THE GEOGRAPHY OF URBAN ARSON IN TORONTO

THE GEOGRAPHY OF URBAN ARSON IN TORONTO

By

EWA KIELASINSKA, B.A. (HONS.)

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AUTHOR: Ewa Kielasinska, B.A. Hons. (McMaster University)

SUPERVISOR: Nikolaos Yiannakoulias

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ABSTRACT

Arson has economic, structural and psychological repercussions. As a crime with such wide-ranging consequences, it has received little academic attention. Our goal in this research is to highlight how arson can be understood from two perspectives: the anthropogenic environment and the physical environment. Study one employs a generalized linear mixed regression model to explore the relationship between street network permeability and the incidence of deliberately-set fire events in the City of Toronto. This research aims to highlight the important influence that navigation of the built environment has on crime, specifically arson, in addition to the social characteristics of place that support criminal behaviour. We hypothesize that neighbourhoods with more permeable (less complex) street networks are more likely to be affected by deliberately-set fire events in the case of Toronto. Also using a multivariate regression model, study two aims to highlight the role of heat aggression on the incidence of fire-setting behaviour in the same study region. We consider fire events occurring between the months of May through September, and particularly those occurring during extended heat-wave conditions. We hypothesize that prolonged episodes of high temperatures will have a positive relationship with arson events. This research highlights that two conceivably different forms of geography (anthropogenic and physical) can impact that same phenomena: criminal fire-setting behaviour.

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"The best part about the future is that is comes only one day at a time." – Abraham Lincoln

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CHAPTER ONE: Introduction

1.1 – Research Objectives

There has been a considerable amount of research done in the field of criminology, very little of which has focused on deliberately set fire. In 2009, the Ontario Office of the Fire Marshal reported a total of 23 967 fire incidents for the province of Ontario. These fires resulted in almost $641 million in losses, 872 injuries, and 97 fatalities (OFM, 2010). Deliberately set fire events can have wide ranging consequences, including economic, structural and psychological. Therefore, the study of deliberate fire setting behaviour deserves more research attention. Conducting this research in Toronto, Canada will also provide insight into the dynamics of criminal behaviour in the Canadian context.

Street network permeability, referring to the complexity of street design in urban environments, influences the incidence of crime. Beavon et al. (1994) explored this idea with respect to property crime, and suggest that future research should consider other forms of crime. Street network patterning influences the level and type of activity each place experiences (Beavon et al., 1994). More complex road networks, more common in suburban environments, are more difficult to navigate by those unfamiliar with the area and are thought to experience less activity as a result. On the other hand, less complex, more grid-style networks often found in urban cores are familiar to larger populations as they are easier to navigate, both on foot or by vehicle (Cozens and Hillier, 2008). Various theories in criminology suggest that the larger the population familiar with an area, the higher the crime rate. We apply this hypothesis to the study of fire-setting behaviour in Toronto, Canada, specifically seeking to answer whether high levels of street network permeability increases the incidence of arson.

Additional research has also been conducted with respect to the relationship between heat aggression and violent crime. Because arson has the capacity to be a violent crime, as well as a property crime, we are interested in exploring the idea that heat aggression may be a predictor of fire-setting behaviour. The body has a natural physiological response to heat by releasing stress hormones that can produce aggressive behaviour in some individuals (Simister and Cooper, 2005). Based on the knowledge that aggressive behaviour increases with exposure to heat, we hypothesize that fire-setting behaviour will increase with extended period of exposure to heat.

Because arson can have widespread consequences, including death, it is important to gain a more thorough understanding of the processes that drive deliberate fire-setting behaviour. Contributing to the understanding of where crime happens (using the results of our permeability study) and when crime happens (using the results of our weather study) can provide a better basis for decision making by appropriate personnel in helping to control criminal activity in the City of Toronto.

1.2 – Chapter Outline

This thesis is organized into four chapters, including this introduction. Chapters 2 and 3 are research topics that relate to each other, but are conceptually different. Chapter four summarizes the findings of both chapters.

Chapter 2 is interested in determining if a relationship between street network permeability and deliberate fire-setting behaviour exists in the City of Toronto. Using a generalized linear mixed regression model we were able to determine that there is evidence of a relationship between accessibility and fire-setting behaviour. The most significant factor alluding to this relationship is the density of laneways or alleyways in Toronto. The permeability of the street network is also significant in influencing fire-setting. Other socioeconomic variables are also included in this analysis and contribute to the understanding of this relationship.

Chapter 3 is also concerned with fire-setting behaviour in Toronto. We are interested in the influence that extended heat wave conditions have on the incidence of fire events. Using multivariate regression, we found that heat wave conditions are not positive predictors of fire events alone, however heat wave conditions early in the warm season (May) are significant for fire events resulting in no monetary loss. Precipitation, however, is a strong deterrent to fire setting behaviour. Also, statutory holidays are positive predictors of deliberate fire-setting behaviour.

Chapter 4 summarizes the research findings specifically as they pertain to each research project. We review some of the contributions and limitations of each project. We conclude with suggestions for future research interested in arson and fire-setting behaviour.

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CHAPTER TWO: The Influence of Street Network Permeability on Urban Arson

2.1 - Introduction

Environmental design and urban planning have been recognized as factors affecting the way individuals perceive and interact with their surroundings with respect to travel patterns and awareness of space. Developing a better understanding of where crime happens is important to understanding why crime happens (Christens and Speer, 2005). In this study, we aim to highlight how higher density, mixed land-use development affects the opportunity for crime (both violent and property crime). Moreover, this paper builds upon the ideas presented by Beavon, Brantingham and Brantingham (1994), who hypothesize that areas with more complex street networks and a limited number of common activity spaces experience lower levels of crime against property, such as burglary and larceny. As accessibility increases, areas become more familiar to a larger population and therefore experience greater levels of activity. Increases in familiarity produce larger target populations for those who seek to commit crimes (Cozens, 2008; Cozens and Hillier, 2008; Beavon et al., 1994; Brantingham and Brantingham, 1993; Cohen and Felson, 1979). This idea has not been considered with respect to arson, which is largely a crime against property. Specifically, we hypothesize that neighbourhoods where street network permeability is greater experience more arson than neighbourhoods with more complex street networks.

The organization of this chapter is as follows. First, we offer a broad introduction of the background in criminology as it relates to urban physical and social environments. Secondly, we will outline the methods used to complete this project, including a discussion of the study area, data acquisition and use, and methods of analysis. The results of the analysis will then be presented, followed by a discussion of our findings, contributions and limitations. We finish by offering a conclusion to our research question.

2.2 – BACKGROUND

2.2.1 – Defining Arson

The reporting and investigation of arson differs from other types of violent or property crime. It is the responsibility of the local fire department (rather than the local police department) to determine the origin of a fire and, therefore, whether a crime was committed (Bennett et al. 1987). The process typically works as follows. First, an initial investigation is conducted to determine cause. Once it is determined that a particular event is the result of an intentional act by an individual or group of individuals, and therefore classified as arson, the investigation is passed on to the local police service for further investigation. Other types of crime (such as violent or property crimes) are first reported and immediately followed by a criminal investigation (Bennett et al., 1987). Additionally, the classifications for arson motivation are numerous and vary throughout the literature. Arson can be motivated by political, financial, homicidal, mischievous or psychological factors (Frizton, 2001; Canter and Frizton, 1998; Hershbarger and Miller, 1978). The motivation of the offender determines how much the built environment influences an offender's ability to commit a crime (Kocsis and Irwin, 1997).

2.2.2 – Urban Design

Urban planning in North America has been highly influenced by the English Garden Suburb style of design (Hess, 2009; Cozens and Hillier, 2008). This is in contrast to older grid-style developments, which are often associated with urban social problems (Cozens and Hillier, 2008). A shift toward the Garden City ideal occurred in the later part of the 19th Century and still persists today (Cozens and Hillier, 2008). Garden suburbs are "composed of small, spatially defined social units" (Hess, 2009, 5). These compact neighbourhoods are bounded by arterials, roads and throughways to accommodate greater volumes of traffic. Within each development is a smaller, more complex network of roads allowing access to residential environments with homes, parks, playgrounds and schools (Hess, 2009).

Studies have shown that the level of neighbourhood permeability is associated with rate of crime in general (Beavon et al., 1994; Rubenstein et al., 1980). Permeability refers to the influence of street networks and pedestrian-accessible routes on the ability for individuals (regardless of modal choice) to navigate (and be familiar with) the built environment. It has been suggested that areas in neighbourhoods with higher levels of accessibility (high permeability) are those which experience higher levels of crime as opposed to their less permeable counterparts (Beavon et al., 1994). Theories supporting the relationship between the built environment and crime include Routine Activity Theory, Rational Choice Theory and Crime Prevention through Environmental Design (CPTED).

Street network patterning is an important factor contributing to the type and volume of activity neighbourhoods experience, and also influences the number of individuals for whom the area is included as part of their 'awareness space' (Beavon et al., 1994). Awareness space is closely related to Routine Activity Theory. An individual grows more familiar with an area the more they are exposed to it as part of routine daily activities, such as travelling to and from work. Awareness space varies by an individual's age and their socioeconomic status and it increases substantially when individuals begin to use motorized forms of transportation (Brantingham and Brantingham, 1993). Awareness space can be categorized into three categories: (1) areas where individuals spend a large portion of their time on a daily basis and that are most familiar such as areas close to home, work or school; (2) the travel paths that are part of routine activities as one's exposure to them is high; (3) spaces that are common to all urban locations, such as the central business district or core areas of cities, where grid-style street networks and high density development are common (Beavon et al., 1994). Grid-style street networks, associated with older, core areas in cities, are easier to navigate, whereas the more suburban style of development characterized by winding streets and culs-de-sacs, familiar to a smaller population, are more difficult (Cozens and Hillier, 2008). Though greater density development presents valid arguments for environmental preservation, ease of transport and aesthetic appeal, it also presents concerns with respect to population dynamics, specifically with regard to crime (Christens and Speer, 2005).

In recent years there has been a shift in perspective to try and move urban development away from suburban structure, characterized by a complex network of feeder streets and culs-de-sacs, back to traditional grid networks, known for their accessibility and right-angles (Cozens, 2008). Jane Jacobs (1961) supports high levels of permeability, proposing that increased accessibility by vehicles and pedestrian traffic produce greater opportunities for surveillance, and therefore produces a deterrent for criminal behaviour. However, this 'new urbanist' perspective has been challenged in the field of environmental criminology (Cozens and Millier, 2008). New age planning perspectives, with increased accessibility and a mixture of land-uses intend to give residents incentives to participate in alternative modes of transportation. However, they increase the awareness space of more individuals, which subsequently bring targets and offenders closer together, creating a larger pool of opportunities for criminal behaviour; this idea will be further discussed with the introduction of Routine Activity Theory.

Physical characteristics of an urban environment also play a vital role in individual decision-making, as part of Rational Choice Theory. Rational Choice Theory contends that offenders will logically assess an opportunity to commit a crime based on a number of factors related to risk, effort and reward (Cozens, 2008). Concepts important to the success of new urbanism, such as rear laneways for car parking, street network accessibility and mixed-use zoning put neighbourhoods at a greater risk of experiencing crime. The typical island-layout of grid-style street networks, where home-fronts face the street make backyards inaccessible (Cozens, 2008). New urbanism adds rear laneways to typical grid-style development; laneways are used to hide vehicles from view, however they add an additional level of permeability to traditional street networks and sidewalk infrastructure (Cozens, 2008). These laneways increase accessibility to backyards, providing another point of access to an offender with less opportunity for detection.

Some features of the built environment contribute to deterring criminal activity in neighbourhoods. A proactive form of crime prevention, CPTED includes various initiatives by architects, planners, landscape architects, and property owners that can deter criminal behaviour (Minnery and Lim, 2005; Cozens, 2002). Property owners practice a form of 'territoriality', where they are protective of the space they own; as a result there is also a defined respect for the territory of others (Cozens, 2002). This increased interest in protecting property and the property of neighbours produces a natural, or 'built-in', surveillance system, increasing the ease of identifying strangers or potential intruders (Cozens, 2002). Other intentional features 'installed' by homeowners, such as landscaping and lighting can contribute to the natural surveillance of areas by residents, in addition to planned surveillance by emergency services (Cozens, 2002). Additional features of the built environment that contribute as forms of natural surveillance include the strategic location of 'guardians', or individuals such as parking lot attendants or desk clerks in office of hotel buildings. The presence of an individual will deter potential criminal offenders, as the risk of committing crime becomes greater (Cozens, 2002).

These principles of CPTED produce obstacles to offenders when considering Rational Choice Theory and Routine Activity Theory. Rational Choice Theory suggests that offenders will logically assess an opportunity to commit a crime. That is, they are able to effectively evaluate and respond to environmental cues that relate to the apparent risk, effort, and reward associated with the execution of a crime; the built environment plays an important role in that decision-making process (Cozens, 2008). Routine Activity Theory emphasizes three criteria coming together to produce a crime: (1) a suitable target, (2) a willing offender, and (3) the lack of appropriate guardianship or other security measures (Andresen, 2006a; Cohen and Felson, 1979). Increased natural surveillance in addition to physical barriers reduces opportunities for criminal behaviour through deterrence. However, the principles of CPTED may be too dependent on the assumption that all neighbourhoods are established with caring and respectful residents. As Social Disorganization Theory supports, neighbourhoods where residents are not connected and experience high resident-turnover are not going to be those where CPTED principles will be implemented by community members.

