with high

numbers of renters and movers (Malczewski and Poetz 2005; Smith and Jarjoura 1989). These factors can contribute to lower levels of neighbourhood cohesion, where strangers (and potentially, offenders) can enter without seeming suspicious or out-of-place, and where neighbours are less likely to act as guardians for one-another, or to intervene in the event that suspicious activity is noticed (Bernasco 2003).

Multiple studies have shown that burglaries occur in areas where the offender feels comfortable – often near their place of residence (Bernasco 2003; Bernasco and Nieuwbeerta 2005; Rand 1986), or around activity hubs, such as commercial districts (Brantingham and Brantingham 1993). These findings relate to the desire of offenders to enter neighbourhoods without appearing suspicious, and also build off of the Brantingham's concept of awareness space, a theory which acknowledges that "[p]eople who commit crimes also engage in non-criminal behaviour" (Brantingham et al. forthcoming). Individuals become familiar with areas around and between home, work, and other activity nodes (such as malls, parks, and city centres), during lawful, daily routines (Brantingham and Brantingham 2000). Offenders will "restrict most of their criminal behaviour to these legitimately known areas" (Brantingham and Brantingham 1993, 9). Finally, structural variables have also been found to impact burglary rates, with low-rise apartments often having higher rates of victimization than single-family dwellings or high-rise buildings (Brantingham and Brantingham 1993).

With these specific, theoretically relevant variables in mind, corresponding sentinel layers have been identified and created. The socio-economic

information, acquired from the 2001 Census, was collected at the Census Tract level. Census data make ideal sentinel layers for such an analysis, as they are available at a uniform scale across a wide range of geographic areas, and are easily accessible to the public. Table 2-1 identifies the sentinel layers chosen for use in this analysis. All sentinels have been standardized into percentages, and Average Household Income has been placed into quintiles for ease of analysis. These individual sentinel layers will be tested for correlation to the actual patterns of the crime within a chosen area of study, and combined using ordinal regression, to create a predicted surface that models the risk of residential burglary victimization.

Table 2-1: Socio-economic conditions chosen for use in sentinel analysis

Dependent Variable:	Break and enters per dwelling (Quintile)
Factor:	Average household income (Quintile)
Covariates:	Percent of Census Tract area occupied by commercial land use Percent separated Percent divorced Percent of lone parent households Percent of households with only one resident Percent renters Percent of households requiring major repairs Percent small apartments Unemployment rate for adults ages 15 and over Percent of residents who have moved within the past year

2.4.3 Data sources

Through a unique partnership between the British Columbian division of the Royal Canadian Mounted Police (RCMP) and the Institute for Canadian

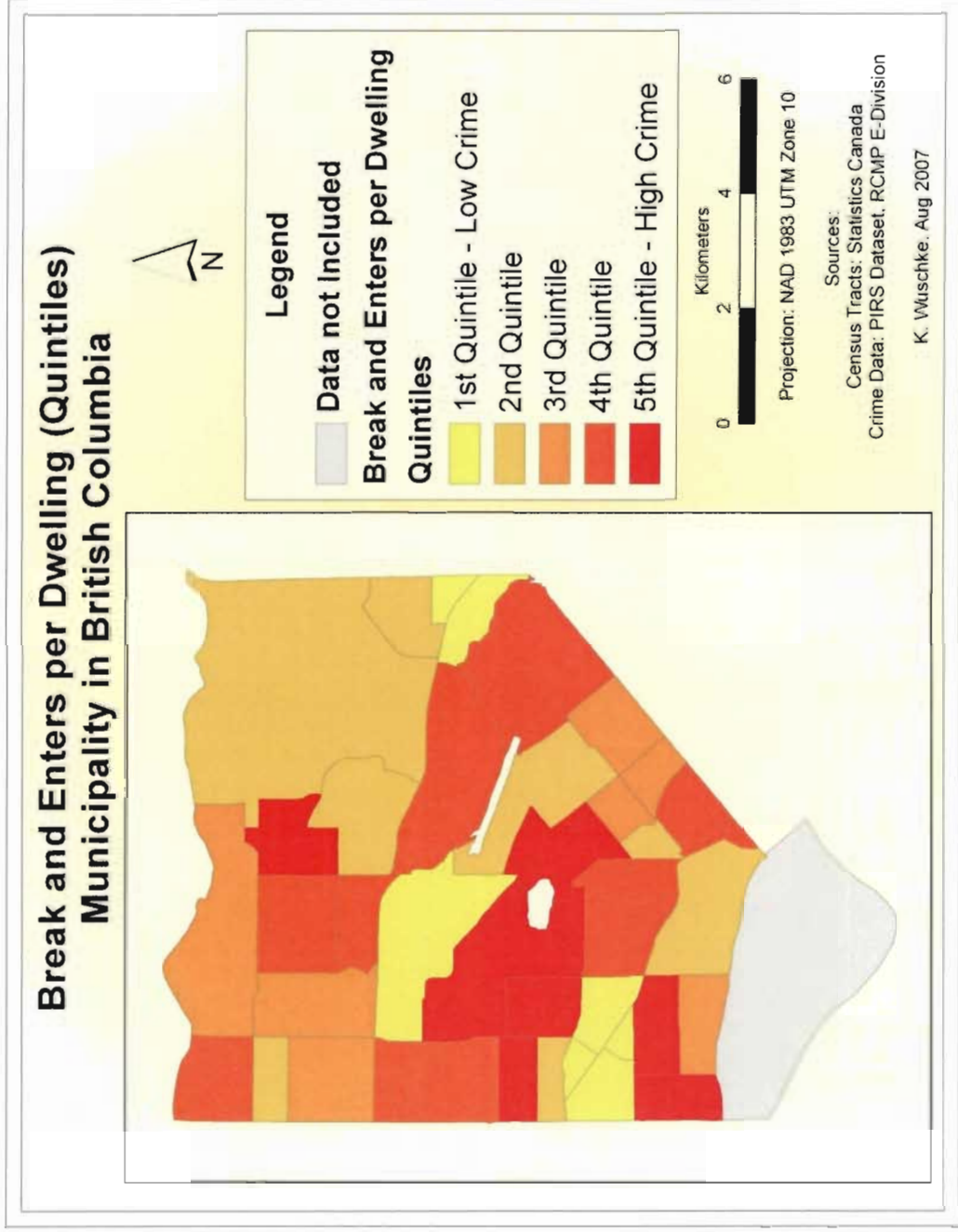
Urban Research Studies (ICURS) at Simon Fraser University, access to crime occurrence data within the province has become available for research purposes. This partnership provides security-cleared members of the ICURS Research Lab with address-level data for recorded crime occurrences between 2004 and 2006. This access is provided with the stipulation that address-level data may only be accessed, analyzed, and displayed within the secure research facility. Such access provides the opportunity for a number of research projects, each with the goal of developing a thorough understanding of crime patterns within British Columbia. The dataset allows for specific queries based on a variety of attributes, including crime type, location, and date of event. All residential burglaries within a chosen municipality in British Columbia have been selected from this extensive dataset. Data security issues require that all crime points be aggregated and stripped of their location identifiers before being presented; therefore, residential burglary addresses have been aggregated to the Census Tract, matching the level of analysis of the publicly available socio-economic data.

The queried subset of data incorporated into this research initially included thirty-eight CTs within the select British Columbian Municipality². Each CT was assigned to a quintile, reflecting the rate of residential burglaries per household within the neighbourhood. One CT was excluded because it had very few households within a relatively large area. The drastically different urban structure made this CT an outlier within the test municipality, and thus, social, economic and crime trends established for the more densely populated areas could not be

² Municipality names must be kept confidential, as required by the RCMP/ICURS data sharing agreement.

applied to this location. The remaining thirty-seven CTs that were formally included in this analysis were not missing any values for the sentinel variables. Figure 2-4 displays the mapped output of the actual residential burglary data between 2004 and 2006 for this selected municipality. Given the actual distribution of crime, this information can be used to run a regression analysis, in order to understand how the theoretically important sentinel variables relate to residential burglary levels within this specific municipality.

Figure 2-4: Actual residential burglary distribution in quintiles, test municipality – reference map



2.4.4 Regression analysis

As emphasized within the remote sensing and GAP analysis literature, multiple sentinel data layers can be used in combination to better explain a phenomenon that is otherwise difficult to measure (Turner et al. 2003). With this in mind, the eleven layers of socio-economic indicators were combined to better explain local risk of victimization patterns. The relevant variables were entered into an ordinal regression model using SPSS (see Table 2-1, above), and the resulting relationships between the actual crime quintiles and the theoretically relevant sentinels provided the complex regression equations for this specific municipality. This model used a single Census Tract's sentinel values to create probabilities that the given CT will fall within *each* of the five ordinal categories of risk of victimization. These results were compared, and the category with the highest probability was selected as the predicted level of relative risk of victimization for the chosen CT. This process was repeated for every included CT in the study area. The resulting output was an ordinal value ranging from one to five; one representing a prediction that the CT will have the lowest risk of residential burglary victimization, and five indicating that the CT is predicted to have the highest relative risk of burglary victimization. Once a relationship between the sentinel variables and the actual crime distribution had been established for the initially selected test municipality, the model's regression equation was then used to estimate relative risk of residential burglary victimization in neighbouring municipalities within the region.

2.5 Results

2.5.1 Ordinal regression in the test municipality

The initial results of the ordinal regression show promise in using the eleven theoretically relevant variables as sentinel indicators of risk of residential burglary victimization in the selected test municipality. The model fitting information, as displayed in Table 2-2, show that the 'final' model, including all of the selected sentinel variables, represents the actual distribution of residential burglary rates significantly better than an intercept-only model. The goodness-of-fit, displayed in Table 2-3, shows that the actual data is consistent with the model's predicted results – however, the small number of Census Tracts in this sample, combined with the large number of continuous covariate sentinels, diminishes the level of confidence that can be attributed to this test alone. The test of parallel lines, shown in Table 2-4, confirms that the sentinel variables included in this analysis are reliable predictors for all quintiles of residential burglary. Table 2-5 displays the parameter estimates for this particular model, showing the significance of each sentinel variable included in the model. These relationships are used to create the predicted risk of victimization category, which represents the estimated levels relative risk of residential burglary victimization within the test municipality.