New ideas in urban development, those which support sustainable development of land through mixed-land use, depend on increases in street network permeability. More permeable neighbourhoods allow access to a larger number of people, including potential offenders. When land-use is separated, as it currently is with most suburban style developments, it is much easier for residents to distinguish residents from non-residents. As discussed by Cozens (2008), opportunities for crime are partly the by-product of the environment in which they occur. This idea is introduced by Beavon et al., (1994) who found that the majority of targets for theft were located near highly accessible, high traffic locations, supporting their hypothesis that neighbourhoods where travel frequency is lower and road complexity is higher should experience lower rates of property crime. However, to fully understand the relationship the built environment has with criminal behaviour, social characteristics of place must also be considered.

2.2.3 – Social Environment

Existing literature on the study of crime suggests that what motivates crime and criminal behaviour can only be meaningfully understood when contextualized alongside demographic, economic and social factors as they exist in place (Asgary et. Al, 2010; Hulchanski, 2010; Corcoran et al., 2007; Andresen, 2006a; Jennings, 1999; Pettiway, 1988; Murrey et al., 1987; Brady, 1983). This type of investigation is useful at the neighbourhood or census tract level. Socially deprived neighbourhoods experience more revenge-related arson events, as well as other crime and delinquency, than those characterized by affluence (Pettiway, 1988). Other characteristics contributing to this relationship include: transient populations, higher proportions of female-headed households, higher rates of low-income families, high proportions of rental units, and a large amount of aged housing in those areas where arson is most frequent (Pettiway, 1988). These observations follow closely with Social Disorganization Theory.

Social Disorganization Theory, developed by Shaw and McKay (1942), states that ethnic heterogeneity and population turnover contribute to social disorganization. Relationships that foster the development of social control within groups never have an opportunity to mature in highly transient populations. Individuals also do not invest in developing relationships within neighbourhoods which they wish to leave as soon as the opportunity arises. Finally, heterogeneous populations struggle to develop lines of communication in order to realize common goals and find solutions to common problems (Bursik, 1988). Social Disorganization Theory makes the attempt at drawing relationships between crime and the social, economic, demographic, urban structures, and characteristics relating to familial structures, as they exist in place (Andresen, 2006).

Additional social factors that have been found to influence incidence of arson or fire-setting behaviour also include: divorce rates, large youth populations (under 24 years), population density, large non-white populations, and the percentage of the population 18 and under living with both parents (Murrey et al., 1987). These findings are consistent with Social Disorganization Theory. Andresen (2006a) hypothesises that social characteristics of urban cores are what drive criminal activity; these include, but are not limited to, population density, population structure, and family income. High concentrations of multi-family dwellings and commercial land in and around the central business district in Springfield, Massachusetts are associated with increased incidence of arson (Bennett et al., 1987). Asgary et al. (2010), in their investigation of general fire incidence in Toronto, Ontario found that all fire incidents (with the exception of those fires caused by child's play) were more common along major arterial roads in the downtown core. They speculate that this area experiences more activity than other areas of the city due to its high density development and concentrated population. Those parts of the city experiencing the lowest incidence of fire are those characterized by lower population density, with a higher standard of living, as well as lower-density development (Asgary et al., 2010). Further research supports that more densely populated urban centres provide more opportunity for crime (Ceccato, 2005; Ackerman and Murray, 2004). The socioeconomic make-up of the City of Toronto will be discussed in more detail in future parts of this work. Considering social characteristics as they exist in place can help draw more concrete conclusions with respect to why crime occurs where it does.

2.3 – Methods

2.3.1 – Study Area

The City of Toronto (which includes the formerly independent municipalities of Etobicoke, York, North York, East York, Toronto and Scarborough) is the largest city in Canada, with a population exceeding 2.5 million residents (Statistics Canada, 2010). The City of Toronto is ideal for this type of study, as it experiences two distinct types of development: one concentrated, the other dispersed (Filion, 2000). The core region of the city is concentrated and is characterized by mixed land use, walkability, public transport, high density development and a concentrated population. On the other hand, the dispersed parts of the city, located in the outer suburbs within Toronto's boundaries, are characterised by low density development and population concentration, high dependence on personal vehicles and monofunctional zoning (i.e. commercial, residential, industrial) (Filion, 2000).

Toronto's Three Cities

As the largest city in Canada, and one of the top destinations for new immigrants, Toronto continually experiences demographic change. Hulchanski (2007) describes Toronto as a 'city of neighbourhoods', citing that though "all cities contain neighbourhoods,[…], Toronto's neighbourhoods are especially varied and distinctive" (pg. 1). Hulchanski (2007) outlines the diversity in Toronto by contrasting the three different geographies that exist within its borders; these are classified as City 1, City 2, and City 3. Figure 1 is an adaptation from Hulchanski (2007), depicting the distribution of the three cities across Toronto. The neighbourhoods brought forward by Hulchanski (2010; 2007) each have a distinct geography that has experienced significant change over time.

City 1 is home to high-income residents. It is a neighbourhood where average individual income has increased 20% more than average (relative to the average individual income in the Toronto Census Metropolitan Area) between 1970 and 2005 (Hulchanski, 2010). These neighbourhoods account for 15% of Toronto's neighbourhoods in 1970, and 19% in 2005 (Hulchanski, 2010). The parts of the city experiencing this type of growth are located in the central region along both north-south and east-west subway lines, as well as a central Etobicoke neighbourhood west of the core (Hulchanski, 2007). This portion of the city is home to about 20% of Toronto's population. The majority of the population is Caucasian (84%) with few ethnic minorities (Hulchanski, 2007). City 1 is home to the smallest percentage of foreign-born residents, which declined from 35% to 32% between 1970 and 2000 (Hulchanski, 2007). Households in these neighbourhoods are the smallest of the three groups, with an average of about 2.2 persons per household in 2001 in contrast to 3.0 per household in 1970. City 1 has the largest number of one-person households (Hulchanski, 2007).

City 2 represents those neighbourhoods that have experienced little change over the study period. These neighbourhoods have had no more than a 20% increase or decrease in average individual income over the study period (relative to the average individual income in the Toronto Census Metropolitan Area). City 2 represented 66% of Toronto in 1970, but only 29% in 2005 (Hulchanski, 2010). This portion of the city is home to approximately 40% of Toronto's residents, and is ethnically diverse relative to City 1 and 3 (Hulchanski, 2007). These neighbourhoods have about 2.5 persons per household as of 2001, a reduction from 3.4 persons per household in 1970.

City 3 represents those neighbourhoods that have experienced a decline of 20% or more in average individual income over the study period (relative to the average individual income in the

Toronto Census Metropolitan Area). This group experienced the greatest amount of growth, from 19% in 1970, to 53% in 2005 (Hulchanski, 2010). Whereas City 2 represented the majority of Toronto in the 1970s, low-income neighbourhoods are now most common. City 3 is home to approximately 40% of the population of Toronto, and has experienced the greatest amount of growth between 1970 and 2000. This is due to a large proportion of the outer suburbs being developed after the 1970s, bringing population growth with development. 43% of the population in this City are ethnic minorities (Hulchanski, 2007). Household sizes here have dropped the least relative to City 1 and City 2, from 3.6 persons per household in 1970 to 3.0 persons per household in 2001.

The Geography of Toronto's Three Cities

The geography of the three cities in Toronto has changed substantially over 35 years (Hulchanski, 2010). The spread of City 3 out of Toronto's core began to occur in the early 1970s, moving north-eastward into York. By the 1980s City 3 had further spread north into North York, with few census tracts experiencing a change to City 3 in the Scarborough region. By 1995, the expansion of City 3 slowed through York, North York and Etobicoke, and increased substantially through Scarborough. By 2005, northern parts of Etobicoke, eastern North York, York, and the majority of Scarborough were identified by Hulchanski (2010) as City 3. During this 35 year time period, the presence of City 2 (the middle class) diminished in size, and City 1 (the upper class) spread south into the core of Toronto and increased its' presence in a portion of eastern Etobicoke (see Hulchanski, 2010).

The most notable change in these findings is that the income gap between the rich and the poor is widening in Toronto. Two studies by Hulchanski (2010; 2007) predict that the disparity between the rich and the poor in the city will continue to grow into the future, as the job market becomes less stable and incomes remain low. An interesting finding of these studies is that the growing income inequalities are due to changing geographies, rather than a widening income gap. The majority of social services available in Toronto were settled, and continue to concentrate, in the urban core, south of the Bloor-Danforth subway corridor (Hulchanski, 2007). Up until the mid-1990s the services and the population taking advantage of them were located in the same area and were highly accessible via transit. Demand for urban living and subsequent gentrification of the core have displaced these populations over 30 years. Toronto's disadvantaged populations are now concentrated in the outer suburbs while services established for them remain in the core. Access to these services is limited by inadequate transit, further segregating the poor and the wealthy in the City (Hulchanski, 2007). It has been suggested that social deprivation has relationships with crime (Andreson, 2006; Bennett et al., 1987; Murrey et al., 1987; Pettiway, 1986). As such, based on the most recent distribution of 'cities' across Toronto, we expect to see similar concentrations of deliberately-set fire activity.

2.3.2 – Data

Fire Data

The Toronto Fire Department classifies deliberately set fire events in four ways; arson, vandalism, youth vandalism, and riot/civil commotion. Arson events are those determined to be caused by an individual for personal gain. Personal gain can include intent to harm an individual, such as homicide or suicide, cause threat to another individual, or for purposes of revenge. Arson can also be attributed to financial gain, either from a beneficiary or insurance policy. A fire event is classified as arson when it can be determined that some level of planning had occurred on the part of the perpetrator. The offender must have considered some aspect of time, persons present or absent, or materials used to cause fire (Wilson, March 14, 2011, Personal Communication).

On the other hand, vandalism is defined as fires lit for no apparent purpose; the same is true for youth vandalism, except it is considered for individuals between the ages of 12 and 17. Fires attributed to vandalism differ from arson in that no intended purpose could be identified other than for the destruction of property; in these cases, investigators could find no evidence of purpose (such as personal gain) or evidence of premeditation or planning, suggesting spontaneous decision-making on the part of the perpetrator (Wilson, March 14, 2011, Personal Communication). Lastly, fires are reported as riot/civil commotion when they occur during such demonstrations (Slade, July 29, 2010, Personal Communication).

For the purposes of this research, we only distinguish between deliberately set fires on the basis of dollar-loss value. Fires resulting in no monetary loss are referred to as *no loss fire events*, whereas *loss fire events* constitute arson events with a monetary loss. Fires with a reported loss value are often reported as arson by the Toronto Fire Department, whereas no loss fires are most often reported as vandalism (see Figures 2 & 3). The fire data we received from the Office of the Fire Marshal (OFM) originally included 25 years of fire event data, from 1983 through 2007. The data were received in two parts: a loss data set for all 25 years, and a no loss data set only for the years 1995 through 2007. Due to various limitations[1] this study only considers the years 2001 through 2007 for both loss and no loss fire events. The total number of events included in this analysis are 3 353 loss fire events, and 2 999 no loss fire events, which account for approximately 80% of the events occurring in the study period. We use this

[1] We required that the fire data used for this study had appropriate geography for each fire events location. The data between 2001 and 2007 were the most complete.

distinction between loss and no loss fire events as opposed to distinguishing between reported cause because there exists less ambiguity in reporting damages by the fire department than with determining cause. Determining the origin of fire events is a task that takes experience and is subjective on the part of the responding captain (Slade, March 15, 2010, Personal Communication; Hershbarger and Miller, 1978). Reporting physical damages in terms of dollar-loss values provides a clearer distinction between each type of event.

Neighbourhood Data

The City of Toronto has 140 neighbourhoods. The GIS boundary file was acquired from the City of Toronto's open data source project (Toronto.ca/open), and represent neighbourhood boundaries for the year 2009 (Neighbourhood Planning Areas, 2009). Neighbourhoods are a larger spatial denomination than census tracts, where each neighbourhood contains an average of 3.7 census tracts and represents approximately 17,600 individuals (Hulchanski, 2010). Though neighbourhoods have a lower spatial resolution than census tracts, we used a larger geography in order to reduce the effect of small numbers on estimating the year-specific rate of arson for each neighbourhood in each year. There are too few fire events across the city in any given year to conduct this study on a smaller geographical scale. In order to reduce the variability in the data across the city and over time, we chose to aggregate the fire data up from the census tract level to the neighbourhood level for our analysis. To accomplish this we also had to use spatial data at the census tract level in order to spatially represent demographic data. Once all of our fire and demographic attributes were joined at the census tract level, the census tract data was aggregated up to the neighbourhood level for complete analysis.

Permeability Measures

The City of Toronto has approximately 5,000 kilometres of road (Hess, 2009). We acquired the DMTI CanMap Streetfiles data from the Lloyd Reeds Map collection at McMaster University (DMTI Spatial Inc., 2007). Street network data was used in order to develop a measure for permeability (PERM). The decision to use street network data alone was due to the lack of data available for sidewalks and trails, which would measure pedestrian activity, separate from vehicle activity. However, only using street network data also allows for one comprehensive measure that also approximates neighbourhood accessibility for pedestrians, as most streets have access to a sidewalk on one or both sides of the road. The only limitation we face for the lack of sidewalk data is the absence of park trail information. This would have added an additional measure for pedestrian accessibility through the city as areas that receive less supervision after dark. In order to maintain one measure for neighbourhood permeability, we used the street network void of any turning restrictions (i.e. one-way streets). Though this type of restriction may limit vehicular traffic, it does not limit pedestrian traffic within or through neighbourhoods. In a study by Frizton (2001), it was shown that arsonists travel a mean distance of approximately 2 kilometres to commit an offence, suggesting that operation on foot is common, supporting the use of street network data void of turn restrictions.

In their investigation of the influence of street networks on property crime, Beavon et al., (1994) used a street network to develop a permeability measure by defining ‘turnings’. Turnings refer to the number of access points available to gain entry onto a street segment. A street segment is a stretch of road occurring between two intersections, and each street segment has a defined number of turnings allowing access. Figure 4 shows a visual representation of how street segment accessibility is calculated. The greater the number of turnings in a defined neighbourhood, the more permeable the neighbourhood is. Conversely, the fewer turnings in a defined neighbourhood, the less permeable the neighbourhood is. Neighbourhoods where permeability is higher are those where we expect to see higher rates of arson activity.

Additionally, we obtained data for existing laneways for the City of Toronto (Toronto Centreline, 2009). These data were important to include as they provide us with information about an additional layer of permeability present in Toronto. Laneways (LANE) are narrow roadways or alleys behind buildings or homes that allow access to vehicles for parking purposes. They can be used, alternatively, by pedestrians, increasing permeability in areas where they are concentrated. The majority of these laneways occur in the downtown area of Toronto, and slightly west of the core (Figure 5). In order to determine laneway density, we measured the total length of laneways in each neighbourhood, and divided that sum by the area of each neighbourhood. This created a laneway density index. A density index was preferred for this measure of permeability as laneways do not exist in all areas of the city. The greater the length of laneways indicates the distance an offender can travel with a reduced chance of being detected. Their purpose increases permeability in a more efficient way for offenders, as laneways and back alleys do not experience the same level of supervision and monitoring as their street-network counterparts, as well allowing easier access to the rear of properties and parked vehicles (Cozens, 2008). Together with the street network, we have created a permeability measure that is as comprehensive as possible, considering both pedestrian and vehicular traffic.

Census Data

The Census of Canada is a census of the population conducted every five years. Up until 2006, it was administered in two ways every five years. Eighty percent of the population receive a short-form census in a census year; the other 20% receive a long-form census, which provides more detailed information about the population. All of the variables included in this analysis, with the exception of our two permeability measures have been acquired from the census results from Statistics Canada (2006; 2001a-e).

In an analysis of crime and criminal activity, it is important to consider the demographic characteristics as they exist in place. Using census variables, we are able to control for differences in the demographic structure of neighbourhoods across the City of Toronto. Using data from both the 2001 and 2006 census, we interpolated between years to reflect the changes in demographics over our 7 year time period at the census tract level. To interpolate, we took the 2001 census results and subtracted them from the 2006 results. We then divided this by 5, which is the number of years between census years, to determine growth per year. These values were then used to add onto the results from the 2001 census to create an estimate for each variable in subsequent years, up to 2006. Without 2011 census results, we assumed the same rate of growth to estimate demographic characteristics for 2007. Once the interpolation process at the census tract level was complete, we aggregated our results up to the neighbourhood level, in order to be able to conduct our analysis at a lower resolution.

The final variables chosen to use in our analysis represent the demographic characteristics of the City of Toronto that are consistent with those used in previous studies on crime in general, and arson in particular. Table 1 is a summary of those variables, the justification for using them, and the scenarios in which they have been considered in previous literature

2.3.3 – Analysis

Kernel density estimation and choropleth mapping are used to visualize the spatial pattern of arson in the City of Toronto. Kernel density estimation is used to display the concentration of fire events across the city. Using kernel density estimation, we are able to show the spatial concentration of events and how, if at all, patterns change from year to year. Kernel density estimation provides a smoothed surface of the density of points that exist around specific event locations within a user-defined radius. The density is highest at the location of the initial point, and decreases to zero at the edge of the search radius (Asgary et al., 2010). For the purposes of this research, a two-kilometre radius was chosen because in a study of serial arsonists, it was noted that an offender would usually operate on foot within a 1-mile, or 1.6 kilometre, radius (Kocsis and Irwin, 1997). A study of serial burglaries, another type of crime against property, determined that the majority of cases occur within five-kilometres of a perpetrator's home; however, the vast majority commit crimes within the two-to-three-kilometre range (Snook, 2004). Though we are not focusing on serial crime, or serial arson, a two-kilometre radial distance is a realistic one for any type offender. This distance was used by Frizton (2001) in an investigation of the relationship between the distance an arsonist is willing to travel and their motivation for setting a fire. Additionally, we modelled relative risk. Here, relative risk is the ratio of the rate of events in each neighbourhood to the city average. It is calculated using the observed number of cases per neighbourhood, divided by the expected number of cases per neighbourhood. The expected number is the number of events under the null hypothesis that risk in the neighbourhoods is equal to the city-wide risk. By modelling relative risk with a random intercept variable, we are able to quantify the variability in arson across neighbourhoods in the city. Furthermore, by including a random intercept variable into this model, relative risk in some neighbourhoods would equal zero (for those neighbourhoods which have zero observed arson events). Random intercepts and their importance are further discussed in the following section. The results are then displayed in a choropleth map (Figures 6 & 7).

Regression

We use a hierarchical Poisson regression model to determine the relationship between arson events and the influence of streets networks (permeability) while controlling for other features of the physical and social environment. We use a Poisson model because arson events are a relatively rare phenomena that occurs as a discrete number of events (0, 1, 2, …). We hypothesize that the locations where arson activity is highest will be areas where street network accessibility is also higher (high permeability), and vice versa. The model used in this analysis is

$$\log(\lambda_{ij}) = \begin{bmatrix} \alpha + \beta_{YEAR} YEAR_{ij} + \beta_{PERM} PERM_j + \beta_{LANE} LANE_j + \beta_{YOUTH} YOUTH_{ij} \\ + \beta_{VALUE} VALUE_{ij} + \beta_{RENT} RENT_{ij} + \beta_{REPAIR} REPAIR_{ij} + \beta_{DENSITY} DENSITY_{ij} + \\ \beta_{OLD} OLD_{ij} + \beta_{SINGLE} SINGLE_{ij} + \beta_{LOW} LOW_{ij} + \beta_{UNEMPLOY} UNEMPLOY_{ij} + \\ \beta_{NEW} NEW_{ij} \end{bmatrix} + \left[\upsilon_j + \nu_j YEAR_i + o_{ij}\right]$$

where

$\log(\lambda_{ij})$ = log of the dependent variable (loss fires and no-loss fires)

α = fixed intercept

β = coefficient of the independent variable

υ_j = random intercept, $N(0,\sigma^2)$

$\nu_j YEAR_{ij}$ = random slope, $N(0,\phi^2)$

o_{ij} = offset (neighbourhood population times the overall rate)

i = time component

j = space component

The Poisson distribution was first developed for the purpose of analyzing conviction rates for criminal offenders in France in the early 19th Century (Osgood, 2000). Working under the assumption that all events are random and independent of one another, Poisson regression calculates the probability of a discrete number of events occurring, given an already established rate (Osgood. 2000). For example, if the rate of arson in a particular city is 5.6 per 10 000 population, the Poisson distribution would calculates the probability of observing that rate in any single neighbourhood within that city.

This method assumes that all events are independent of one another. In this application, we are aware that not all arson events are independent; arson is a crime that can have serial tendencies. Toronto has been known to experience some serial arson during our study period (Cherry, 2007). We also know that the rate of arson varies between neighbourhoods, despite an overall rate for the city. Also, because our study period considers multiple years, each neighbourhood in any given year is similar to itself in any other year of the study period. Therefore, our observations from year to year are not independent of one another, given that the attributes of place do not change significantly over relatively short periods of time. By not controlling for this lack of independence, the standard error our model produced is artificially small, suggesting relationships between our fixed effects and the incidence of fire events that may not actually exist. To control for this lack of independence between neighbourhoods, we include a random intercept effect to represent the similarities, or clustering, between years within neighbourhoods. This allows our model to produce more accurate results by controlling for the fact that we do not exactly have as many independent observations as 140 neighbourhoods over a 7 year study period might suggest. This could have been accomplished by dummy coding our neighbourhoods as fixed effects (using one neighbourhood as a reference category), however using a random intercept is more efficient (Grace-Martin, 2011). We also include a random slope effect, which measures if the underlying trend in arson over time varies between neighbourhoods. Finally, the offset variable in the model is the natural log of the overall crude rate of arson for the city (loss and no loss) multiplied by the population of each neighbourhood. A population offset is generally used when calculating crime rates because it reflects the number of potential offenders or targets in an area (Farley and Hansel, 1981). This offset variable accounts for the underlying variation in neighbourhood population, and has an implicit model coefficient equal to one.

Statistical modelling was completed using Statistical Analysis Software (SAS, 2009). Before attempting the completed model, bivariate regression analysis was done to determine the relationship each independent variable has on the dependent variable (both loss and no loss fire events) (Table 1). A two-way interaction analysis was also completed for both loss and no loss models in order to determine any changes in the relationship between the independent variables and arson incidence over time. Only significant interaction variables have been included in our final model. We run two models, using the same independent variables; Model 1 for loss fire events as the dependent variable, and Model 2 for no loss fire events.

2.4 – Results

2.4.1 – Visual Results

Kernel density estimates (Figures 8 & 9) suggest that the highest concentration of events occur in the core of the city, and spreads northward into the former municipalities of York and North York in the case of loss fire events. Over the course of the study period, deliberately set fire events resulting in loss appeared to increasingly concentrate in the core of the city and the York region. In 2001 the spread of events across the city is greater than in 2007. Nodes of activity through the western part of the city have been decreasing. For no loss fire events, the concentration of events does no change as dramatically over the study period relative to loss fire events. The concentration of events appears to be spreading in the case of no loss fire events further through the former municipalities of York, North York and Scarborough, with more nodes of activity in northern parts of the city than with loss fire events. In 2006 and 2007, the concentration of no loss fire events is increasing in the Etobicoke region, a pattern that does not occur for loss fire events.

The results for modelled relative risk present similar patterns to the concentration of deliberately set fire events produced by the kernel density estimation. Those neighbourhoods where relative risk exceeds one are those which experience a higher risk of experiencing arson based on the observed number of events. Areas with a higher relative risk are in similar areas where deliberately set fire events concentrate according to the kernel density estimation. Some, though fewer, neighbourhoods experience increased risk in North York, East York, and Scarborough. Relative risk for no loss deliberately set fire events produces similar patterns across the city.

2.4.2 – Bivariate Regression Analysis

A bivariate regression analysis was completed against loss fire events and no loss fire events individually and for each year in our study period. Each independent variable was measured once against the dependent variable to determine their relationship. We set the threshold of statistical significance at p=<0.05, however not all variables included in our final model meet this threshold. Originally, we measured 14 variables against both dependent variables. Table 2 summarizes the results of the bivariate regression analysis for all individual independent variables against loss fire events. Similarly, Table 3 is a summary of the bivariate regression analysis for no loss fire events.

Social Factors

Many of the social variables chosen for use in this analysis reflect the importance of Social Disorganization Theory and factors suggesting social disadvantage throughout the literature, as well as to reflect the significant changes Toronto has experienced in terms of their social environment. Average household income (HOUSE) is a variable originally considered for the final model. HOUSE measures the sum of the total income of households, divided by the number of households. HOUSE produces a statistically significant negative relationship with loss fire events for the years 2001 through 2005. It loses significance at the $p=<0.05$ threshold in 2006 ($p=0.159$), and is insignificant ($p=0.9494$) in 2007. HOUSE is statistically significant for all years when measured against no loss fire events, also producing a negative relationship. This measure is not included in the final model because we were more interested in the prevalence of low-income families (to reflect social disadvantage), therefore we only include the low-income variable (LOW). LOW income is statistically significant (at $p=<0.05$), producing a small positive relationship with both types of fire events, for all years in the study period for both loss and no loss events. Therefore, to avoid redundancy, we chose to omit HOUSE and only include LOW.

Another variable used to indicate social disadvantage, consistent with social disorganization theory, is the percentage of rentals in a neighbourhood (RENT). RENT is statistically significant (at $p=<0.05$) for all years in the study period for both types of fire events, except 2007 in the case off loss fires. RENT has a weak positive relationship with loss and no loss fire events. The percentage of new residents (NEW), however, does not meet the threshold for statistical significance (at $p=<0.05$). It approaches significance for one year, 2003, during the study period in the case of loss fire events. The same is true for no loss events, where NEW is insignificant for all years, however approaches significance (p=0.0546) in 2005. It remains in the final model because of its importance in social disorganization theory, alluding to transient populations lacking ties to the neighbourhoods in which they reside.

Family and population structure is also important to social disorganization theory. Lone parent families (SINGLE), measured against loss fire events, are statistically significant (at p=<0.05) for all years in the study period for loss fire events; the same is true for no loss events. SINGLE produces a positive relationship with respect to both types of fire events. We include it in our final model for its significance, and because it is consistent with social disorganization theory. Large youth populations (YOUTH) are also a factor in social disorganization. However, when considering loss fire events, youth population is only statistically significant (at p=<0.05) in 2001, and almost in 2003 (0.069); it is not significant for any year for no loss fire events.

Likewise, unemployment (UNEMPLOY) is a factor in social disorganization, being attributed to higher levels of crime where unemployment is high. It does not reach statistical significance with loss fire events. With regard to no loss fire events, it approached significance in 2001, 2002, 2004 and 2006 (only at p=<0.1), and is significant (at p=<0.05) in 2003; it has a consistently positive relationship to all fire events. Despite an overall lack of significance at the p=<0.05 threshold, unemployment is still included in the final model to remain consistent with the literature.

Urban Factors

The literature suggests that the built environment is as important to the study of crime in general, and arson in particular, as social factors. Variables specific to housing structures in neighbourhoods include average dwelling value (VALUE), housing density (DENSITY), percentage of housing requiring major repairs (REPAIR), and percentage of old housing (OLD).