Table 2-2: Model fitting information, test municipality

Model	-2 Log Likelihood	Chi-Square	Degrees of Freedom	Significance
Intercept Only	118.94			
Final	79.33	39.60	14	0.0003

Table 2-3: Goodness of fit, test municipality

	Chi-Square	Degrees of Freedom	Significance
Pearson	94.61	130	0.9916
Deviance	79.33	130	0.9999

Table 2-4: Test of parallel lines, test municipality

Model	-2 Log Likelihood	Chi-Square	Degrees of Freedom	Significance
Null Hypothesis	79.33			
General	57.24	22.10	42	0.9951

Table 2-5: Parameter estimates, test municipality

		Est	Sig	95% Confidence Interval	
				Upper Bound	Lower Bound
Threshold	[B&EQuint = 1]	-4.96	0.1166	-11.15	1.23
	[B&EQuint = 2]	-2.22	0.4713	-8.26	3.82
	[B&EQuint = 3]	-0.83	0.7848	-6.79	5.13
	[B&EQuint = 4]	0.94	0.7549	-4.98	6.87
Location	PercComm	-0.08	0.1992	-0.19	0.04
	PerSepd	1.72	0.1713	-0.75	4.19
	PerDivd	-1.60	0.0363	-3.09	-0.10
	PerLonePar	0.26	0.0327	0.02	0.50
	Per1perHH	0.15	0.2313	-0.10	0.40
	PerRented	-0.15	0.0255	-0.28	-0.02
	PerMajorRep	-0.17	0.4416	-0.60	0.26
	PerSmApt	-0.03	0.5506	-0.11	0.06
	UERate15	0.40	0.0822	-0.05	0.85
	Pmovers	-0.11	0.4912	-0.43	0.21
	[AvHHIncQ=1]	0.74	0.8402	-6.41	7.89
	[AvHHIncQ=2]	0.39	0.8554	-3.81	4.59
	[AvHHIncQ=3]	2.82	0.0844	-0.38	6.02
	[AvHHIncQ=4]	0.80	0.5627	-1.90	3.49
[AvHHIncQ=5]	0.00	.	.	.	

A cross-tabulation of the predicted risk of victimization categories with the originally observed quintiles produces the results displayed in Table 2-6. With the exception of Quintile 3, this model has successfully classified more Census Tracts into the correct category, than into any other group. The regression equation has also been reasonably accurate in maintaining the size of each group – while the original five quintiles each contained either seven or eight of the Census Tracts under investigation, the predicted groups contain between two and twelve each. A Chi-Square test determines that there is not a significant difference between the group sizes. Overall, this model correctly predicted the categories of 48.6 percent of the Census Tracts, with 89.2 percent of the CTs falling within plus-or-minus one classification group.

Table 2-6: Cross-tabulation of actual break and entry quintiles with predicted risk of victimization category

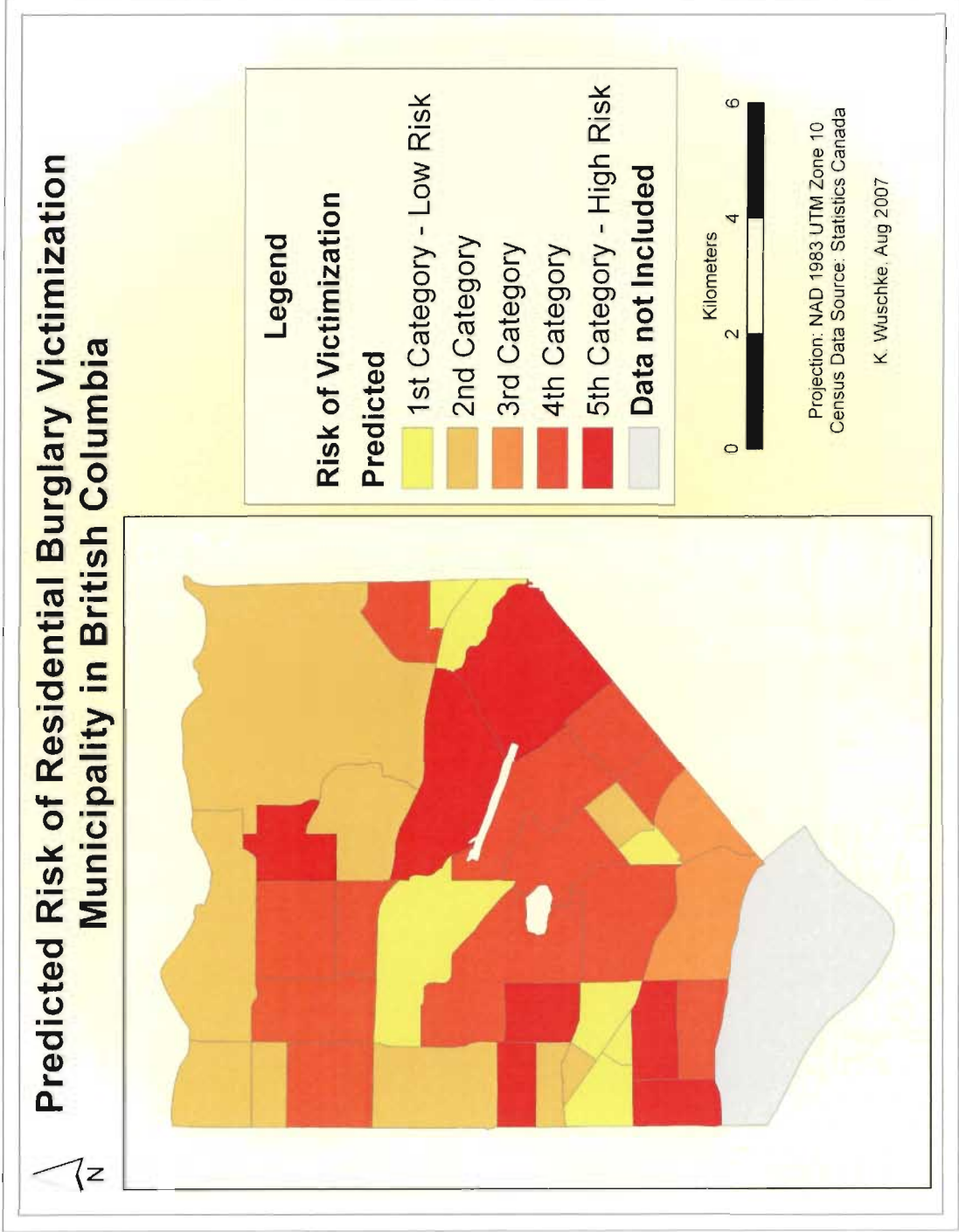
		Predicted Category					Total
		1	2	3	4	5	
Actual B&E Quintile	1	6 16.22	1 2.70	0 0.00	0 0.00	0 0.00	7 18.92
	2	1 2.70	4 10.81	1 2.70	2 5.41	0 0.00	8 21.62
	3	0 0.00	2 5.41	0 0.00	5 13.51	0 0.00	7 18.92
	4	0 0.00	2 5.41	1 2.70	3 8.11	2 5.41	8 21.62
	5	0 0.00	0 0.00	0 0.00	2 5.41	5 13.51	7 18.92
Total		7 18.92	9 24.32	2 5.41	12 32.43	7 18.92	37 100.00

The correlation between the sentinel variables and the original burglary rate quintiles (Table 2-7) show that not only are the predicted categories significantly correlated, this category is more correlated to the actual burglary rates than is any other sentinel layer. The relative risk of residential burglary victimization, as predicted through the use of the sentinel conditions, can now be mapped to display a surface of predicted risk of residential burglary victimization throughout the selected British Columbian Municipality (see Figure 2-5). In order to test for spatial autocorrelation, a global Moran's I test statistic was performed on both the actual and predicted distributions. Neither was found to be significantly spatially autocorrelated, indicating that there is not significant clustering of either hot or cool spots of criminal activity at this spatial level of analysis. This is an interesting and unexpected finding, and is most likely attributed to the size of the unit of analysis (the Census Tract), and to the small sample size used in this study.

Table 2-7: Correlation between sentinel input and actual residential burglary quintile

Sentinel Condition	Correlation to Burglary Quintile	Significance
Average household income (Quintile)	0.5278	0.0008
Percent of Census Tract area occupied by commercial land use	-0.2758	0.0985
Percent separated	-0.5589	0.0003
Percent divorced	-0.7186	0.0000
Percent of lone parent households	-0.4392	0.0065
Percent of households with only one resident	-0.6079	0.0001
Percent renters	-0.6351	0.0000
Percent of households requiring major repairs	-0.3049	0.0666
Percent small apartments	-0.4845	0.0024
Unemployment rate for adults ages 15 and over	-0.3322	0.0446
Percent of residents who have moved within the past year	-0.4355	0.0071
Predicted Risk of Victimization Category	0.8064	0.0000

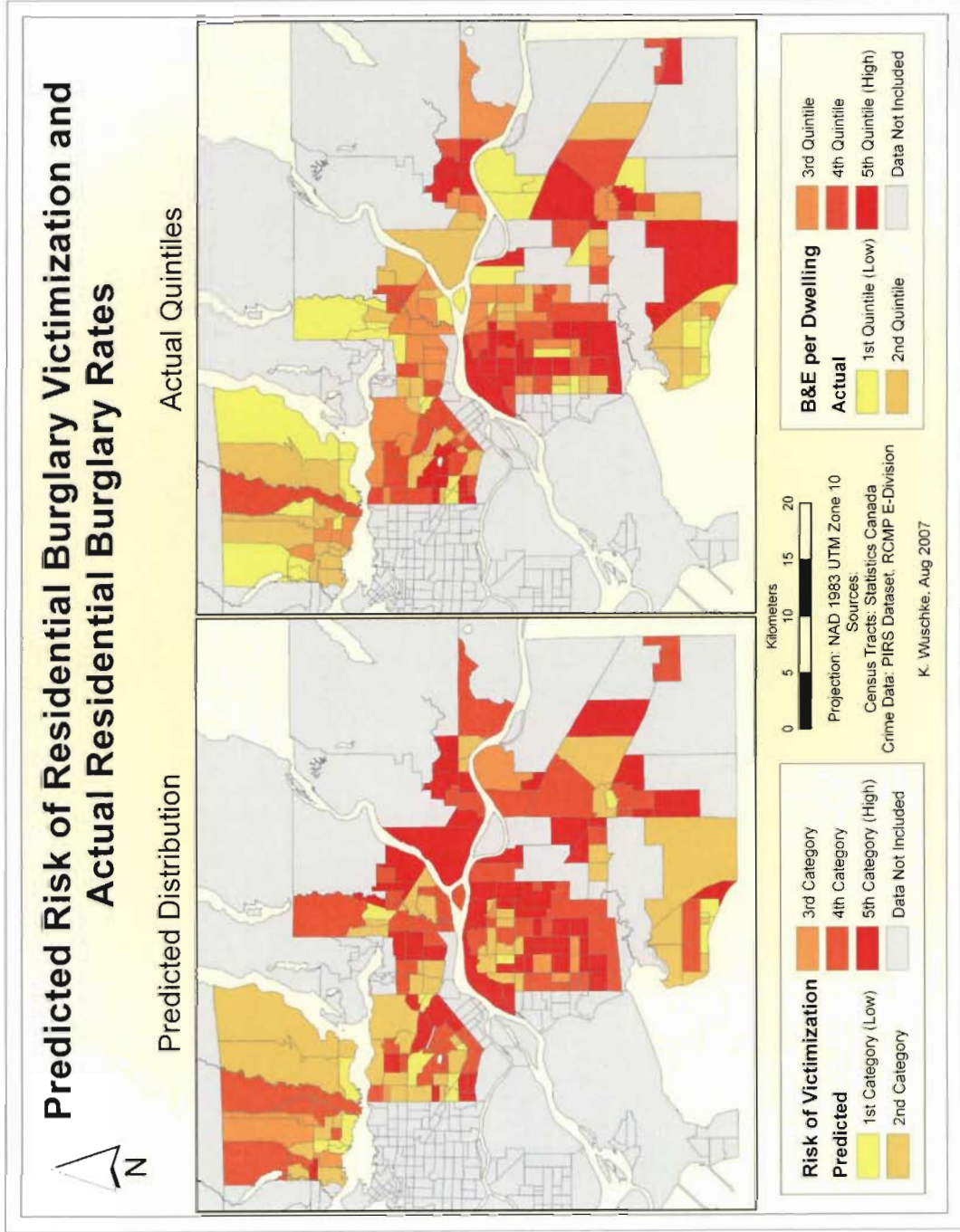
Figure 2-5: Predicted relative risk of residential burglary victimization, test municipality