The literature suggests that undesirable housing is more often targeted in deliberate fire events; VALUE is used as a measure to indicate the concentration of undesirable housing or an undesirable neighbourhood in those areas where VALUE is low. This variable is only significant (at p=<0.05) for one year with respect to loss fires, and significant for all year with respect to no loss fires. VALUE has a negative relationship to both types of fire, regardless of its' significance. Similarly, the literature suggests that housing in disrepair, or in a derelict/abandoned state, is often targeted in arson events. REPAIR is significant for all years during our study period for both types of fire events, supporting previous research, and is included in the final model. Housing older than 20 years (OLD) is similar to REPAIR, however it is not as significant in the bivariate regression analysis. OLD is only significant (at p=<0.05) for 2002 and 2007, and approaches significance in 2005 and 2006, and is not significant for any year with respect to no loss events. Finally, housing density (DENSITY) is used to indicate urban versus suburban environments. In the case of loss deliberately set fire events, DENSITY is only significant (at p=<0.05) in 2001 and 2003 for loss fire events; with respect to no loss events, DENSITY is significant for all years. In both cases, DENSITY density has a positive relationship with fire events. The literature suggests that urban areas experience higher rates of crime in general, including arson. Housing density is also important when considering arson because the target population (physical structures).

The factors that are most important in answering our research question are those measuring neighbourhood permeability. When completing our bivariate regression analysis, we considered two types of street network permeability measures: permeability, not considering turning restrictions for vehicular traffic (PERM), and permeability including turning restrictions for vehicular traffic (PERM2). Our additional measure for permeability is a laneway density index

(LANE), a measure that adds an additional element of accessibility to neighbourhoods. LANE is statistically significant for all year for both types of fire, producing a positive relationship. PERM is only significant in the case of loss fire events, with a relatively strong positive relationship with arson, for all years in the study period. PERM2 is not statistically significant for any year for loss fire events. On the contrary, PERM is not significant for any year in the study period for no loss fire events, while PERM2 is significant for all years. PERM2 produced a negative relationship with deliberately set fire events, opposite to that of PERM. We chose to use PERM as the measure for neighbourhood permeability in the final regression model because it can include accessibility by pedestrians, as well as motorized or non-motorized forms of transportation.

The results of the bivariate regression analysis are what we expected considering what had been seen in the literature on crime in general, and arson in particular. Though not all important independent variables are statistically significant on their own, they are included in the final regression models for the reasons addressed above. The final group of independent variables includes: VALUE, LANE, PERM, DENSITY, LOW, SINGLE, REPAIR, NEW, OLD, RENT, YOUTH, and UNEMPLOY.

2.4.3 – Multivariate Regression Results

Table 4 summarizes the results for Model 1, with loss fire events as the dependent variable. The independent variables, as part of the fixed effects, which prove to be significant (p=<0.05) predictors of loss fire events are LANE, SINGLE, and YEAR. LANE and SINGLE have a positive relationship to loss fire events, while YEAR produces a negative relationship. PERM is approaching significance at the p=<0.1 level. LANE is significant at p=<0.0025, suggesting it plays a very important role with respect to accessibility and arson. Also significant in this model is the interaction between YEAR and VALUE. It is highly significant at p=<0.0001, however the coefficient is almost zero. Though the significance suggests that there is an increase in deliberately set fire events as housing values increase from year-to-year, the strength of the relationship is a weak positive one. The non-zero random intercept effects in the model suggests that some neighbourhoods appear to vary significantly in terms of arson rate, when compared to the overall average for the city after controlling for all the fixed effects in the model (UN[1,1]). Based on the results for the random slope effect, there does not appear to be variation in the relationship with arson rate over time between neighbourhoods. This suggests that the rate of change over the year is similar for all neighbourhoods.

Table 5 summarizes the multivariate regression results for Model 2, with no loss deliberately set fire events as the dependent variable. A large number of independent variables are significant at p=<0.05 when considering no loss events. LANE is significant where p=0.0089 and a positive coefficient of 0.1246. PERM is approaching significance with a p-value of 0.0684 and a negative relation to fire events. YEAR and NEW are also significant at the p=<0.05 level, where both have a negative relationship with no loss deliberately set fire events. VALUE has a negative significant relationship with no loss events. The same is true in terms of the interaction between YEAR and VALUE, however the coefficient is very close to zero. The interaction between YEAR and LANE is significant at p=<0.1, with a p-value of 0.0884 and a positive coefficient. The random intercept effects in the model suggests that neighbourhoods have significantly different rates of arson after controlling for the fixed effects in the model (UN[1,1]). Based on the results for the random slope effect, there does not appear to be variation in the relationship with arson rate over time between neighbourhoods.

2.5 – Discussion

We set out to discover whether street network permeability influences the incidence of deliberately set fire events at the neighbourhood level. Based on the results of our regression analysis, we conclude that neighbourhood permeability is associated with the incidence of loss arson events. More specifically, neighbourhoods with higher levels of street network permeability, and especially those where the density of laneways is greater, experience higher rates of arson than areas with lower levels of permeability. No loss fire events are more common where the concentration of laneways is highest, however, an indirect relationship exists with permeability and no loss fire event incidence.

Part of our goal is to compare and contrast the socioeconomic structure of the city of Toronto (as presented by Hulchanski, 2010; 2007) with the incidence of deliberately set fire events. Figures 6 & 7 of modelled relative risk show a similar pattern to the one we see in Figure 1, Hulchanski's (2007) map of changes in average individual income. Hulchanski (2007) classifies Toronto by three varying geographies, based on changes in average individual income over a 30 year period. Though he uses average individual income as a benchmark to create three groups, he notes that these groups share many other common characteristics in addition to income status. If factors relating to social deprivation are associated with arson, we would expect to see the same spatial pattern of relative risk across the city as we do the distribution of City 3, as presented by Hulchanski (2007). However, we only see that portions of Etobicoke, North York, and York regions are those most affected by high rates of fire incidence, whereas the outer suburbs of Scarborough are largely unaffected by increased risk of arson despite being identified as underprivileged socioeconomic areas.

Additionally, if we consider Hulchanski's (2010; 2007) three cities, there should not exist a concentration of arson events in Toronto's core given this is where the highest concentration of the upper class (City 1) reside. This concentration of events can be explained if we consider the type of activities most common in the downtown core. A highlight of the downtown region is its abundance of entertainment, such as night clubs, bars and restaurants. Some authors have suggested that the participation in the consumption of alcohol and recreational drugs can provide a possible explanation as to why individuals participate in criminal behaviour such as arson (Asgary et al., 2010; Druckers, 2010; Doley, 2003; Brady, 1983). These activities can further exacerbate the incidence of arson events as these areas are some of the most permeable in the city (Figure 5). We do not include a variable in our final regression analysis indicating the concentration of establishments serving alcohol. Future research on the topic of social phenomena with respect to arson might consider this in order to determine whether a relationship exists. Although the visual representation of relative risk compared to the socioeconomic structure of the City have various similarities, the results of our regression analysis do not produce sufficient results to confirm the relationship between socioeconomic characteristics in the city of Toronto with the incidence of deliberately set fire events.

In the case of Toronto, social factors may not be as important in predicting the incidence of deliberately set fire events relative to the built environment. Previous literature has alluded to factors relating to social deprivation as being important in predicting crime in general, and arson in particular (Corcoran et al., 2009; Pettiway, 1988; Pettiway, 1987). Also, the pattern of arson behaviour does not closely mirror the patterns of factors relating to social deprivation Hulchanski (2010, 2007). The results of our regression analysis also suggest that the variables relating to the socioeconomic structure of neighbourhoods are not significant in predicting deliberately set fire events at the neighbourhood level. Only in the case of loss fire events was the percentage of single parent families statistically significant as a predictor (p=0.009) with a small positive relationship with loss fire (0.0388). The other social factors we included in our model (YOUTH, LOW, UNEMPLOY, RENT and NEW) are not significant predictors. In terms of no loss fire events, none of the social factors we included as part of our model produced statistically significant relationship (at p=0.05) in predicting fire events. The proportion of new residents (NEW) is significant (p=0.0445), however the coefficient is negative. This is contrary to what we would expect based on the literature. Percentage of new residents is included as part of the analysis to represent transient populations. We would expect a positive relationship with arson if Social Disorganization Theory applied to arson, and transient populations were a predictor of crime. In the case of Toronto, transient populations do not produce the relationship we would expect with criminal fire setting. We would also expect to see a relationship with the proportion of rental accommodations (RENT) if Social Disorganization Theory did follow with deliberately set fire incidence.

Our regression results visually confirm our analysis of relative risk and kernel density, where fire events are most common in the core of the city, characterized by an older, more permeable grid-style network of streets. Figure 5 shows laneway density for neighbourhoods in Toronto. Comparing Figure 5 to Figures 8 & 9 (of kernel density estimation results for loss and no loss fire events) we can see that those areas where laneways are most common are also those where deliberately set fire events are most concentrated. Based on the results, our regression analysis suggests that laneway density is significant (p=<0.05) with respect to both types of fire events. Figures 8 & 9 also show a concentration of fire events across similar neighbourhoods that Figures 6 & 7 of modelled relative risk identify as being at higher risk of experiencing deliberately set fire events. These similarities suggest that a relationship exists between deliberately set fire events and the built environment. The interaction between year and laneway density is also significant at p=<0.1 for no loss fire events. This positive relationship suggests that in areas where laneway density is high, the incidence of deliberately set fire events in increasing. The overall trend in fire events, both loss and no loss, is negative. For the entire city, the incidence of fire is decreasing over time, except for in the areas where laneway density is high. This relationship is not true for loss fire events, which further supports that no loss fire events are those committed as a result of spontaneous decision making by the offender.

We can confirm the importance of alleyways and laneways in real terms. During the last year of our study period (2007), Toronto experienced what is believed to have been a serial string of deliberately set fire events. On the night of Jul 2, 2007 fourteen properties were damaged within a four to five block area in the west-end of Toronto (Henry, 2007; Cherry, 2007). Six fires, started within 55 minutes of one another, were estimated to have caused over two-million dollars in damages. Each of these fires was ignited in rear laneways at properties within walking distance of one another (Henry, 2007a). During the summer of 2007, more fires were reported and believed to have been connected to the fires of July 2nd. On July 17, 2007 four fires were reported within a half-an-hour of each other, in close proximity to those on July 2nd. On July 31st, eleven fires were started in garbage cans and dumpsters within a 2 hour period (Henry, 2007b). We have identified the potential of serial arson as a limitation in this research as we are aware that it is a factor underlying some spatial patterning during our study period. We cannot fully control for the effects of serial arson on our model because there is no way to distinguish serial from non-serial arson events. However, the random intercept effect included in our models helps to control for the possible effects of spatial dependence to some degree.

Our regression analysis highlights that permeability influences loss and no loss fire events differently. In terms of loss fire events, permeability is approaching statistical significance (where p=0.061) and suggests a positive association with arson incidence (0.311). Conversely, in the case of no loss fire events, permeability is also approaching statistical significance (at p=0.0684) but in the opposite direction (-0.3682). It is possible that loss deliberately set fire events would be those where permeability would not be a significant predictor. This is because loss fires are often those specifically targeted by offenders, regardless of the type of built environment. Additionally, because these properties are targeted, the offender is likely already familiar with, and can effectively navigate, the built environment in the area. On the other hand, no loss fire events, which are most often classed as 'vandalism' are targeted out of convenience. Intuitively, an offender committing a crime will want to avoid detection, and therefore may be more interested in navigating a more permeable environment. However, the negative relationship we find between no loss fire events and permeability has merit. Offenders committing offences out of convenience and spontaneity are likely not concerned with the built environment within which they find themselves. In spontaneous situations an offender willing to light a fire will do so, and then decide the best way to escape the situation; they will not consider the built environment prior to committing the offence, as the offence was not previously planned.

In addition to the significance of permeability and laneways, no loss fire events are associated with two other factors related to the built environment. We would anticipate that neighbourhoods with more new residents may have higher rates of deliberately set fire events. Some literature has suggested that areas with high proportions of new residents, or with large transient populations are more likely to experience more arson than those neighbourhoods with more stable populations (Pettiway, 1988). However, the relationship that our model has identified is negative; neighbourhoods with higher proportions of new residents are less likely to experience deliberately set fire. Another anticipated relationship between deliberately set fire events exists with average housing value. Average housing value produces a negative statistically significant (p=0.0002) relationship with respect to no loss arson events. This is consistent with the literature; whereas housing value decreases, we anticipate the incidence of deliberately set fire events to increase. Average housing value is used to indicate less desirable housing conditions or neighbourhoods and has been used in previous literature to indicate such conditions (Bennett et al., 1987). However, this relationship is not fully realized, because major repairs (REPAIR) and the age of housing (OLD) do not produce any relationship with the incidence of fire. Additionally, our multivariate analysis suggests that there is an additional relationship with average housing value. The interaction between year and average housing value has a very statistically significant (p=<0.0001) relationship for both loss and no loss fire events. this relationship is positive, suggesting that the incidence of deliberately set fire events increasing in areas with higher average housing values. However, for both loss and no loss events, the coefficient is very close to zero, suggesting that though the relationship is significant, it is very weak.

2.5.1 – Contributions

This paper addresses a need for future research proposed by Beavon et al., (1994). The results of their own research on property crime suggest a need for future work with regard to street network patterning and other types of crime. Their findings conclude local and regional governments unknowingly support the development of street networks conducive to criminal activity, specifically crimes against property. They emphasize that future work in this field should focus on more specific and varying forms of crime in order to determine whether a similar relationships could be found. We address this concern at the local level in the City of Toronto.

The implications of our research are threefold: contributions to literature, contributions to community, and contributions to future planning initiatives. First, we contribute to the body of literature that addresses environmental criminology and environmental psychology. There has not been a considerable amount of research published in the area of arson in general, and how the crime is influenced by the physical environment in particular. Second, we contribute to the understanding of arson by local emergency service personnel. Though the physical characteristics of place can not be easily changed, this research will provide police and fire personnel a greater comprehension of where to focus their energy when dealing with arson. Third, this research contributes to the understanding of how street network patterning affects activity within a built environment. With a greater focus on sustainable development in terms of increasing pedestrian flow and decreasing reliance on automobiles and fossil fuels, it is important that developers and planners fully understand what other types of behaviours might emerge that may not have been previously considered. In this case, a potential increase in criminal activity may outweigh the impact of maintaining current levels of pedestrian and traffic volumes, depending on the severity of crime. Though this research focuses specifically on arson, a crime that can have serious implications on physical infrastructure and the potential to take lives, street network patterning and increasing accessibility can have implications on other types of crime as well, including homicide and assault.