2.5.2 Predicting burglary levels in the surrounding region

The relationship between the eleven selected socio-economic sentinel conditions, and residential burglary rates was established for a single test municipality. Next, the area of interest is expanded to include many additional municipalities in the surrounding region. The eleven sentinel conditions were collected at the Census Tract level for the entire region, standardized into percentages and placed into quintiles where necessary. Several municipalities within the region of interest were excluded from further analysis at this stage, due to lack of access to municipal residential burglary data. While this information is not needed in order to *predict* the risk of victimization at the CT level, groundtruthing remains an important aspect of the sentinel analysis at this developmental stage, therefore access to this data is required in order to verify predicted results. Fifteen additional Census Tracts from across the region were removed from the analysis due to incomplete census data or exceptionally small population densities. The final, complete dataset contains 188 Census Tracts spanning across nine distinct municipalities. This dataset was used as the starting point, from which the relative risk of residential burglary victimization is predicted without relying on often-restricted crime records. The Census Tract-level sentinel values are input into the regression equations established in the previous section, and based on the resulting probabilities, a value ranging from 1 to 5 is assigned to each area, indicating a predicted relative risk of victimization. Figure 2-6 displays both the predicted relative risks, and actual residential burglary quintiles for the region of interest.

Figure 2-6: Predicted risk of victimization and actual distribution of residential burglary rates, test region



In order to determine how successful the sentinel conditions are at predicting the risk of residential burglary victimization for the test region, a cross-tabulation between the predicted categories, and actual crime quintiles was performed (see Table 2-8). While the region-wide predictions are not as accurate as the single test municipality predictions, this was expected. Using the sentinel conditions alone, 26.6 percent of the Census Tracts within the test region have been correctly classified into the appropriate category of risk of residential burglary victimization, with 62.8 percent being classified to within one category. Table 2-9 displays the ordinal-by-ordinal symmetric measures for the cross-tabulation table, with results indicating that there are significant similarities between the two datasets. Finally, when correlating the actual crime distribution for the entire region, with the predicted risk categories and all chosen sentinels, we see that again, the predicted risk of victimization category is significantly correlated to the actual crime quintiles, and is more correlated than any single sentinel measure is on its own (Table 2-10). A global Moran's I test statistic was also performed on both actual distribution and predicted risk surface at the regional level. When analyzing the sentinel conditions at the regional level, both actual and predicted surfaces proved to be significantly spatially autocorrelated.

Table 2-8: Cross-tabulation of actual residential burglary rates and predicted risk of residential burglary victimization, test region

		Predicted Risk of Victimization Category					Total
		1	2	3	4	5	
Actual B&E Quintile	1	8 4.26	11 5.85	1 0.53	10 5.32	7 3.72	37 19.68
	2	6 3.19	7 3.72	4 2.13	10 5.32	11 5.85	38 20.21
	3	3 1.60	13 6.91	3 1.60	11 5.85	8 4.26	38 20.21
	4	0 0.00	9 4.79	1 0.53	15 7.98	13 6.91	38 20.21
	5	1 0.53	9 4.79	1 0.53	9 4.79	17 9.04	37 19.68
Total		18 9.57	49 26.06	10 5.32	55 29.26	56 29.79	188 100.00

Table 2-9: Symmetric measures for predicted category and actual quintile, test region

		Value	Asymp. Std. Error	Approx. T	Approx. Sig.
Ordinal By Ordinal	Kendall's tau-b	0.2010	0.0593	3.3704	0.0008
	Kendall's tau-c	0.1940	0.0576	3.3704	0.0008
	Gamma	0.2582	0.0753	3.3704	0.0008
	Spearman	0.2422	0.0711	3.4050	0.0008

Table 2-10: Correlation between sentinel input, and actual burglary quintiles, test region

Sentinel Condition	Correlation to Burglary Quintile	Significance
Average household income (Quintile)	-0.1481	0.0426
Percent of Census Tract area occupied by commercial land use	0.0101	0.8909
Percent separated	0.2100	0.0038
Percent divorced	0.0256	0.7276
Percent of lone parent households	0.1955	0.0072
Percent of households with only one resident	-0.0422	0.5653
Percent renters	0.1471	0.0439
Percent of households requiring major repairs	0.1524	0.0368
Percent small apartments	0.0047	0.9489
Unemployment rate for adults ages 15 and over	0.2134	0.0033
Percent of residents who have moved within the past year	0.1282	0.0794
Predicted Risk of Victimization Category	0.2422	0.0008

2.6 Discussion

A unique partnership between the RCMP and ICURS Research Lab provided an opportunity to develop a methodology that uses theoretically relevant socio-economic data as sentinel conditions to predict relative risk of residential burglary victimization. Through the use of ordinal regression, a model was created to describe the relationship between eleven theoretically relevant socio-economic sentinel layers, and residential burglary event data within a select municipality in British Columbia. The resulting layer of estimated victimization risk is significantly correlated to the original quintiles of residential burglary, and provides a better measure of the crime than any one of the sentinel conditions can do on its own. The output from the ordinal regression analysis for this test

municipality shows that all of the theoretically relevant sentinel conditions can be used to create a representative model of risk of residential burglary victimization within the area. While some of the sentinel variables, such as the percentages of renters, lone parent households, and divorced adults, contribute much more significantly to this model than others, all sentinel variables have been included in this preliminary model, based on the strong bodies of literature that stress their important relationship to residential burglary.

This framework was expanded to allow for the estimation of relative burglary levels within the surrounding region. This method also produces significant results, and provides a better estimation of relative victimization risk than any single, theoretically relevant sentinel layer would on its own. However, there is definite room for improvement within the model. Several of the chosen sentinel conditions were included based on previous research indicating that offenders will target areas that they are most familiar with (Bernasco 2003; Bernasco and Nieuwbeerta 2005; Brantingham and Brantingham 1993; Rand 1986). It is possible that these features could be better captured at a different spatial scale – for example, the same analysis performed at the Dissemination Area level, a small census area containing between four hundred and seven hundred residents (Statistics Canada 2007b), may more accurately reflect an area of familiarity for an offender. Additionally, the preliminary model has been created and tested in one geographic region within British Columbia. Performing similar risk of victimization predictions in areas that are geographically separated from the original municipality will test the versatility of this proxy crime measure,

and will increase the understanding of how the relationship between the sentinel conditions and actual distributions of residential burglary change across the urban landscape.

It must be noted, however, that these socio-economic conditions can never model risk of victimization completely accurately. There will always be a *dark figure* of crime – a percentage that goes unreported – and thus cannot be accounted for in such an analysis. In addition to this, there will always be unique local features that attract or prevent crime on a situational basis that will inhibit complete representation through such a model.

2.7 Limitations of Research

While this methodology contributes novel techniques to crime mapping, several limitations must also be noted. As with all data aggregated to an area, results are affected by the Modifiable Area Unit Problem (MAUP), meaning that hotspots arising at the Census Tract level may appear differently when mapped at a different spatial unit. In addition, this method of hotspot mapping does not account for short-term temporal variation in crime rates. Because crime is unevenly distributed across both space *and* time (Ratcliffe 2002a), the areas of high risk identified using this mapping technique are necessarily generalized to the temporal level of the sentinels themselves. The sentinel conditions, developed from census data, are updated every 5 years, and may not truly reflect the current neighbourhood socio-economic status. As this methodology relies on proxy estimates of crime, it is less accurate than using actual crime data, and

requires verification and groundtruthing in its conception, in order to ensure that estimated trends are reasonable proxies of the actual occurrences.

2.8 Conclusion

Sentinel conditions are widely used to bridge gaps in data analysis by providing information that may be difficult or problematic to investigate directly. When applied to crime mapping, the use of sentinels has the potential to estimate the risk of victimization without requiring actual crime occurrence data. This is of value within a field where such information can be difficult to obtain for research purposes, and must be restricted from public dissemination due to individual security concerns (Boulos et al. 2005, Ratcliffe 2002b). Employing census variables related to residential burglary, this methodology creates a sentinel layer to estimate relative risk of victimization. Residential burglary, like many forms of criminal activity, is a complex and multifaceted phenomenon. No single census variable currently available can – or should – be used as a proxy of burglary on its own. However, when used in combination with other relevant socio-economic variables, publicly available census information can be a powerful sentinel indicator, providing a statistically significant estimate of risk of victimization.

Access to such information can be of value to researchers, policy makers, and police forces, alike. When crime data is unavailable, the relationship between the sentinel conditions and actual burglary rates, as established through this research, can be used as a proxy to identify locations with high risk of victimization. This availability can expand the possibilities of research and

analyses that have been previously hindered by data access issues. When crime data *is* available, sentinel conditions can provide insight into the social and economic composition of an area, increasing the understanding of the changing relationship between the sentinels and areas of high crime, and allowing policing tactics to cater specifically to the unique needs of each individual crime hotspot.

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CHAPTER 3: ADAPTING A RISK OF VICTIMIZATION MODEL FOR MID-SIZED CITIES

3.1 Abstract

Residential burglary, one of the most prevalent crimes in Canada, has been the subject of extensive research in recent decades. This research has resulted in the identification of several socio-economic conditions that have been found to relate to this crime. These publicly available attributes can be combined using ordinal regression, with the resulting relationship used to create a sentinel map layer. The sentinel layer can be used by researchers to estimate the relative risk of residential burglary victimization. This paper begins with a sentinel model created for use in dense metropolitan areas of British Columbia, and adapts the framework to better represent risk of burglary victimization in the Province's smaller urban areas. In doing so, it builds a greater understanding of how the relationship between theoretically relevant socio-economic sentinel conditions and levels of residential burglary transforms in different urban settings.

3.2 Introduction

Sentinel analysis involves the use of one or more proxies in order to measure a phenomenon that may otherwise be difficult to study. Established and commonly applied in ecological and remote sensing research, this framework has been modified and used to develop a proxy to estimate risk of residential burglary victimization within a densely-populated urban area in British

Columbia (Wuschke, Schuurman and Brantingham submitted 2007). This adapted methodology focuses on the socio-economic conditions that exist alongside areas of high crime, using these theoretically relevant factors as sentinel proxies to estimate victimization patterns within the region. Sentinel conditions are chosen based on an extensive literature review, identifying the social and economic variables that have been found to correlate with residential burglary. The relationship between the sentinels and the actual patterns of burglary is modelled using ordinal regression. This model is then used to estimate the risk of victimization for an extended urban region.

The benefits of such a model are twofold. First, the use of sentinel analysis within the crime studies allows researchers to establish an approximate risk surface of residential burglary victimization, relying on publicly available socio-economic conditions instead of crime data itself. In choosing sentinel layers that are widely supported by criminological theories and decades of previous analysis, this model provides researchers with an alternative data source that can be used in lieu of actual crime occurrence data when such information is unavailable or difficult to acquire. Using sentinel layers available within the Canadian census data, an estimation of the risk of residential burglary victimization can be created and used without requiring extensive security clearances, or without compromising the privacy of either the victim, or the offender of the crime. In addition, this form of analysis also allows for an increased understanding of how these theoretically relevant socio-economic

sentinel conditions relate to residential burglary patterns in an urban metropolitan area, and how this relationship changes across geographic space.

This model was found to be successful for a densely populated urban region in British Columbia, but does not accurately estimate the risk of victimization within the province's mid-sized cities (Wuschke, Schuurman and Brantingham submitted 2007). This finding is consistent with recent releases from Statistics Canada, which have emphasized the uneven distribution of burglary rates (or breaking and entering in the Canadian Criminal Code) across the country. These studies have confirmed that Canada's small urban areas (urban centres with populations greater than 1000 people) have the highest rates of property crimes (Francisco and Chénier 2007), and that smaller CMAs (cities with populations greater than 100,000 people) have higher rates of breaking and entering than larger CMAs (Fedorowycz 2004). In addition, previous research incorporating socio-economic factors has revealed that local phenomenon is best represented through the use of locally developed models (Bell, Schuurman and Hayes 2007; Fiedler, Schuurman and Hyndman 2006a, 2006b). With this in mind, the original sentinel model is adapted for specific use within British Columbia's mid-sized cities. A place-specific model is created that draws on the demonstrated socio-economic conditions used for high-density urban areas. This model is then modified to accommodate the unique character of smaller urban centres, with the goal of understanding how factors relating to residential burglary change across different urban landscapes.

3.3 Background

As maps and Geographic Information Systems (GIS) play an increasingly important role within crime analysis, researchers strive to find new and innovative ways to represent patterns of criminal activity (Lodha and Verma 1999; Verma and Lodha 2002, Ratcliffe 2004a). A variety of hotspot mapping techniques have become commonplace within the policing environment, allowing law enforcement officers to better direct limited resources (Paulsen 2004). While such methods and advancements are valuable additions to crime analysis, each relies upon the availability of crime occurrence data in order to produce spatial output. As with many forms of individual-level data, however, crime records are often confidential in nature, and are therefore problematic and time-consuming to acquire. Such information often requires significant security clearances and special permissions from ethics and review panels before approval for use is granted (Boulos et al. 2006). Furthermore, criminal event data is often prevented from public release in order to protect the privacy of both the victim and the offender (Ratcliffe 2002b). The difficulties associated with acquiring such data limit its use to governmental and law enforcement settings or to researchers with special access. Sentinel conditions help to fill the gap in current crime mapping methods. By switching the emphasis of crime maps from actual occurrence data, and instead focusing on publicly available socio-economic crime correlates, patterns in victimization risk can be identified without interfering with the privacy of victims and offenders alike.

3.3.1 Sentinel conditions: development of a model for a large urban centre

An innovative methodology for the identification of areas with a high risk of victimization was developed in order to avoid a range of data accessibility and privacy concerns (Wuschke, Schuurman & Brantingham submitted 2007). A sentinel-based model was created for use within a crime analysis setting, which produces an estimated distribution of the risk of residential burglary victimization by relying on publicly available, neighbourhood-level data. The model was built around a set of socio-economic variables identified by an in-depth literature review, which are widely accepted to be correlated to the existence of residential burglary. A select municipality within British Columbia was chosen as a test site, and the relationship between these socio-economic variables, and the actual distribution of neighbourhood-level residential burglary rates was modelled for this location, using ordinal regression. Upon establishing this relationship, the focus of the study was extended to include eight additional municipalities surrounding the test location. The sentinel methodology was applied across this wider region, to create a proxy layer that estimates the relative risk of residential burglary victimization across the expanded area. Results showed that this original sentinel model represents risk of residential burglary victimization throughout the wider urban region significantly well, without requiring secure crime data input (Ibid).

3.3.2 Identifying socio-economic input

Residential breaking and entering is one of the most common property crimes in Canada (Fedorowycz 2004). This crime impacts every province and

territory, and is of specific concern to British Columbia, which reports the second-highest rates of break and entry of all Canadian provinces (Silver 2007). There has been a significant amount of research in recent decades, dedicated to revealing the socio-economic conditions that correlate with this crime (Rengert & Wasilchick 1985). A review of prominent research in criminology has identified eleven neighbourhood-level socio-economic indicators that have widely been found to correlate to the existence of residential burglary at this scale. Each of these variables is publicly available through the Canadian census, or through other easily accessible municipal data sources. Such public accessibility is an important feature of this research, as it meets the conditions of sentinel frameworks, which require that all proxies be easy to acquire and measure.

Several variables were included to represent the often-reported propensity for burglaries to occur in unoccupied or unguarded dwellings (Cromwell, Olson & Wester Avary 1991; Rengert & Wasilchick 1985; Cohen & Felson 1979). Additional indicators were identified to reflect neighbourhood instability, which is often associated with an increased risk of victimization (Malczewski & Poetz 2005; Bernasco 2003; Brantingham & Brantingham 1993; Cohen & Felson 1979). A variable was also selected to measure the prominence of commercial land uses within each neighbourhood. This was added to capture the existence of activity hubs and crime attractors, as such features may allow offenders to enter the area without appearing suspicious or out of place, or permit the offender to become more familiar and comfortable with the area during regular, routine activities (Brantingham & Brantingham, 2000, 1993; Brantingham et al.,

forthcoming; Bernasco & Nieuwbeerta 2005; Bernasco 2003). Additionally, a variable to account for the existence of low-rise apartments was identified, as such structures have been found to have higher rates of victimization than other types of residential dwellings (Brantingham & Brantingham 1993). Table 3-1 displays the eleven selected neighbourhood level socio-economic sentinels. These variables, chosen and modelled in the initial urban region study, will form the foundation of this second model, which aims at estimating the risk of residential burglary victimization within smaller urban areas across British Columbia.

Table 3-1: Socio-economic sentinel conditions relating to residential burglary

Socio-Economic Conditions
Percent of neighbourhood area occupied by commercial land use
Percent separated
Percent divorced
Percent of lone parent households
Percent of households with only one resident
Percent renters
Percent of households requiring major repairs
Percent small apartments
Unemployment rate for adults ages 15 and over
Percent of residents who have moved within the past year
Average Household Income

3.4 Data and Methodology

Preliminary applications of sentinel conditions within a crime analysis setting have proven to be successful. By combining eleven socio-economic crime correlates, the resulting sentinel layer provides an estimation of the relative risk

of residential burglary victimization, which is significantly correlated to actual crime distributions within the region for which it was created. In addition, this spatial layer provides a more accurate estimation of residential burglary victimization than any one of the socio-economic correlates would provide on its own (Wuschke, Schuurman & Brantingham submitted 2007). This model, however, is unsuccessful at estimating burglary patterns in smaller urban areas located outside of the initial test region. This is expected, as burglary rates are known to change across different urban settings (Francisco & Chénier, 2007). With this in mind, it is evident that a sentinel crime model created for use in large British Columbian CMAs should *not* be able to provide accurate estimates of victimization trends within the province's mid-sized cities. Therefore, an adjusted sentinel crime model has been created for use within these distinctive urban centres, in order to better capture their unique residential burglary trends.

3.4.1 Crime data source

The Institute for Canadian Urban Research Studies (ICURS) in Simon Fraser University's School of Criminology has formed a unique partnership with British Columbia's Royal Canadian Mounted Police (RCMP). This collaboration has resulted in the opportunity for the multidisciplinary ICURS research team to access a database containing address-level data for reported criminal occurrences in British Columbia between 2004 and 2006. Along with this access, came stringent data handling regulations, and restrictions from disseminating any individual-level information. The RCMP required all data handlers to pass a rigorous security clearance, and limited data access to within the secure ICURS

research facility. All data had to be aggregated and stripped of location identifiers before being presented.

All break and enters occurring in three select mid-sized cities were selected from this dataset. Data from one urban centre (referred to as City 'A'), located in central B.C., were used to create the sentinel model for risk of victimization within mid-sized cities. The remaining two cities (one located in northern B.C. (referred to as City 'B'), the other (City 'C') on the British Columbian coast) were used as model-testing locations, with actual breaking and entering data needed only to verify the model's estimated results. These mid-sized cities range in population from roughly 72,000, to 78,000 residents. The names of these urban centres cannot be identified, as required by the ICURS/RCMP data sharing agreement.