2.5.2 – Limitations

There are a number of limitations that we faced when completing this study. The most notable limitations occurred with respect to data. The fire data we received from the Ontario

Office of the Fire Marshal (OFM) was comprehensive as far as fire events go. However, often there was information missing in the dataset. Most importantly, much of the error in the data occurs where geographic information is concerned. The fire officials responsible for filing incident reports, or those coding the information electronically, have introduced error to the geography by recording addresses incorrectly. This limited our ability to properly locate events within the city. Therefore, these events were not used in the analysis as they would introduce error if improperly located. Initially, the data received from the OFM included 7 702 loss deliberately set fire events and 5 911 no loss deliberately set fire events between 1995 and 2007. Due to improper coding by fire personnel, not all years were viable for use in this analysis, limiting our study to 2001 through 2007. For this time period, 3 097 are loss deliberately set fire events, and 2 883 are no loss deliberately set fire events. In order to mitigate this type of error in the future, it would be recommended that each fire response vehicle be equipped with a portable GPS device, so that responding fire officials would be able to accurately identify event location. Having access to more accurate and consistent geographic information will improve research with respect to the geography of arson in Toronto. Supporting similar data limitations and the use of portable GPS devices are Corcoran et al., (2007), noting the need for more accurate data for service and monitoring improvements with respect to fire event response in South-Wales, UK.

In creating a permeability measure from street network data for the City of Toronto, we also faced limitations. In some cases, the amount of detail geocoded into the street network is too great. For example, along major arterials separated by a median, or barrier, the road was geocoded to represent two parallel lengths of road. These would eventually meet and turn into one stretch of road where the median is no longer present. In such cases, our permeability measure would recognize where the length of road splits as an intersection of segments, increasing the number of turnings present in a defined area. Because Toronto has an extensive network of roads, being able to mitigate this problem efficiently was not an option.

Another data limitation in this study is the lack of consistent GIS data used throughout the analysis. We used the most recent GIS data available to us, which was not always current, and did not match with varying levels of geography. We used census tract data for 2001, neighbourhood data for 2003, laneway data for 2009 and road network data for 2007. Each neighbourhood in the city has one measure for permeability and laneway density as a result of data availability. Despite this inconsistency, however, Toronto has not experienced significant road development within the last few years. Therefore, we do not anticipate that our findings are notably affected.

Further, arson is a crime that can have serial tendencies. Therefore, it is possible that some of the spatial patterning we see in the city is a result of serial crime. Figures 8 & 9 show the spatial concentration of fire events in the City of Toronto based on a kernel density estimation, and relative risk of fire events, respectively. We cannot know which events are attributed to serial offenders, as we only have data about the fire event. Information regarding serial offences and criminal charges are not included as part of the data obtained from the OFM. It is the responsibility of the local police department to investigate and determine whether a group of events are related to one offender, and to lay charges in those cases (Slade, March 2010, Personal Communication). We are only concerned with the distribution of events across the city as opposed to serial criminal activity. Similarly, repeat-victimization, or ‘copycat’ crime, can also affect the spatial distribution of events. Copycat crime refers to criminal events that are perpetuated by different offenders, but affect the same group in terms of proximity. For example, the near-repeat burglary hypothesis presents that homes that have experienced some form of burglary, and those homes in their vicinity, are at higher risk of being victims of the same, or similar, crimes than homes further away (Townsley et al., 2003). Moreover, this *contagious* process is further amplified in areas where housing types are similar, or homogeneous. With the exception of murder and manslaughter, all crime types have an element of repeat-victimization (Townsley et al., 2003).

2.6 – Conclusions

Overall, we were successful in identifying a relationship between the built environment and deliberately set fire events in the City of Toronto. Locations where neighbourhood permeability is increased with the presence of laneways are most susceptible to loss and no loss fire events. Both loss and no loss fire events produced a relationship with general street network permeability, confirming our hypothesis that increased levels of accessibility are more conducive to fire setting behaviour. Though no loss fire events did not produce the same type of relationship, we can justify that no loss events, often those related to vandalism, are those initiated out of convenience or spontaneity, where the built environment would not come under scrutiny.

Future research should continue to consider the impact of street network accessibility and the incidence of crime in general, and arson in particular. Accessibility is an influence regardless of modal choice; increased ability to navigate an environment can produce conditions conducive to criminal behaviour. More research with respect to accessibility should be considered by professionals in the field of urban planning and development. At the peak of our dependence on oil and fossil fuels in order to maintain the Western lifestyles we have become accustomed to, we must consider alternatives to development that consider and mitigate one problem without producing another.

2.7 – Tables and Figures

Table 1: Neighbourhood variables used in study

Variable	***Justification***
Percent Youth (YOUTH)	A large youth population has been noted as being a contributor to delinquency in cities (Corocran et al., 2009; Ceccato, 2005; Jennings, 1999; Murrey at al., 1987). This variable is available from Statistics Canada, calculated by dividing the *total population under 24* by the *total population* in each neighbourhood, multiplied by 100.
Average Dwelling Value (VALUE)	The literature suggests that derelict properties are more susceptible to arson (Bennett et al., 1987). Dwelling values are all adjusted to reflect 2006 dollar values (CAN) and are used to represent less desirable housing conditions. *Average dwelling values* occurs in the census as it's own variable, and only changed to reflect a consistent dollar market (2006 $'s). For analysis in SAS 9.2, this value was divided by 100 000.
Percentage Rentals (RENT)	Social Disorganization Theory suggests neighbourhoods with transient populations experience a greater amount of criminal activity. This is due to individuals residing in those areas unsuccessful in developing a sense of camaraderie among their neighbours. The lack of attachment to place facilitates criminal behaviour (Andresen, 2006; Pettiway, 1988; Bursik, 1988; Shaw and McKay, 1942). The concentration of rental properties is included as a measure of transiency to reflect Social Disorganization Theory. To calculate this variable we used the number of *rented occupied private dwellings* and divided it by the *total number of private occupied dwellings*, multiplied by 100.
Percentage of Housing Requiring Major Repairs (REPAIR)	The literature has suggested that derelict properties are often targets for deliberate fires for the purposes of financial gain on the part of the landlord. Also supports Social Disorganization Theory in that derelict properties are usually occupied by individuals who have no interest in maintaining properties, as they harbour the hope to leave as soon as the opportunity arises (Pettiway, 1988; Bennett et al., 1987). This measure was calculated using *major repairs, occupied private dwellings* divided by *total occupied private dwellings*, multiplied by 100.
Housing Density (DENSITY)	Urban, more densely populated areas are said to experience higher rates of crime in general, and arson in particular. Housing density is a measure used to be an indicator of target population (structures) as well as a stand in for total population (Andresen, 2006; Ceccato, 2005; Murrey et al., 1987). This measure is calculated by taking the sum of *apartment, duplex, occupied private dwellings; apartments, 5+ storeys; and apartments, >5 storeys* and dividing it by *total occupied private dwellings,* multiplied by 100.

Percentage of Housing Older than 20 Years (OLD)	Though twenty years is not necessarily old for housing, it was the only consistent duration across the census that we could use to measure age of housing. It has been said that the age of housing, especially old and unkept housing, is often at greatest risk of experiencing arson (Asgary, 2010; Pettiway, 1988). This measure is calculated using *housing older than 20 years* and divided by *total occupied private dwellings,* multiplied by 100.
Percentage of Lone Parent Families (SINGLE)	Lone parent families are used to control for the level of social disorganization that neighbourhoods face. It has been used in previous research in crime, suggesting that children of lone parent households are more likely to participate in criminal behaviour (Corcoran et al., 2009; Andresen, 2006). This measure is calculated using *total number of lone parent families* divided by the *total number of census families*, multiplied by 100.
Unemployment Rate (UNEMPLOY)	Unemployment rate encompasses only those individuals who are unemployed, but actively seeking work. Those who are unemployed and not seeking work are not included in this figure. Higher rates of unemployment have been associated with increased levels of crime and delinquency (Asgary; 2010; Andresen, 2006). This is a measure that appears in the census: unemployment rate, population 15+. This figure presents the rate of unemployment for those individuals aged 15+. Statistics Canada measures this by taking the number of individuals unemployed in the reference period (census day) and dividing it by the total number of individuals in the labour force, multiplied by 100.
Percentage of Low Income Families (LOW)	Low income neighbourhoods are said to experience higher levels of crime and criminal activity, for various reasons (Asgary, 2010; Corcoran et al., 2009; Andresen, 2006; Pettiway, 1988). This is a measure that appears in the census on its own. It is defined as being the percentage of economic families or individuals who spend more than 20% more of their before-tax income on food, shelter and clothing (necessities) than average. Measures of *low income* are already adjusted for inflation.
Percentage of New Residents (NEW)	This is another variable that will support social disorganization theory, where more transient neighbourhoods are those said to experience higher levels of criminal activity (Asgary, 2010; Corcoran et al., 2009; Andresen, 2006; Pettiway, 1988; Shaw and McKay, 1942). To calculate this variable, we took the sum of *interprovincial migrants, internal migrants, movers, mobility status 1 year ago*; and *external migrants, movers, mobility status 1 year ago* divided by the *total population,* multiplied by 100.

Source: (Statistics Canada 2006; 2001a-e)

Table 2: Results, Bivariate regression analysis for all variables against All Loss Fire Events

Variable	2001		2002		2003		2004		2005		2006		2007	
	Coefficient	Significance	CO	SIG	CO	SIG	CO	SIG	CO	SIG	CO	SIG	CO	SIG
DENSITY	0.009447	0.0062	0.005988	0.1027	0.01203	0.0005	0.01324	0.0005	0.01202	0.0024	0.01149	0.0054	0.007579	0.0631
HOUSE	-5.01E-06	0.0176	-3.72E-06	0.0634	-4.34E-06	0.0247	-8.66E-06	0.0005	-4.98E-06	0.0148	-2.44E-06	0.159	-7.86E-06	0.9494
LANE	0.1718	<.0001	0.15	<.0001	0.1696	<.0001	0.1913	<.0001	0.1622	<.0001	0.2034	<.0001	0.1642	<.0001
LOW	0.0209	0.0034	0.02385	0.001	0.02143	0.0029	0.033	<.0001	0.02528	0.0011	0.02501	0.0023	0.02176	0.0079
NEW	0.03198	0.4695	0.02107	0.6587	0.08975	0.0567	0.03677	0.4869	-0.01374	0.8058	-0.00375	0.9503	0.005108	0.9275
OLD	0.005695	0.2257	0.01075	0.034	0.005015	0.3005	0.00817	0.1271	0.01071	0.0588	0.01115	0.0586	0.01275	0.0282
PERM	0.744	0.0002	0.4936	0.0163	0.6792	0.0006	0.5952	0.0047	0.6215	0.0038	0.6501	0.0033	0.477	0.0347
PERM2	-0.06209	0.4615	-0.05752	0.5063	-0.07126	0.3906	-0.1154	0.1936	-0.05576	0.5366	-0.08694	0.3557	-0.06452	0.4934
RENT	0.01629	<.0001	0.0122	0.0034	0.0161	<.0001	0.01779	<.0001	0.01739	<.0001	0.01437	0.0016	0.005524	0.724
REPAIR	0.0631	0.0089	0.09065	0.0003	0.08987	0.0002	0.129	<.0001	0.1002	<.0001	0.1085	<.0001	0.09221	<.0001
SINGLE	0.03335	0.0107	0.03315	0.0123	0.02795	0.0293	0.04921	0.0002	0.04618	0.0003	0.04262	0.0014	0.03503	0.0056
UNEMPLOY	0.01331	0.7187	0.06652	0.0689	0.02579	0.4827	0.07146	0.0689	0.01819	0.646	0.05751	0.1541	0.04649	0.2231
VALUE	-0.0645	0.2656	-0.06961	0.2147	-0.05283	0.2953	-0.1166	0.0355	-0.05146	0.2941	-0.04697	0.3218	-0.00389	0.9243
YOUTH	-0.03109	0.022	-0.0045	0.754	-0.02481	0.0697	-0.01535	0.299	-0.00749	0.6225	-0.0005	0.9748	0.005524	0.724

Table 3: Results, Bivariate regression analysis for all variables against All No Loss Fire Events