3.4.2 Choosing spatial units of analysis

As socio-economic census information was required for the creation of this sentinel model, the Canadian census was used to identify potential areas by which to aggregate the data, narrowing options to Census Tracts (CTs) or Dissemination Areas (DAs). CTs are small, geographically and temporally stable areas that contain between 2500 and 8000 people (Statistics Canada 2007a). All Canadian CMAs and urban centres with populations greater than 50,000 have socio-economic data available and easily accessible at this geographic level. The initial sentinel model was based around CTs, and this spatial scale proved to be a successful unit of analysis when investigating large, densely populated urban regions. However, when shifting the focus to smaller urban centres, CTs proved

to be somewhat problematic. Therefore, DAs were selected for spatial aggregation of crime data within mid-sized urban areas, because they provided a more appropriate sample size for these smaller locations. Ranging between four hundred and seven hundred residents, DAs are the smallest spatial unit for which the entire Canadian census is publicly available (Statistics Canada 2007b).

All address-level crime occurrence data were aggregated to the DA level, and stripped of any individual identifiers. The corresponding socio-economic data was also collected from the Canadian census at this level. Commercial land use information was acquired from the individual municipalities used in this study. Each DA was then investigated for completeness of socio-economic data, and areas with missing or incomplete information, and those with exceptionally low occupied private dwelling densities, were excluded from the analysis. Table 3-2 displays the number of Dissemination Areas available for, and included in, this analysis. Residential burglary data was then used to calculate a rate of burglaries per household, and each remaining DA was placed into a quintile according to this calculation, with the first quintile representing the lowest rates of residential burglary, and the fifth representing the highest. Socio-economic data was also standardized into percentages where necessary.

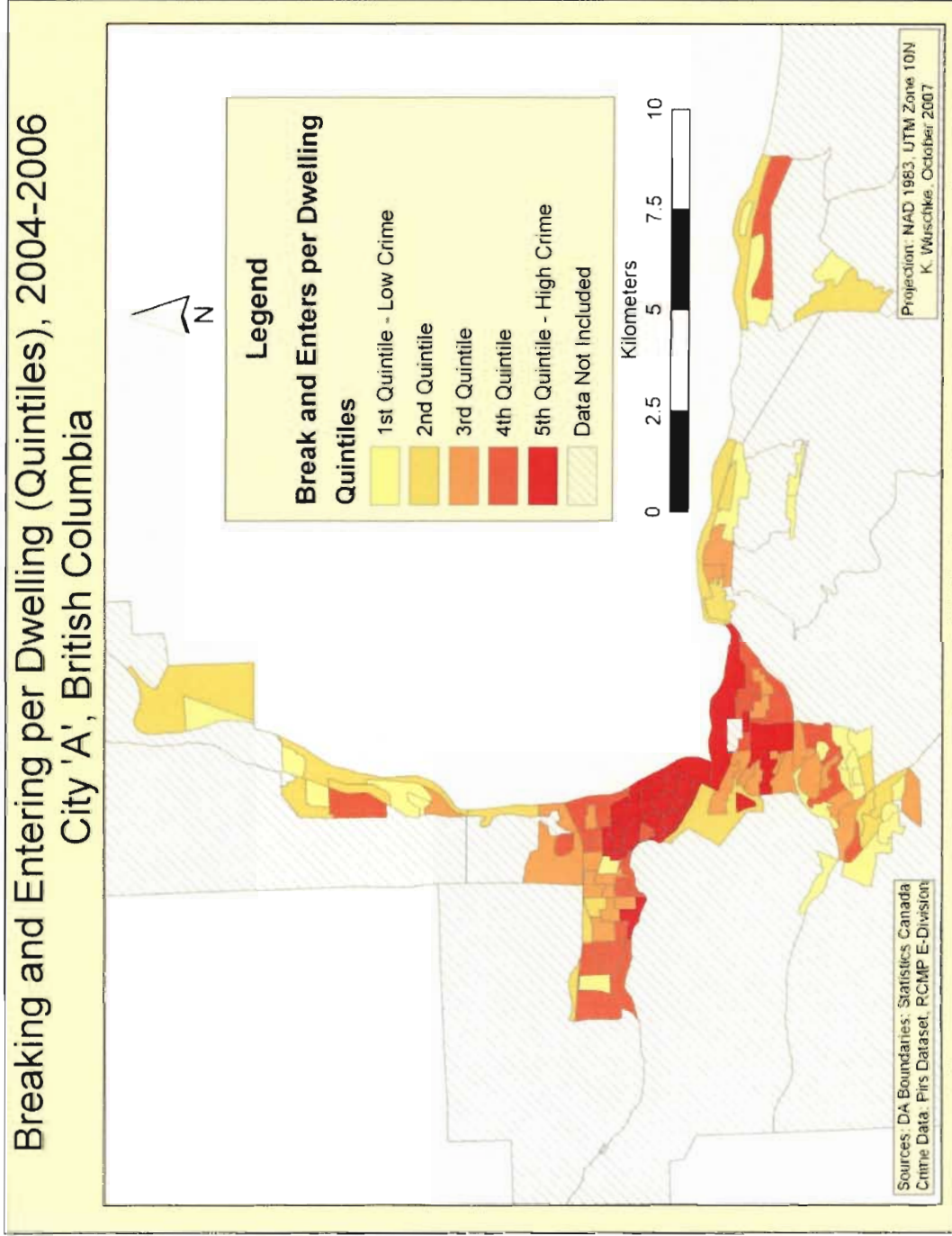
Table 3-2: Breakdown of Dissemination Areas included in analysis, by location

Mid-Sized B.C. Cities	DAs within city	DAs with incomplete Census data	DAs with low dwelling densities	Total DAs included in analysis
City 'A'	133	1	14	118
City 'B'	136	8	13	115
City 'C'	97	14	9	74

3.4.3 Ordinal regression analysis: City 'A'

City 'A', a mid-sided urban centre located in central British Columbia, was selected as the model location, and formed the basis of this sentinel analysis. Figure 3-1 displays the actual distribution of residential burglary quintiles within this city. Using these quintiles as the dependent variable, and the eleven socio-economic crime correlates as the independents, these values were used as data in an ordinal regression analysis with the goal of estimating the relative risk of residential burglary victimization. Preliminary tests incorporating all theoretically relevant socio-economic conditions quickly identified several independent variables that did not contribute to the model. These variables were omitted, and the ordinal regression was performed again, with the model containing the theoretical independent variables that contributed to its' overall performance. The resulting reduced model described the complex relationship between the input socio-economic variables, and the distribution of residential burglary rates in City 'A'. This final model formed the sentinel layer, which was then used to estimate the relative risk of residential burglary victimization in different mid-sized British Columbian cities.

Figure 3-1: Actual distribution of breaking and entering quintiles, City 'A' - reference map



3.4.4 Testing the sentinel model: Cities 'B' and 'C'

When moved to alternate test cities (City 'B' and City 'C'), the sentinel model used only on the publicly available, local socio-economic variables as inputs. For each individual DA, the model used the standardized sentinel variables, and output probabilities that the given DA fell within *each* of the five ordinal categories of risk of victimization. These probabilities were then compared, and each DA was assigned a value ranging from one to five, with one indicating that there is the greatest probability that this specific area experiences the lowest risk of residential burglary victimization, and five indicating a high probability that the given DA faces the highest relative risk. This sentinel framework was used within each DA in both test cities, and the resulting estimated risk surface was then mapped and statistically compared to actual distributions within each city, in order to validate the predicted results.

3.5 Results

3.5.1 Creating the mid-sized city sentinel model

When inputting the eleven theoretically relevant socio-economic sentinel layers into an ordinal regression equation for City 'A', initial results indicated that several independent variables were unnecessary, and were not contributing to the model's success. In order to best understand how each of these variables were impacting the overall model, they were removed, one-at-a-time, beginning with the socio-economic variables that contributed the *least*. The final, simplified model contains seven socio-economic variables, having excluded the percentage

of divorced individuals, the percentage of residents who have moved within the past year, the percentage of homes requiring major repairs, and the average household income from the analysis. Each of the excluded variables is quite highly correlated to other independents that remain in the analysis.

Table 3-3: Model fitting information, City 'A'

Model	-2 Log Likelihood	Chi-Square	Degrees of Freedom	Significance
Intercept Only	377.733			
Final	311.079	66.653	7	0.000

The final sentinel model, relying on the seven remaining socio-economic variables, represents the relative risk of residential burglary victimization within City 'A'. Table 3-3 displays the model fitting information, and indicates that this model reflects the actual distribution of residential burglary rates significantly better than a more general model. The test of parallel lines, shown in Table 3-4, indicates that the seven sentinel variables included in this ordinal regression equation are appropriate predictors for all five quintiles of residential burglary. Table 3-5 displays the parameter estimates resulting from this model. The information provided by this table is used to determine probabilities, which lead to the creation of an estimated risk surface for residential burglary victimization within City 'A'. These parameters will also permit this sentinel model to predict burglary distributions in other mid-sized British Columbian cities. By reworking the ordinal regression model to include the calculated parameter estimates and

actual socio-economic sentinel variables, the estimated risk surface (or the dependent variable) can be calculated without any input crime data.

Table 3-4: Test of parallel lines, City 'A'

Model	-2 Log Likelihood	Chi-Square	Degrees of Freedom	Significance
Null Hypothesis	311.097			
General	301.268	9.811	21	0.981

Table 3-5: Parameter estimates, City 'A'

		Estimate	Significance	95% Confidence Interval	
				Upper Bound	Lower Bound
Threshold	[BE/DwellQuint = 1]	1.77	0.001	0.741	2.810
	[BE/DwellQuint = 2]	2.83	0.000	1.749	3.911
	[BE/DwellQuint = 3]	1.48	0.000	2.996	5.400
	[BE/DwellQuint = 4]	5.73	0.000	4.320	7.159
Location	%Commercial	-0.019	0.511	-0.077	0.038
	%Separated	0.205	0.142	-0.068	0.478
	%LoneParent	0.012	0.404	-0.017	0.042
	%1PersonHHolds	0.073	0.002	0.026	0.120
	%Rented	0.019	0.179	-0.009	0.048
	%Low-RiseApts	-0.011	0.520	-0.044	0.022
	UnemployRate	0.016	0.100	-0.003	0.035

In order to evaluate the success of this initial sentinel model, Table 3-6 displays a cross-tabulation of the predicted risk of victimization categories, with the actual crime rates for City 'A'. This initial model correctly classified 46.6% of the Dissemination Areas into the appropriate quintile. A large majority of DAs belonging to the first and fifth quintiles of residential burglary were correctly classified by this model. However, not a single DA was classified into the second

quintile – an occurrence that leads to significant deviation from the expected group sizes. While the original quintiles each contained approximately equal percentages of the total number of Dissemination Areas, the predicted categories contain between zero and thirty-five percent of the total DAs, and as determined by a Chi-Square test statistic, are significantly different in size. However, in spite of these deviations, 77.1% of the Dissemination Areas have been classified correctly, or within one category of their expected quintile.

Table 3-6: Cross-tabulation of actual and predicted crime distributions, City 'A'

			Predicted Category					Total
			1	2	3	4	5	
Actual B&E Quintile	1	Count	17	0	6	1	1	25
		%	14.4	0	5.1	0.8	0.8	21.2
	2	Count	9	0	8	1	0	18
		%	7.6	0	6.8	0.8	0	15.3
	3	Count	4	0	13	4	6	27
		%	3.4	0	11.0	3.4	5.1	22.9
	4	Count	4	0	11	8	2	25
		%	3.4	0	9.3	6.8	1.7	21.2
	5	Count	1	0	3	2	17	23
		%	0.8	0	2.5	1.7	14.4	19.5
Total		Count	35	0	41	16	26	118
		%	29.7	0	34.7	13.6	22.0	100.0

Table 3-7 displays the correlations between the actual residential burglary rate quintiles, and the predicted categories. This table shows that the predicted risk of residential burglary victimization, as derived through the use of the seven socio-economic sentinel inputs, is significantly correlated to the actual distribution of this crime within City 'A'. Not only this, the predicted layer is *more*

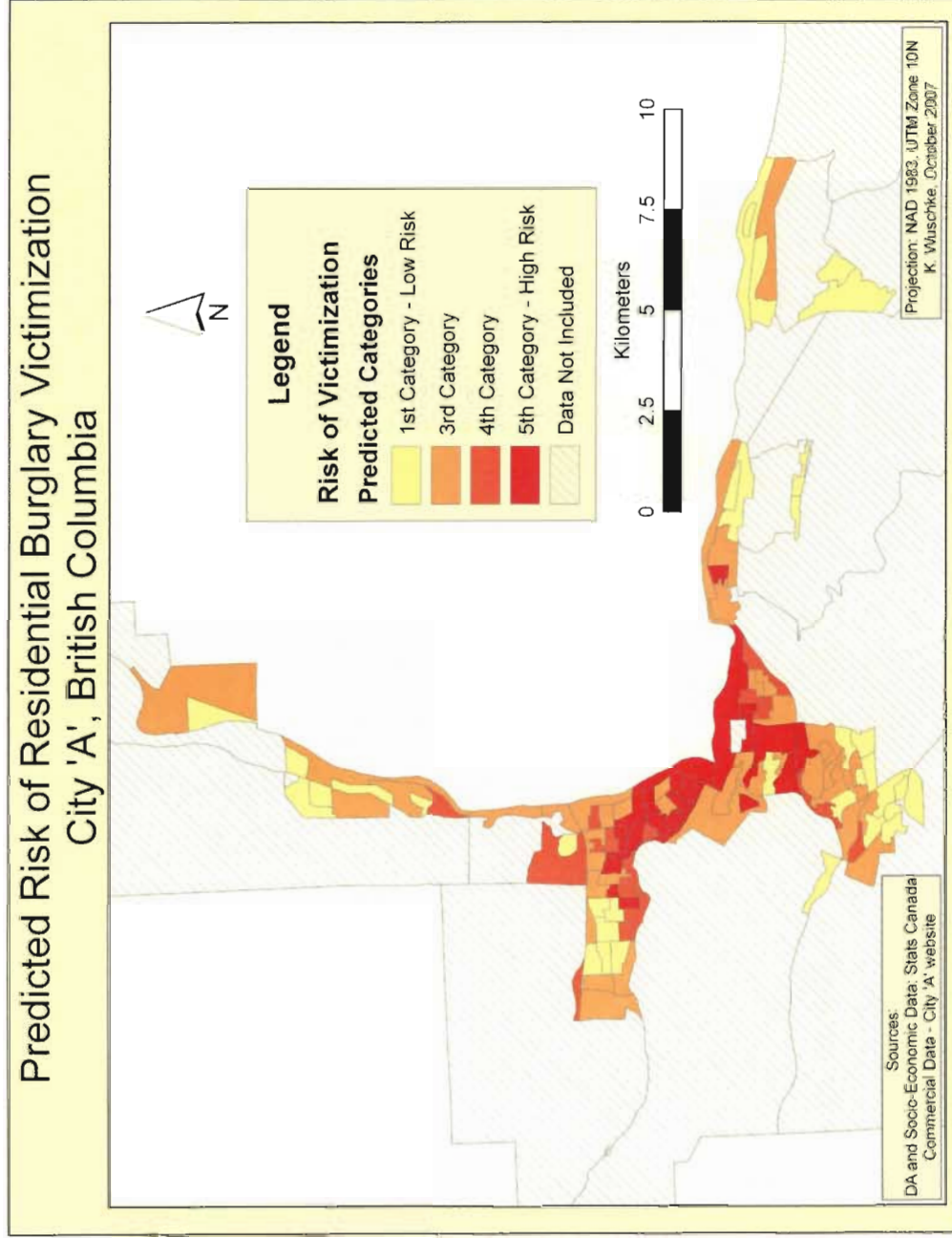
correlated to the actual distribution than any other single sentinel predictor used in this analysis is.

Table 3-7: Correlation of sentinel inputs to actual residential burglary quintile, City 'A'

Sentinel Condition	Correlation to B&E Quintile	Significance
Percent of Census Tract area occupied by commercial land use	0.164	0.077
Percent separated	0.514	0.000
Percent of lone parent households	0.527	0.000
Percent of households with only one resident	0.584	0.000
Percent renters	0.568	0.000
Percent small apartments	0.508	0.000
Unemployment rate for adults ages 15 and over	0.281	0.002
Predicted Risk of Victimization Category	0.612	0.000

The predicted risk of residential burglary victimization for City 'A' is mapped and displayed in Figure 3-2. A global Moran's I, tested on both the actual distribution of residential burglary, and the predicted output of this sentinel analysis, reveals that both distributions exhibit spatial autocorrelation. This indicates that there is a significant amount of spatial clustering of both areas with high rates (or high risk) of residential burglary, and areas with low rates (or low risks) of this crime, in the actual and predicted maps of City 'A'.

Figure 3-2: Predicted risk of residential burglary victimization, City 'A'



3.5.2 Predicting relative risk of victimization: City 'B'

The next phase uses the ordinal-based sentinel model to estimate residential burglary risk of victimization in geographically separate mid-sized cities located across the province. City 'B' is identified as the first test location, and the standardized socio-economic sentinel conditions are input into the ordinal regression model, in order to develop a predicted layer of relative risk of residential burglary victimization for this area. A value ranging from one to five is given to each dissemination area across the mid-sized test location, with one indicating a high probability that the given dissemination area has the lowest relative risk of victimization, and five indicating a high probability that the DA falls within the highest relative risk category.

Table 3-8 displays the predicted risk of victimization layer, cross-tabulated with the actual crime distribution for City 'B'. Using the sentinel model created from the relationship between residential burglary and the associated socio-economic conditions within City 'A', 39.1% of the Dissemination Areas within City 'B' have been correctly classified. Similar to the results found within City 'A', no DAs have been predicted to fall into the second quintile of residential burglary, a trend that again disrupts the predicted group sizes. A Chi-Square test statistic reinforces this finding, identifying a significant difference in size between the five predicted categories. However, the sentinel model has predicted 80.9% of the DAs correctly, or within one grouping of their expected category within this test location. As identified in the Table 3-9 ordinal-by-ordinal symmetric measurements, the predicted and actual distributions are significantly similar.

Table 3-8: Cross-tabulation of actual and predicted residential burglary rates, City 'B'

			Predicted Category					Total
			1	2	3	4	5	
Actual B&E Quintile	1	Count	14	0	7	0	0	21
		%	12.2	0	6.1	0	0	18.3
	2	Count	19	0	4	4	0	27
		%	16.5	0	3.5	3.5	0	23.5
	3	Count	7	0	9	4	2	22
%		6.1	0	7.8	3.5	1.7	19.1	
4	Count	0	0	7	8	7	22	
	%	0	0	6.1	7.0	6.1	19.1	
5	Count	1	0	1	7	14	23	
	%	0.9	0	0.9	6.1	12.2	20.0	
Total		Count	41	0	28	23	23	115
		%	35.7	0	24.3	20.0	20.0	100.0

Table 3-9: Symmetric measures of actual residential burglary rates, and predicted risk of victimization categories, City 'B'

		Value	Asymp. Std. Error	Approx. T	Est. Sig.
Ordinal By	Kendall's tau-b	0.616	0.043	13.918	0.000
	Kendall's tau-c	0.628	0.045	13.918	0.000
Ordinal	Gamma	0.757	0.047	13.918	0.000
	Spearman	0.721	0.045	11.052	0.000