Variable	2001		2002		2003		2004		2005		2006		2007	
	Coefficient	Significance	CO	SIG	CO	SIG	CO	SIG	CO	SIG	CO	SIG	CO	SIG
DENSITY	0.01068	0.0058	0.01169	0.0029	0.01179	0.0038	0.01258	0.0055	0.01534	0.0009	0.01657	0.0002	0.01556	0.0002
HOUSE	-9.77E-06	0.0005	-6.35E-06	0.0106	-0.00001	0.0003	-0.00001	0.0006	-6.74E-06	0.0073	-7.51E-06	0.0016	-6.54E-06	0.0042
LANE	0.1481	0.0005	0.108	0.0125	0.1155	0.0064	0.1961	<.0001	0.2097	<.0001	0.163	0.0002	0.2025	<.0001
LOW	0.03643	<.0001	0.0327	<.0001	0.04211	<.0001	0.03557	<.0001	0.03998	<.0001	0.0387	<.0001	0.03099	0.0003
NEW	0.04798	0.3353	0.03535	0.4995	0.06596	0.2352	-0.00811	0.8994	0.124	0.0546	0.08342	0.1761	0.06159	0.3027
OLD	0.001325	0.8	0.000043	0.9935	-0.00065	0.9062	0.004344	0.4748	0.002176	0.7355	-0.00118	0.8458	-0.0004	0.9454
PERM	0.2294	0.3485	0.1321	0.5868	-0.0329	0.8947	0.3447	0.1825	0.1364	0.6147	0.1212	0.6352	0.2796	0.2585
PERM2	-0.3478	0.0004	-0.2172	0.0259	-0.4614	<.0001	-0.3579	0.0007	-0.4532	<.0001	-0.2998	0.0033	-0.4362	<.0001
RENT	0.01635	0.0003	0.0163	0.0003	0.01651	0.0002	0.01532	0.0019	0.01899	0.0002	0.01794	0.0002	0.01431	0.0028
REPAIR	0.06734	0.0136	0.06102	0.0285	0.06997	0.0124	0.1307	<.0001	0.1219	<.0001	0.0934	0.0005	0.09582	0.0001
SINGLE	0.06057	<.0001	0.05311	<.0001	0.0611	<.0001	0.05974	0.0001	0.04403	0.0051	0.04331	0.0027	0.02995	0.035
UNEMPLOY	0.06968	0.0754	0.07371	0.0614	0.1324	0.0009	0.07914	0.0746	0.1008	0.27	0.07882	0.061	0.04452	0.2756
VALUE	-0.2574	0.0007	-0.2019	0.0038	-0.3054	<.0001	-0.2183	0.0024	-0.1357	0.0231	-0.1305	0.0149	-0.1501	0.0056
YOUTH	-0.00126	0.9354	-0.00139	0.9276	0.01809	0.2574	-0.01104	0.5135	0.01097	0.5359	0.006447	0.7018	-0.01307	0.4217

TABLE 4: Model 1, Loss Fire Multivariate Regression Results

Dependent	Effect	Estimate	Pr > |t|	Covariance Parameter	Subject	Estimate	Standard Error
Loss Events	**PERM**	0.311	0.061	UN(1,1)	HOOD	0.402	0.08984
	LANE	0.1286	0.0025	UN(2,1)	HOOD	-0.0133	0.01122
	YOUTH	-0.013	0.3697	UN(2,2)	HOOD	0.00253	0.002031
	VALUE	0.02671	0.6471				
	RENT	0.01012	0.1476				
	REPAIR	0.00872	0.6741				
	OLD	-0.0033	0.3871				
	DENSITY	-0.0039	0.5126				
	SINGLE	0.0388	0.009				
	LOW	8.4E-05	0.9936				
	UNEMPLOY	0.02615	0.4641				
	NEW	-0.0145	0.7317				
	YEARVALUE	4.06E-08	<.0001				
	YEAR LANE	0.00448	0.5023				
	YEAR	-0.0996	0.004				
	INTERCEPT	-1.9363	0.0359				

Table 5: Model 2, Loss Fire Multivariate Regression Results

Dependent	Effect	Estimate	Pr > |t|	Covariance Parameter	Subject	Estimate	Standard Error
No Loss Events	**PERM**	-0.3682	0.0684	UN(1,1)	HOOD	0.402	0.08984
	LANE	0.1246	0.0089	UN(2,1)	HOOD	-0.0133	0.01122
	YOUTH	0.00105	0.9479	UN(2,2)	HOOD	0.00253	0.002031
	VALUE	-0.2859	0.0002				
	RENT	0.00993	0.1923				
	REPAIR	0.0197	0.3396				
	OLD	-0.0023	0.58				
	DENSITY	0.0049	0.4427				
	SINGLE	-0.0147	0.3597				
	LOW	0.01136	0.3075				
	UNEMPLOY	-0.0217	0.5182				
	NEW	-0.0913	0.0445				
	YEAR×VALUE	2.92E-07	<.0001				
	YEAR×LANE	0.01082	0.0884				
	YEAR	-0.0772	0.0263				
	INTERCEPT	1.7595	0.1073				

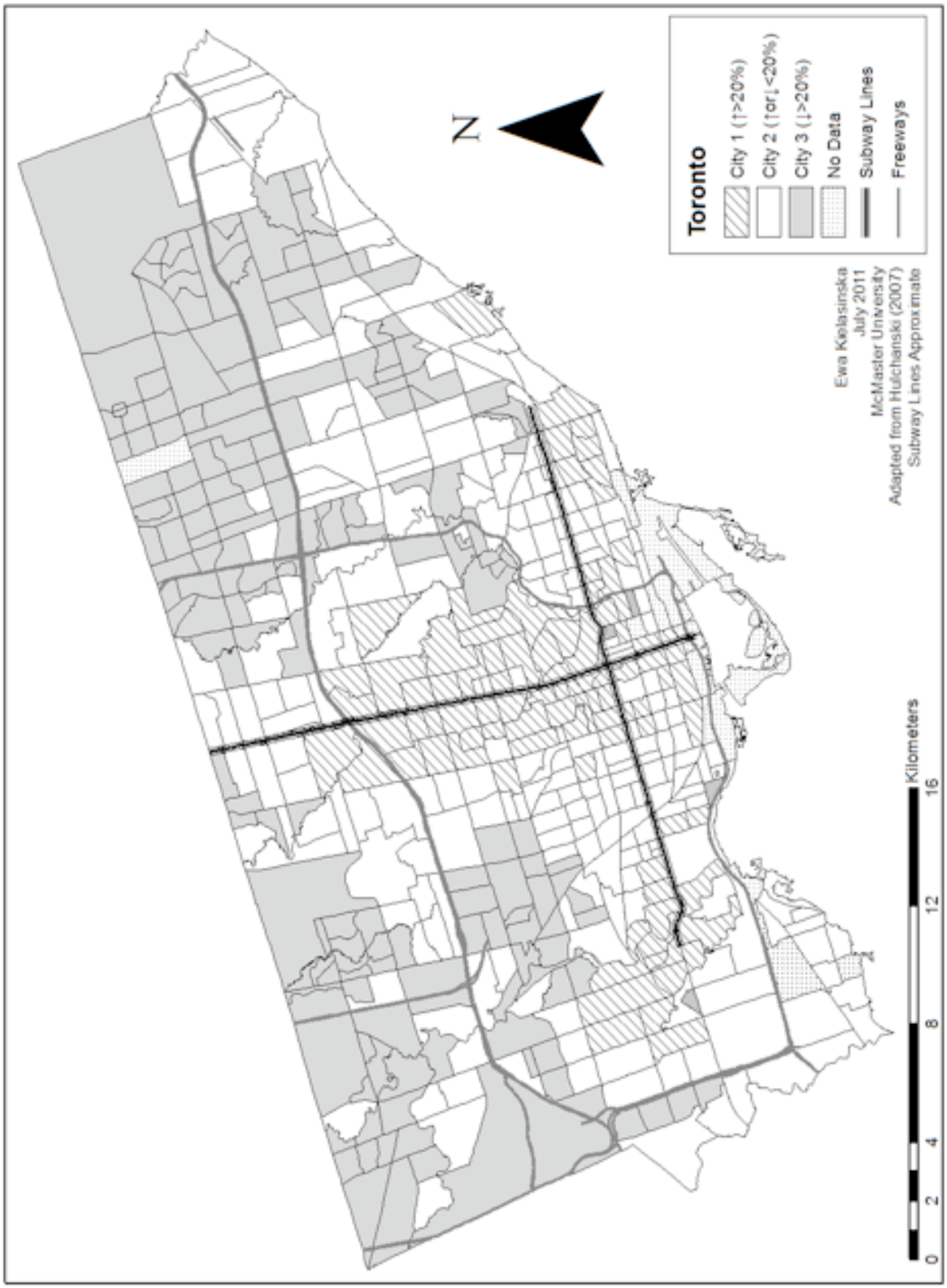


Figure 1: Change in Average Individual Income, City of Toronto, Relative to the Toronto CMA, 1970-2000 from Hulchanski (2007)

Figure 2: Number of no loss fire events by day classified by possible cause

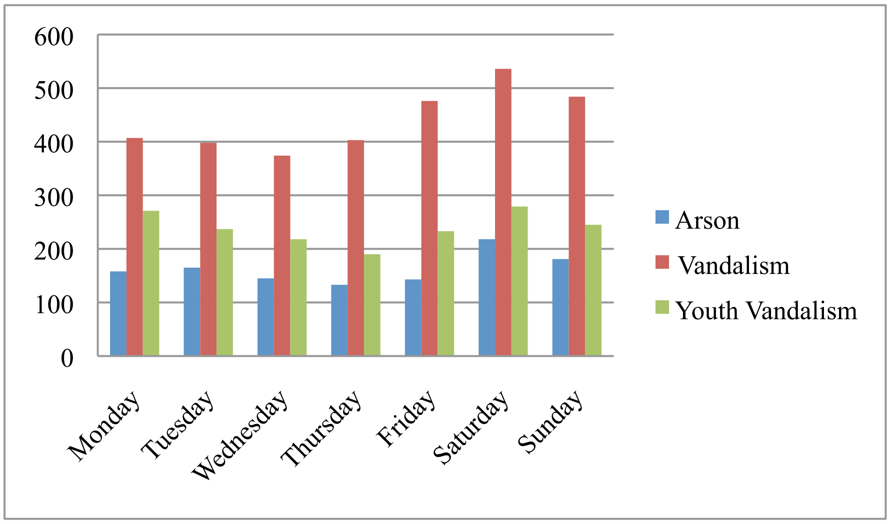


Figure 3: Number of loss fire events by day classified by possible cause.

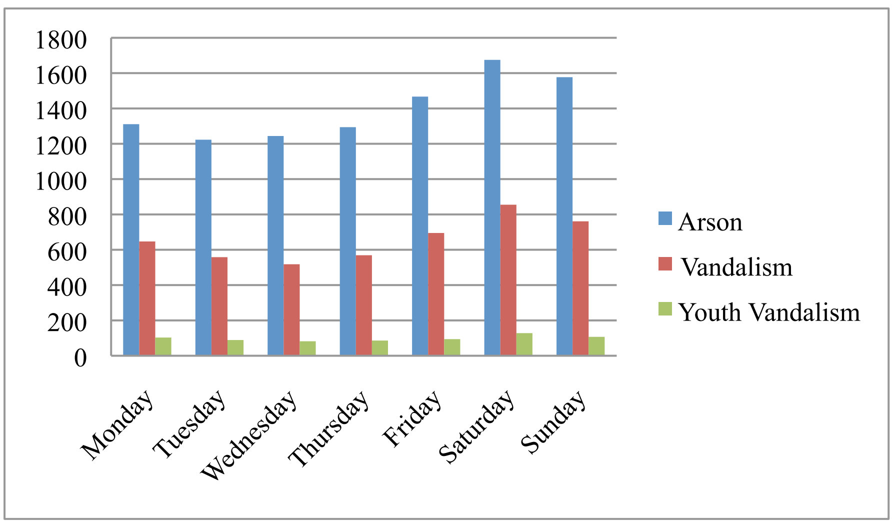
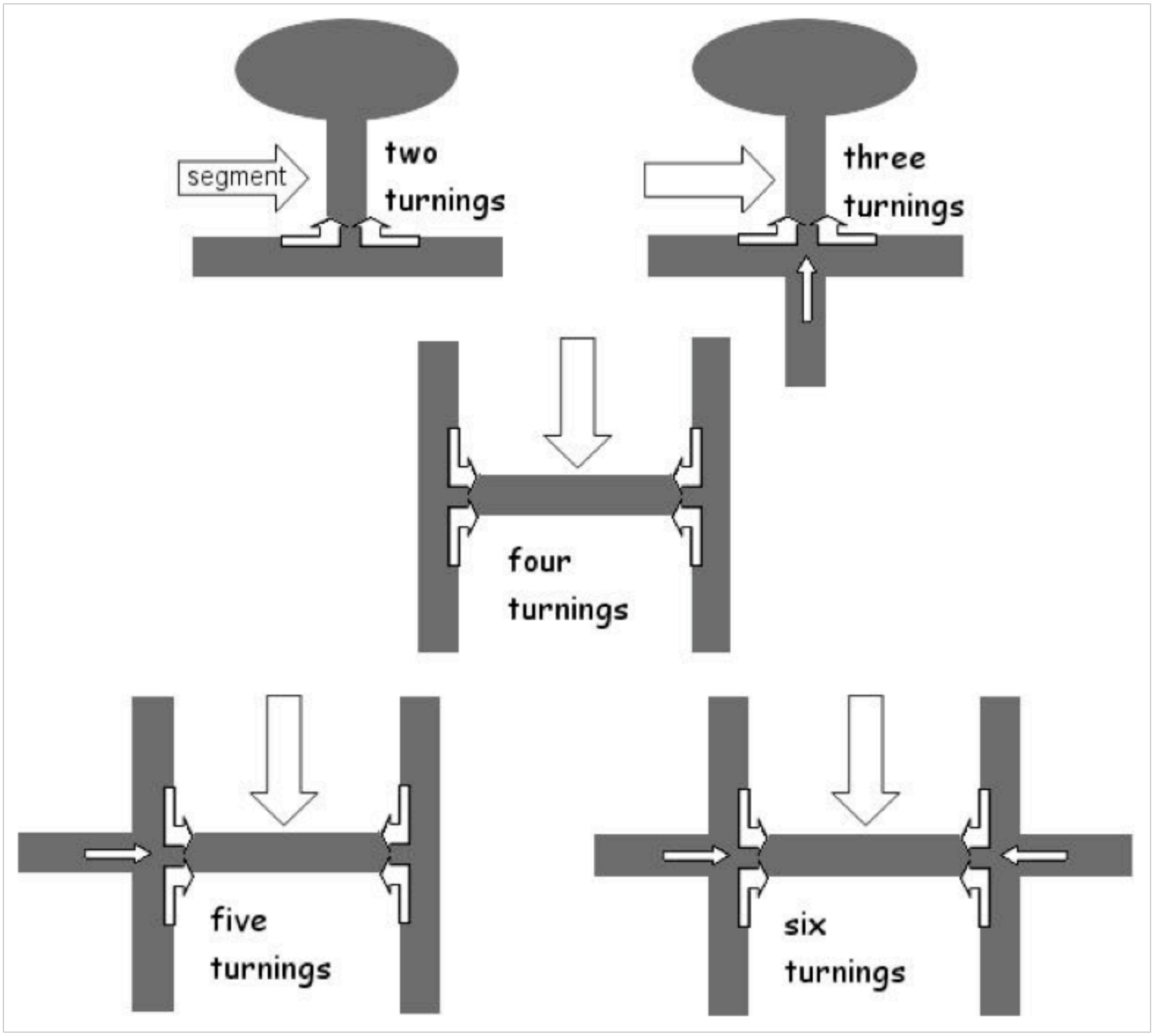


Figure 4: Measure of Accessibility, Adapted from Beavon et al., (1994)



Adapted from Beavon et al. (1994)

Caption: Beavon et al. (1994) used this as a guide to measure street network accessibility in their study of the influences of street network on crime. Their study uses two additional measures for accessibility, one for a one-turn scenario, and one for a different three-turn scenario than illustrated above. However, when we considered these two other options, we considered those scenarios to be obsolete, as they illustrated additional turnings based on the existence of a bend along a street segment. Our definition of a street segment is the stretch of road between two intersections, unless the street segment is only accessible from one intersection (i.e. a culs-de-sac). Therefore, the minimum number of turnings to gain access onto a street segment is two, as illustrated above.

Figure 6: Laneway Density Index, City of Toronto

Figure 6: Modelled Relative Risk for Loss Fire Events, 2001-2007

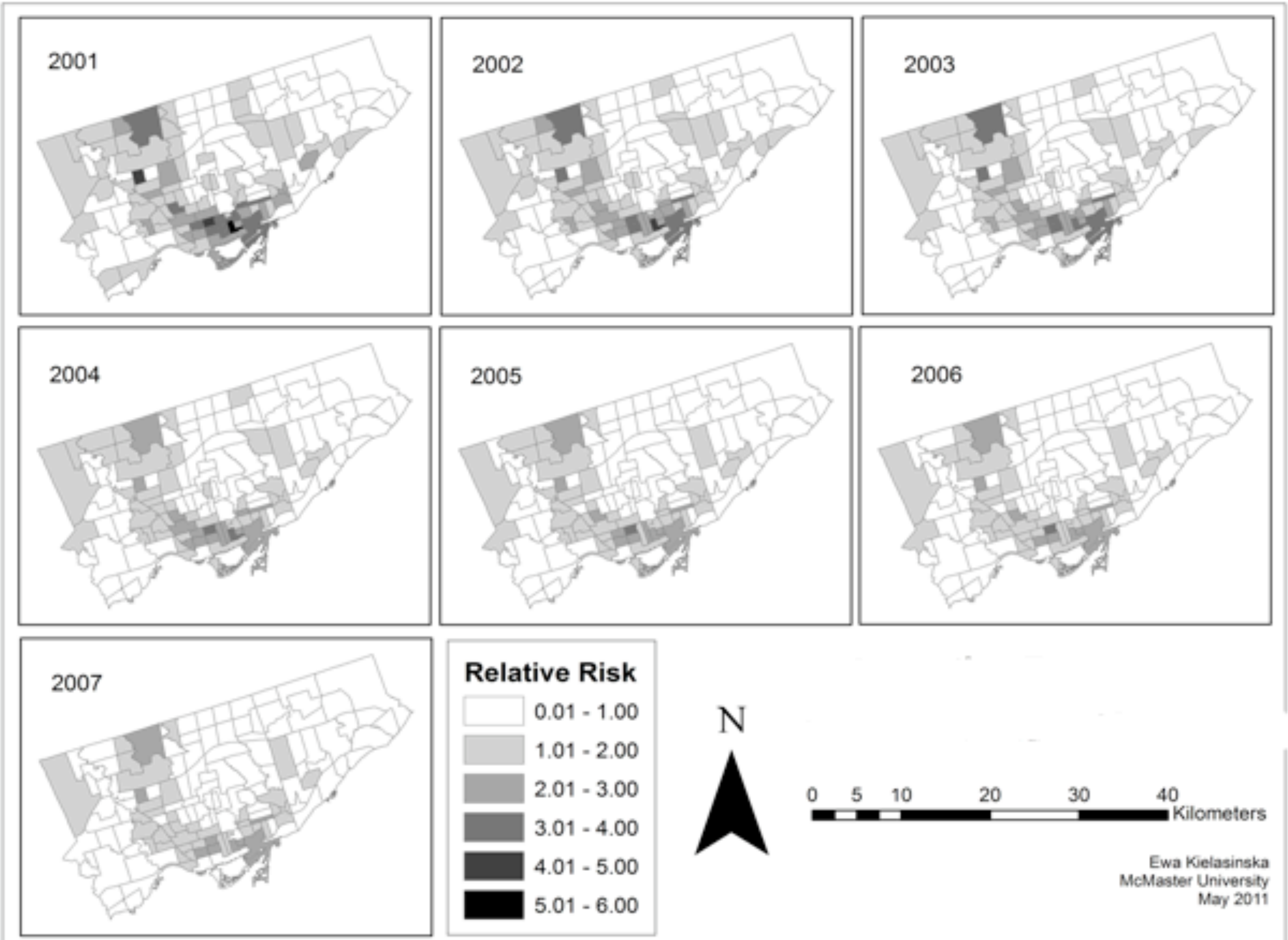


Figure 7: Modelled Relative Risk for No Loss Fire Events, 2001-2007

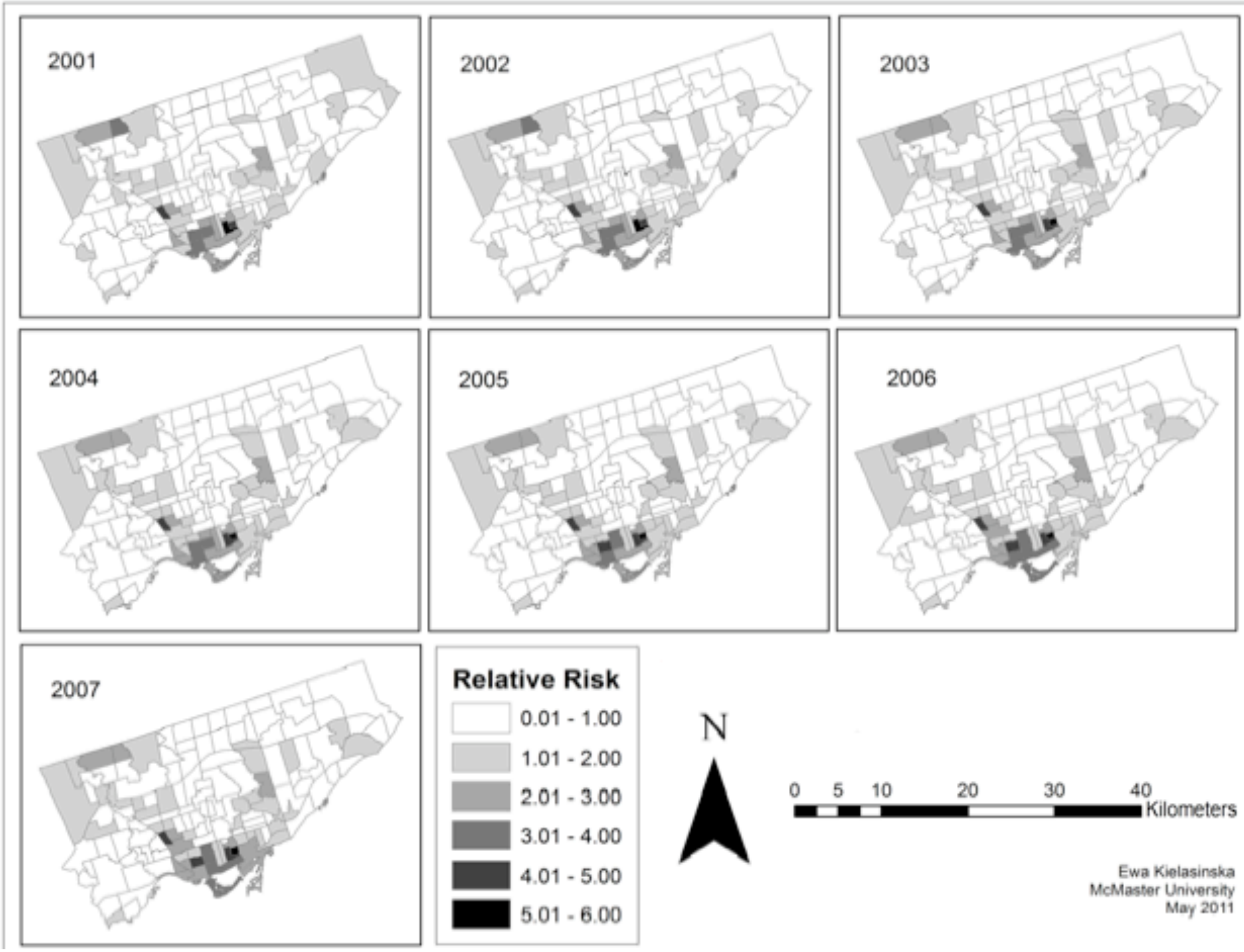


Figure 8: Kernel Density Estimation, Loss Fire Events, 2001-2007

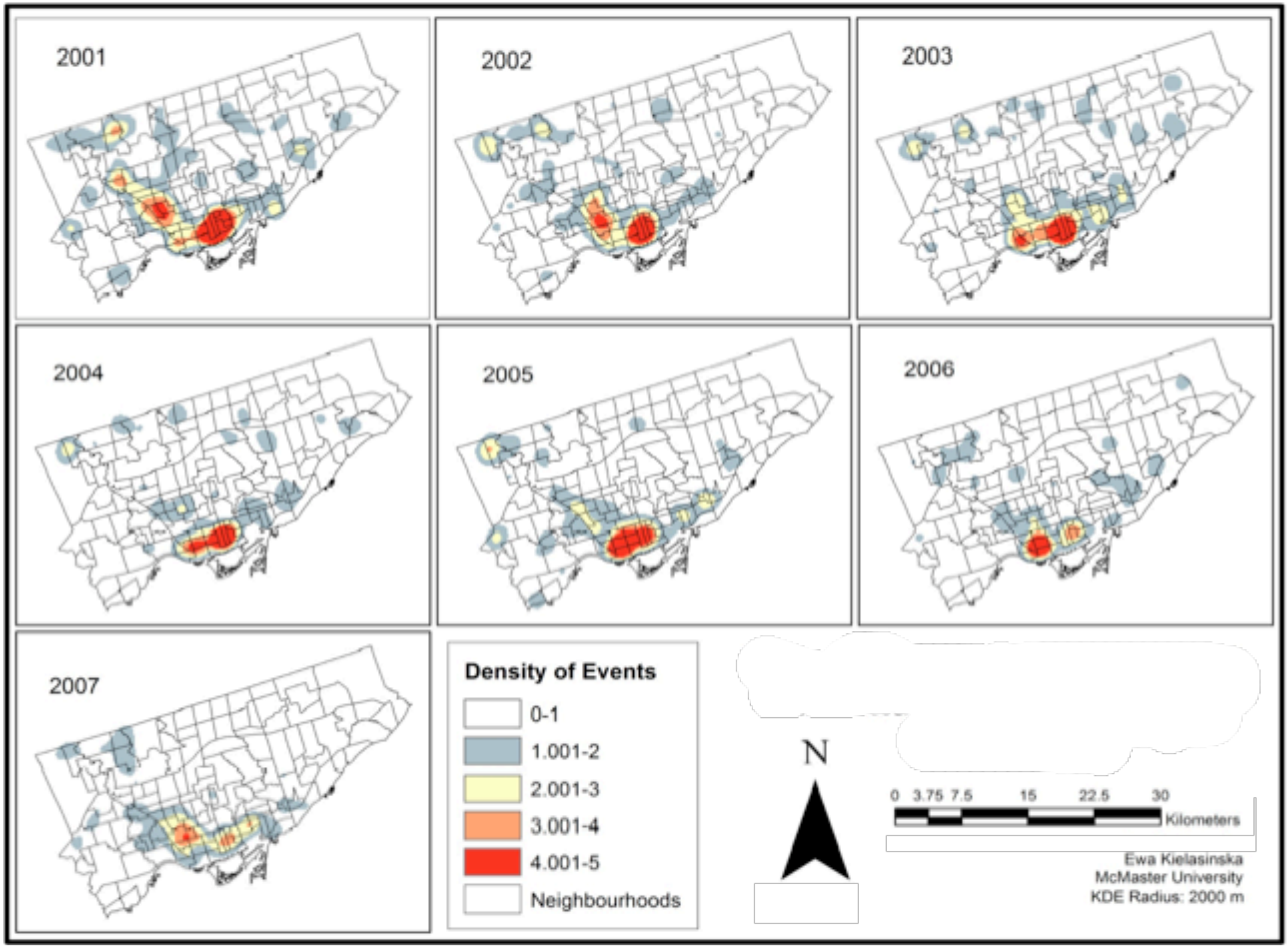
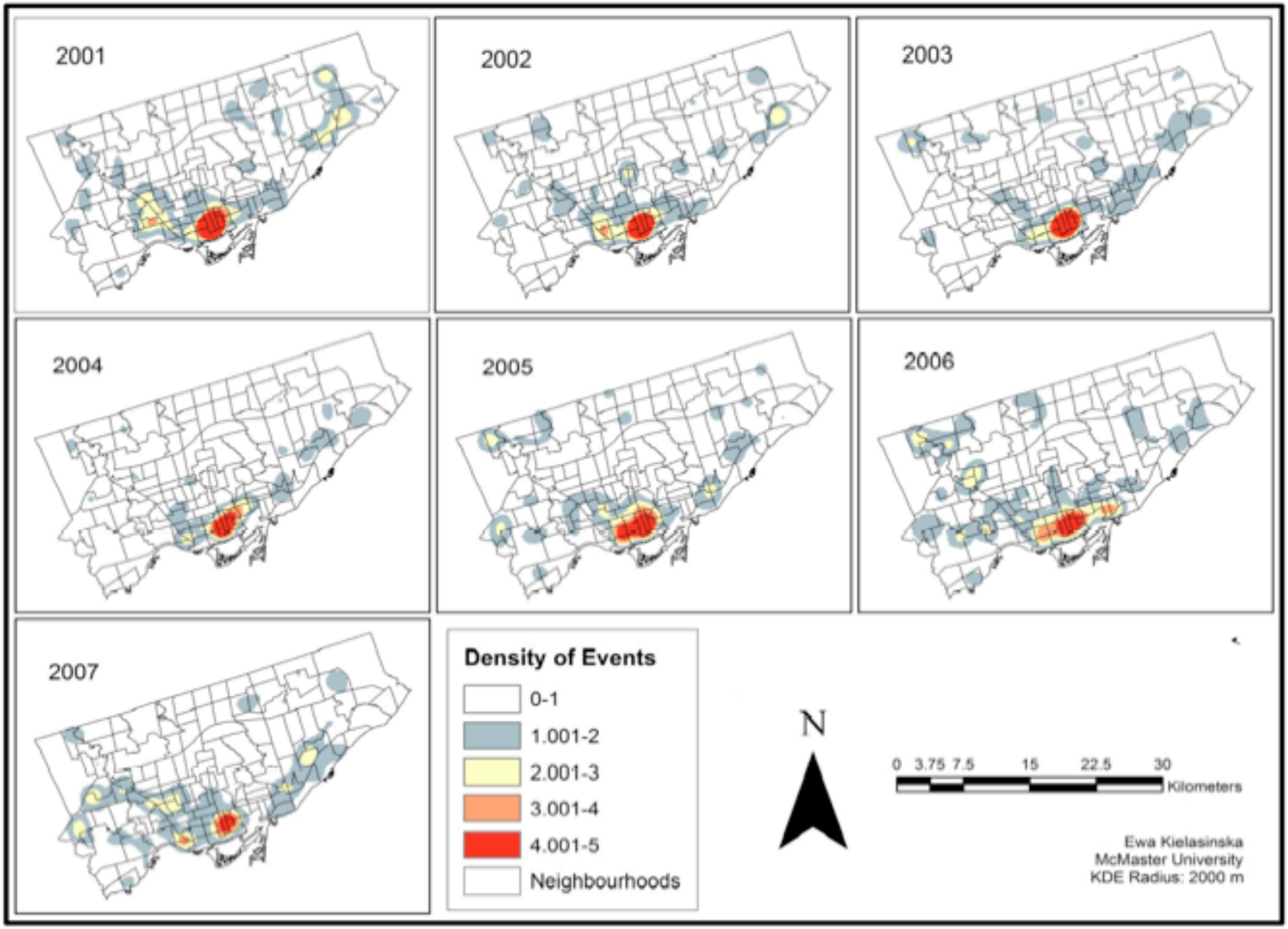