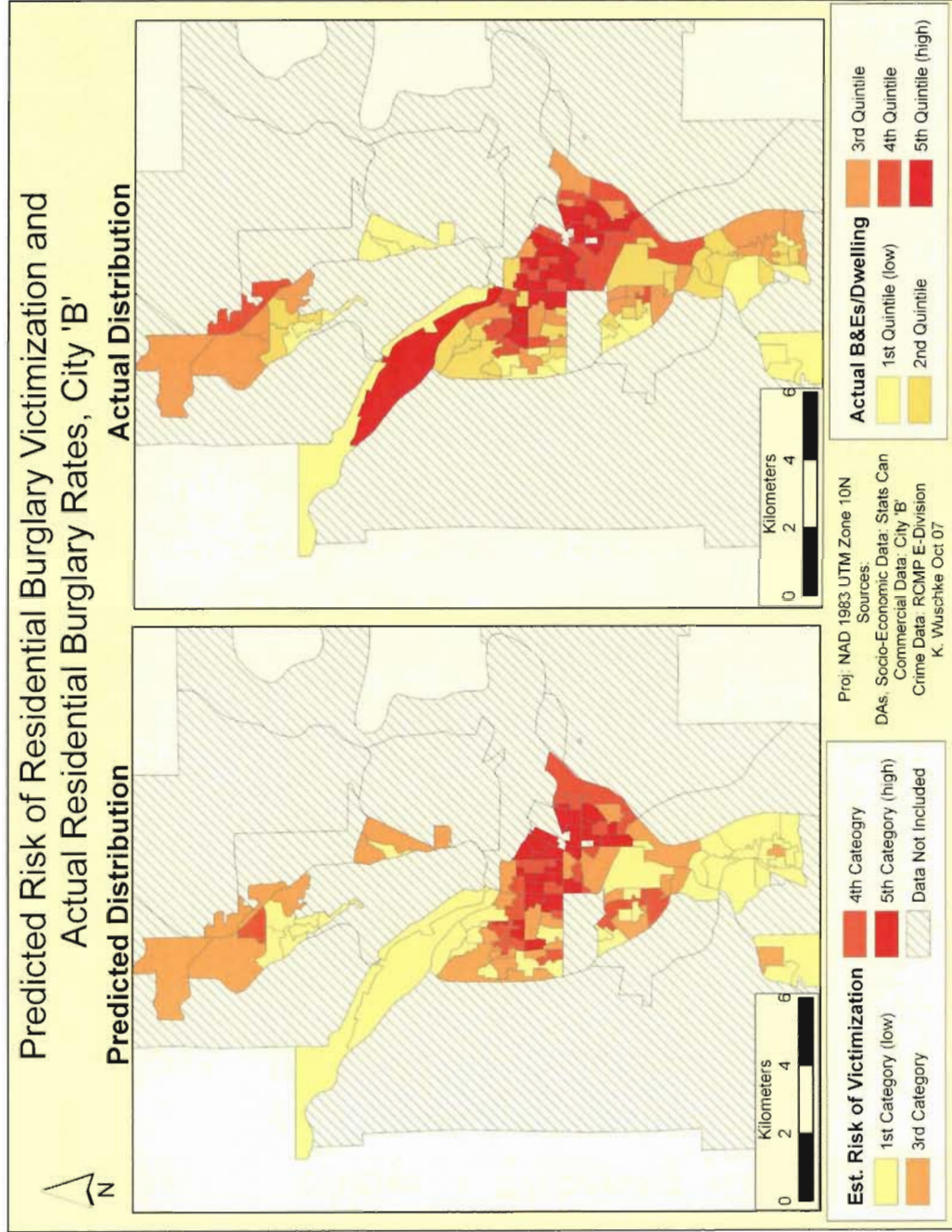
Upon correlating the actual distribution of residential burglary rates of City 'B' with the sentinel inputs and predicted results from the mid-sized city sentinel model (Table 3-10), it becomes clear that the predicted risk surface of relative burglary victimization is significantly related to the actual distribution. Additionally, this predicted sentinel layer is again, *more* significantly correlated to the actual distribution than any one of the socio-economic inputs is individually.

Figure 3-3 displays the predicted relative risk of residential burglary victimization of City 'B', alongside the actual burglary distribution for this mid-sized location. A global Moran's I test is again performed on both spatial distributions, and once again reveals significant spatial clustering of both hotspots of and coolspots of residential burglary (or risk of burglary) in both the predicted and the actual crime maps.

Table 3-10: Correlation of sentinel inputs to actual residential burglary quintile, City 'B'

Sentinel Condition	Correlation to B&E Quintile	Significance
Percent of Census Tract area occupied by commercial land use	0.268	0.004
Percent separated	0.674	0.000
Percent of lone parent households	0.665	0.000
Percent of households with only one resident	0.566	0.000
Percent renters	0.601	0.000
Percent small apartments	0.374	0.000
Unemployment rate for adults ages 15 and over	0.351	0.000
Predicted Risk of Victimization Category	0.721	0.000

Figure 3-3: Predicted and actual distribution of residential burglary rates, City 'B'



3.5.3 Predicting relative residential burglary rates: City 'C'

The adapted sentinel model has estimated relative risk of residential burglary victimization within two mid-sized British Columbian cities. In an effort to understand how well this model performs across a range of small urban areas within the province, a new test location is selected for further analysis. City 'C' is geographically separated from both Cities 'A' and 'B'. With a slightly smaller population and a vastly different economic framework, this city is selected in order to determine whether this sentinel methodology can successfully predict burglary distributions within a wide variety of mid-sized locales. Local socio-economic indicators are once again input into the sentinel model created in City 'A', and the resulting predicted risk of relative residential burglary victimization is further examined for correlation to the actual distribution of this crime within City 'C'.

Table 3-11: Cross-tabulation of actual and predicted residential burglary rates, City 'C'

			Predicted Category					Total
			1	2	3	4	5	
Actual B&E Quintile	1	Count %	8 10.8	0 0	2 2.7	1 1.4	0 0	11 14.9
	2	Count %	5 6.8	0 0	4 5.4	5 6.8	4 5.4	18 24.3
	3	Count %	7 9.5	0 0	2 2.7	2 2.7	4 5.4	15 20.3
	4	Count %	0 0	0 0	5 6.8	5 6.8	5 6.8	15 20.3
	5	Count %	0 0	0 0	2 2.7	6 8.1	7 9.5	15 20.3
Total		Count %	20 27.0	0 0	15 20.3	19 25.7	20 27.0	74 100.0

The predicted risk of residential burglary victimization, as established by the sentinel model, are cross-tabulated with the actual distribution of burglary within City 'C', with the results displayed in Table 3-11. This table shows that 29.7% of Dissemination Areas have been correctly classified into the appropriate quintile of residential burglary. Consistent with earlier predictions using this sentinel framework, no DAs have been classified into the second quintile of residential burglary, and predicted group sizes are once again, significantly different from each other, and from their expected size. 66.2% of DAs were classified correctly, or within one ordinal level of their actual category. While these predicted results are somewhat lower than findings from the other test locations across British Columbia, Table 3-12 reinforces that the sentinel layer of residential burglary is still significantly similar to the actual distribution within City 'C'.

Table 3-12: Symmetric measures of actual residential burglary rates and predicted risk of victimization categories, City 'C'

		Value	Asymp. Std. Error	Approx. T	Est. Sig.
Ordinal By Ordinal	Kendall's tau-b	0.408	0.071	5.691	0.000
	Kendall's tau-c	0.419	0.074	5.691	0.000
	Gamma	0.513	0.086	5.691	0.000
	Spearman	0.495	0.084	4.840	0.000

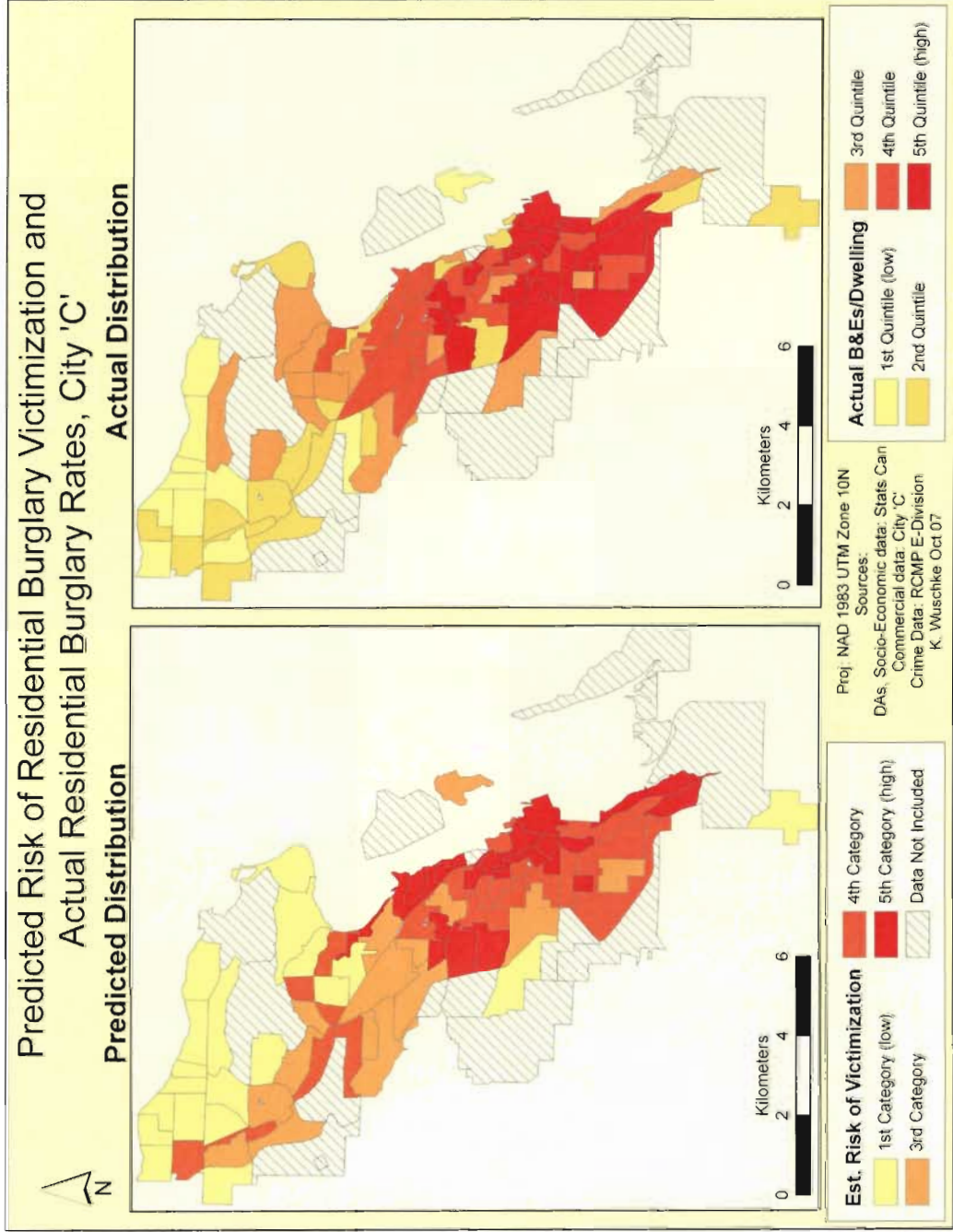
Table 3-13 displays the correlation between the actual distribution of residential burglary rates within City 'C', and the input sentinels and predicted risk of victimization classifications. While the predicted sentinel layer is significantly correlated to the actual distribution of residential burglary within this mid-sized

location, it is no longer higher correlated to the actual distribution than any one of the input socio-economic variables would be on their own. The predicted and actual distributions for City 'C' are mapped and presented in Figure 3-4. A global Moran's I reveals once again that both the actual patterns of residential burglary within this municipality, as well as the predicted risk of burglary victimization, are significantly spatially autocorrelated, in that hotspots are located near other hotspots, and likewise, coolspots are spatially clustered near other coolspots.

Table 3-13: Correlation of sentinel inputs to actual residential burglary quintile, City 'C'

Sentinel Condition	Correlation to B&E Quintile	Significance
Percent of Census Tract area occupied by commercial land use	0.124	0.294
Percent separated	0.444	0.000
Percent of lone parent households	0.561	0.000
Percent of households with only one resident	0.327	0.004
Percent renters	0.606	0.000
Percent small apartments	0.353	0.000
Unemployment rate for adults ages 15 and over	0.569	0.000
Predicted Risk of Victimization Category	0.495	0.000

Figure 3-4: Predicted and actual distribution of residential burglary rates, City 'C'



3.6 Discussion

By modelling the relationship between seven theoretically relevant socio-economic variables, and the actual distribution of residential burglary throughout one mid-sized municipality in British Columbia (City 'A'), a sentinel framework has been adapted to predict relative risks of burglary victimization within mid-sized cities in rural surrounds. This methodology, modified from a similar structure that was originally designed to estimate victimization risk within a densely populated Census Metropolitan Area, provides a technique to model the unique crime patterns that occur in smaller urban settings. This sentinel tool has estimated the risk of residential burglary victimization across three mid-sized urban centres significantly well, at the Dissemination Area level. This level of aggregation not only provides a sufficient sample size when modelling mid-sized urban centres in British Columbia, it is also available for every area of Canada, and therefore increases the geographic range for which this model can be applied. While estimations were more accurate in some test centres than in others, the model's prediction proved to be significantly similar to the actual spatial patterning of neighbourhood-level residential burglary rates at all test sites.

While adapting the original sentinel model to better reflect crime patterns of mid-sized cities, four key socio-economic factors were removed as independent variables. The percentage of divorced adults, the percentage of residents who have moved in the past year, the percentage of homes in need of major repairs, and the average household income were all excluded as

independent variables in the mid-sized city sentinel model. Each of these variables has been identified in previous research as relating to the existence of residential burglary, so their exclusion from this model required careful consideration. However, these four variables did not contribute to the success of the overall sentinel model, and were also significantly correlated to socio-economic variables that *did* add to the model. Their removal was further justified in that no theoretically accepted factors were left unrepresented in the more concise model. While divorced adults and movers were originally included to measure levels of neighbourhood instability, these socio-economic characteristics are still represented by unemployment variables, separated adults, and lone parent households. A variable measuring the presence of homes requiring repairs was originally used to represent both neighbourhood instability and the absence of a suitable guardian. However the latter attribute is accounted for by measurements of one-person households (among others). Finally, while a significant sector of the residential burglary literature identifies average household income as a key feature relating to the presence of this crime (see, for example, Malczewski and Poetz 2005; Smith and Jarjoura 1989), this variable was found to be highly correlated to the percentage of renters, and the unemployment rate within a neighbourhood. Therefore, while the original large urban area sentinel model worked optimally with all eleven theoretically relevant socio-economic crime indicators, the adapted mid-sized city model requires fewer sentinel inputs to predict neighbourhood-level variations in victimization risk.

The mid-sized urban model was clearly successful when predicting the relative risk of residential burglary victimization within both cities 'A' and 'B'. When inputting the socio-economic sentinels into the ordinal regression equation, the resulting predicted crime categories were not only very significantly correlated to the actual distribution of residential burglary within these locations but the model's outputs were *more* correlated to this actual distribution than any one of the seven sentinel inputs would have been on its own. These positive results reinforce the argument that local phenomena are best represented with locally centred models.

City 'C' was included in this analysis in order to test the geographic and socio-economic range of this mid-sized burglary model. This test site is quite geographically separated from all other locations, and the economic and demographic structure of this city is different from that found in either City 'A' or City 'B'. Predictably, the sentinel model did not perform as well in this location as it did in the two previous test sites. While risk of victimization estimates were still significantly correlated to the actual distribution within this location, several of the seven input variables more highly correlated to the actual crime rates than was the predicted output. While this finding limits the geographic range of the mid-sized city model, it is expected, and further emphasizes both the complex nature of residential burglary, and the need for specific, local models that can account for the unique variations in crime and socio-economic trends across different urban settings.

3.7 Conclusion

Sentinel conditions have been applied across disciplinary boundaries, in order to better understand a phenomenon that is difficult to measure directly. In many cases, criminal patterns can fit into this category. While crime trends can be important additions to a variety of research areas, such data can be difficult and time-consuming to acquire, often requiring extensive security clearances and limitations on how the data may be used and if it may be disseminated. When faced with such data accessibility issues, sentinel conditions present an appropriate method to predict general crime trends and patterns, by relying instead on publicly available, easily accessible data.

Sentinel methodology has been adapted for use within a crime analysis setting, allowing for the estimation of the relative risk of residential burglary victimization, across a variety of urban settings. Originally designed and tested within a densely populated Census Metropolitan Area in British Columbia, this framework has been further adapted to better estimate trends within B.C.'s mid-sized urban settings. Building from an extensive body of literature relating multiple socio-economic conditions to the existence of residential burglary, this adapted model relies on neighbourhood-level census data to create probabilities, which can be used to determine the expected risk of burglary victimization within mid-sized cities in B.C. This framework creates a strong sentinel indicator that can estimate the risk of victimization with significant accuracy.

However, in spite of the clear success of this sentinel model, caution must be used when applying it across a variety of urban settings. As residential

burglary rates change across urban settings, this model is limited in its potential applications, and should be used primarily as a sentinel to estimate the risk burglary victimization within mid-sized cities in the British Columbian interior. Furthermore, this model is only as reliable as the data on which it was built. Using census data as inputs in this sentinel model has resulted in an easy-to-create and replicate framework that can potentially be adjusted to work across a variety of landscapes. However, this data is collected every five years, and as such, does not take into account new additions to a neighbourhood which may change its' susceptibility to residential burglary. By relying on neighbourhood-level proxy data, it is also comparably less accurate than address-level data. Finally, it must be noted that these models were created and verified using RCMP datasets, which can only account for *reported* residential burglary occurrences. Actual residential burglary patterns may be significantly underreported in some neighbourhoods.

In spite of the limitations of using proxies, this sentinel framework provides a practical alternative to address-level crime occurrence data. In doing so, it increases our understanding of how patterns of residential burglary change across the urban landscape, and reinforces the need for locally designed models to better reflect local phenomena. This research has further identified the changing relationship between theoretically relevant socio-economic correlates of residential burglary, and actual neighbourhood-level crime trends. While specific socio-economic variables may be highly related to burglary rates within one urban setting, the same indicators can be seemingly uncorrelated to crime

patterns in another centre. This finding opens the door to additional sentinel research, as crime patterns within small urban centres and rural areas will almost certainly require an adapted, locally developed socio-economic framework in order to best represent their unique trends.

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CHAPTER 4: CONCLUSION

Sentinel conditions can be useful when applied within a crime analysis setting. By studying and combining easily accessible socio-economic conditions, researchers can create a sentinel layer, which estimates risk of victimization without requiring access to secure, individual-level crime data. This research has identified and tested this methodology, incorporating socio-economic sentinels to estimate relative risk of residential burglary victimization within a variety of urban settings across British Columbia. The sentinel layers are chosen through extensive literature reviews, identifying the specific neighbourhood-level social and economic features that are strongly and repeatedly found to relate to the existence of residential burglary. These sentinel features are combined within a test municipality, and their relationship to actual burglary rates at this location is modelled using ordinal regression. This ordinal model can then be applied across a larger surrounding urban region, creating a sentinel layer to estimate the risk of residential burglary victimization, while relying only on publicly available, socio-economic inputs.

This original, sentinel model estimates relative risk of victimization with significant success within the initial, densely populated urban region. However, when testing the same model within geographically separate locations, it cannot accurately approximate residential burglary rates. As breaking and entering patterns change dramatically across different urban settings, a framework

constructed by modelling socio-economic patterns in a large municipality cannot be expected to perform accurately within mid-sized cities. Therefore, an additional model has been created to better represent the risk of residential burglary victimization within smaller British Columbian centres. Beginning with the theoretically relevant sentinel conditions identified for use within the original, dense urban area model, a new, place-specific framework is developed that takes into account the unique correlation between socio-economic conditions and residential burglary in mid-sized locations.

This research has created the opportunity to explore how the relationship between socio-economic conditions and residential burglary rates change across geographic space, by developing an additional model to focus on mid-sized urban centres. Eleven socio-economic inputs, identified through an extensive literature review, were included and combined to form an initial sentinel model, centred on a large British Columbian municipality. This model estimated the relative risk of residential burglary victimization throughout an extended, populous urban region with significant accuracy. When modelling the risk of victimization within smaller urban centres, however, only seven out of the original eleven socio-economic variables were needed in order to significantly estimate patterns. The four excluded variables (percent of divorced individuals, percent of movers, percent of households in need of major repair, and average household income) did not contribute positively to the mid-sized city sentinel model, but were found to be considerably more influential within the initial dense urban area model. This discrepancy reflects not only the changing relationship between

socio-economic conditions and residential burglary rates as urban structure changes, but also may indicate a more complex relationship between such variables within densely populated urban regions.

4.1 Research contribution

There are multiple benefits to applying a sentinel model within a crime analysis setting. When incorporating sentinel conditions, researchers are able to develop an estimate of the relative risk of residential burglary victimization by relying on widely available socio-economic data instead of individual criminal occurrence records. Focusing specifically on non-criminal data sources, this framework reduces the need for publicly available crime data, while simultaneously encouraging researchers to focus on the social and economic conditions that occur alongside areas of high crime. This methodology not only identifies estimated risk of victimization trends in the absence of access to more accurate criminal occurrence information, but also refocuses the analysis onto the existing social framework of the study area – an important component that can add greatly to crime analysis research.

By incorporating widely available socio-economic data from the Canadian census, the risk of burglary victimization estimates created through this methodology does not require extensive security clearances, and does not compromise the privacy of either the victim of residential burglary, or the offender. Furthermore, by adjusting and redeveloping this sentinel model to better represent residential burglary victimization patterns within mid-sized locations in British Columbia, this analysis allows for an increased understanding

of how the relationship between the theoretically relevant socio-economic sentinel conditions and residential burglary patterns transform across distinct urban space.

4.2 Future research

This research opens the door to further examinations surrounding applications of sentinel conditions within crime analysis settings. Additional sentinel models should be developed to better represent the risk of residential burglary victimization within small cities, towns and rural areas by incorporating the understanding that crime patterns change greatly across different urban settings,. In doing so, this will further reduce the need to disseminate individual-level crime occurrence information, and will allow for estimates of victimization risk to be included in a greater variety of urban and rural research. Such models will also encourage additional analysis of how socio-economic variables differently relate to burglary patterns as the urban setting changes.

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