Figure 9: Kernel Density Estimation, No Loss Fire Events, 2001-2007



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CHAPTER THREE: Heat Aggression and the Incidence of Urban Arson

3.1 – Introduction

Heat can affect individuals both physiologically and psychologically. It can lead to aggressive behaviour in some individuals, increasing their propensity to commit crime (Ceccato, 2005; Rotton and Cohn, 2004; Cohn, 1990; Baron and Ransberger, 1978). The relationship between heat and aggression has most commonly been investigated with respect to violent crime, including assault and homicide. To a lesser extent, the relationship has also been explored with respect to property crimes, such as robbery (Ceccato, 2005; Rotton and Cohn, 2004; Cohn, 1990). Few researchers have had access to detailed weather data and disaggregate fire incident data in order to successfully explore the influence of weather conditions on fire incidence at the local level (Corcoran et al., 2009). In this study, we aim to develop an understanding of how heat aggression affects the incidence of deliberately set fire events in the City of Toronto. More specifically, we are interested in excess exposure to heat resulting from extended heat wave conditions. We hypothesize that during episodes of excess heat, the incidence of deliberately set fire events increases. This idea has not been explored with respect to arson, though the relationship has been investigated with regard the general incidence of fire (Corcoran et al., 2009) as well as other forms of crime (Ceccato, 2005; Rotton and Cohn, 2004; Cohn, 1990).

The organization of this chapter is as follows. First, we offer an introduction to the research and theory previously published with respect to physiological responses to heat, heat aggression and criminal activity. The methods used to complete this project are outlined next. This section includes the description of the study area, data acquisition and use, and methods of analysis. Next, the results of our analysis are presented followed by a discussion of our findings as they relate to the literature, contributions resulting from this work, and limitations we faced during the process. We conclude with a culminating discussion of our research question.

3.2 – Background

3.2.1 – Physiology of Heat and Aggressive Behaviour

Researchers have been interested in the relationship between heat and criminal behaviour since the late 1970s. The physiological effects of heat can manifest in various forms, both physically and emotionally. The human body maintains a core temperature of approximately 37°C (degrees Celsius). The production of stress hormones occurs when the body is exposed to temperature extremes and begins processes in order to maintain its core temperature (Simister and Cooper, 2005). Stress hormones are necessary for human beings to be able to navigate various life situations, however, these hormones can have unwanted effects, such as aggressive behaviour. Additionally, the body produces neural responses in order to moderate the effects of the external environment on the body (Simister and Cooper, 2005; Anderson, 1989). It is believed that the response to the regulation of body temperature occurs in the hypothalamus. When exposed to high temperatures, the hypothalamus releases the neurotransmitters neropinephrine and epinephrine which produce a response for the body to reduce its core temperature. Epinephrine, otherwise known as adrenaline, is increased in hot conditions in both men and women (Simister and Cooper, 2005). Adrenaline influences the body to cool off by increasing vasodilation, heart rate and raising blood pressure. Adrenaline has also been associated with increases in aggressive behaviour (Simister and Cooper, 2005). Serotonin and acetylcholine are released to increase core temperature when exposed to cold (Anderson, 1989). Serotonin has been documented as an inhibitor to aggressive behaviour, whereas acetylcholine has been found to increase aggression.

When exploring the relationship between temperature and aggressive behaviour there has been a large focus on the effect of exposure to heat. In a study of 100 males and females, Boyanowsky (1998) found that when individuals are asked to describe physical reactions to emotions, 98 associated the emotion with increases in temperature of their face and head, such as flushing, when referring to anger. The English language is also full of metaphors describing the feeling of anger or frustration. "Tempers flare," "in the heat of passion," or getting "hot under the collar" are phrases used to describe situations associated with feelings of anger while supporting the relationship with heat (Boyanowsky, 1999; Anderson, 1989).

3.2.2 – Theory

There are a number of functional forms we can consider when investigating the relationship between heat and aggressive behaviour by individuals, however only two will be considered in this study (Figure 1). A linear relationship is the most simple. As temperature increases, the incidence of aggressive behaviour also increases, showing a direct positive relationship between the two factors. The argument is made that this relationship can only really exist within a 'normal' range of temperatures (Anderson, 1989). At extreme temperatures, both hot and cold, the body is not capable of functioning at a normal level and will begin processes in order to maintain its inner temperature, overriding the need to aggress (Anderson, 1989). In the case of the inverted-U shaped relationship, it is argued that aggressive behaviour increases as temperature rises from cold to moderate to hot. However, once temperatures reach a particular threshold, aggressive behaviour begins to plateau and decrease with further exposure to heat (Anderson, 1989). The justification for this shape with respect to how temperature affects aggressive behaviour is that the need to avoid further discomfort as temperatures rise (especially at temperature extremes), overrides the individuals need to aggress (Anderson, 1989).

There are also two approaches available to understanding the relationship between heat and criminal behaviour: Negative Affect Escape Model and Routine Activity Theory. The negative affect escape model suggests that negative feelings such as aggression, annoyance and discomfort are positively associated with increases in temperature. However, when a certain temperature threshold is met and surpassed, violent behaviour decreases as a result of individuals needing to avoid further discomfort (Baron and Bell, 1976; Butke and Sheridan, 2010). The shape of this relationship can be described as the inverted-U (Figure 1). In a laboratory study, subjects exposed to excess heat showed an increased tendency to aggress when not previously provoked (Boyanowsky, 1999).

The suggestion has been made that an instigating element amplifies aggressive response when an individual is already exposed to extreme temperatures. Boyanowsky (1999) furthered his understanding of the relationship between heat and aggression by adding another element to his analysis. When the same study was repeated using subjects exposed to heat and asking them to respond by delivering shock, the addition of negative feedback from the 'teacher' was introduced in the form of an insult. It was found that the responses by the subjects were even further amplified. The mean shock intensity reported was approximately two to 2.5 times higher in hot conditions with the addition of an insult than in hot conditions alone (Boyanowsky, 1999). This finding presents an increased level of complexity to understanding the relationship between temperature and aggressive behaviour. Conversely, the escape mechanism became apparent when subjects were exposed to heat and were also previously provoked. When provoked for a second time, their aggressive responses were diminished. However, the critique is made that because this was a laboratory study, the design only allowed subjects one available response: the level of intensity at which to administer a shock (Boyanowsky, 1999). Perhaps reducing shock intensity is a conscious choice by the subject as a new tactic in order to be excused from further increases in temperature and discomfort and not necessarily a true representation of a reduction in feelings of aggression.

Routine Activity Theory, developed by Cohen and Felson (1979), emphasizes three criteria necessary for a crime to occur: a willing offender, a suitable target, and a lack of guardianship. Activities outside of the home provide opportunities for property crime, where there is lack of guardianship in and around the property. In the case of property crime, the number of targets always remains the same, or similar, over time regardless of temperature. However, more conducive temperatures may increase a perpetrators willingness to offend, as well as influence guardians (i.e. property owners, neighbours) to be absent. It is this change in behaviour, resulting from more pleasant conditions, that influences the rate of property crime (Hipp et al., 2004). With respect to crimes against persons, the routine activities of individuals in warmer weather conditions are more likely to bring offenders and victims together in public areas so as to influence the occurrence of violent crime. Assaults are most likely to occur outdoors and in the streets as opposed to indoors (Rotton and Cohn, 2004). Ceccato (2005) justifies that her findings regarding the relationship between heat aggression and homicide are consistent with routine activity theory, with incidents peaking during periods of individual free time. She reasons that the longer days during the warmer periods of the year puts larger groups of individuals in contact with one another for longer periods of time. In these situations the opportunity for crime to occur is low. Therefore, it is important to consider theories in crime and criminal behaviour along with specific situational factors such as acute events, including weather, that affect the likelihood of an event occurring (Cohn, 1990). Routine activity is not solely dependent on fluctuations in temperature. However, changes in temperature are a significant driver of changes in social behaviour, and is therefore important to consider in the case of evaluating possible drivers for property crime (Hipp et al., 2004). With that, we consider routine activity theory to have a linear relationship with the incidence of deliberately set fire events, where temperatures more conducive to time spent outside of the home provide better opportunities for offenders to commit crimes.

3.2.3 – Empirical Evidence

Various forms of crime have been considered in field studies to further the empirical understanding of the relationship between heat and aggressive behaviour. Associations between temperature and crime have been found in studies of group violence, such as riots (Baron and Ransberger, 1978). Baron and Ransberger's (1978) findings suggest that riots are more likely to occur with temperatures up to 85ºF (degrees Fahrenheit), above which their incidence decreases. These findings support an inverted-U shaped relationship between group violence and its association with temperature, with aggression peaking at a given threshold and decreasing thereafter (Figure 1). Carlsmith and Anderson (1979) reexamined the study and found that Baron and Ransberger did not account for the fact that there are fewer days with temperatures exceeding 85ºF in their study region. After controlling for the number of days at observed temperatures, they were able to conclude that group violence has a positive linear relationship with heat up to at least 85ºF (Figure 1). The positive linear relationship does not recognize an inflection point beyond which aggressive behaviour begins to decrease.

There are also consistent findings that assault and heat are positively correlated. Feldman and Jarmon (1979), Harries and Stadler (1983) and Rotton and Frey (1985) all find significant positive relationships between assault and temperature. Rotton and Cohn (2003) found that assaults are significantly correlated with temperature at both the national- and state-level (in the

United States). Anderson et al. (1997) also found that assaults, especially violent assaults and homicide, are correlated with temperature using data from the 50 largest Standard Metropolitan Statistical Areas in the United States between 1950 and 1995. Specifically, their findings suggest that with every 1 degree Celsius (ºC) increase in temperature, the rate of violent or deadly assaults increases by 6.6 per 100 000 population (Anderson et al. 1997). However, DeFronzo (1984) was not able to find a relationship between the number of days with temperatures exceeding 90ºF and the rate of assault. For those studies able to confirm a relationship between rising temperatures and aggressive behaviour, specifically assault, the relationship is positive and linear (Figure 1).

The evidence in support of the relationship between heat and homicide is more controversial. Some studies have found an association between temperature and homicide. Cohn (1990) summarizes that two intra-jurisdiction and three inter-jurisdiction studies found a positive relationship between heat and homicide incidence, while 15 intra-jurisdiction studies found that there is no association. Ceccato (2005) found that homicides are most likely to occur during warmer months of the year in Sao Paulo, Brazil. The justification for conducting this research in Sao Paulo was to see if the relationship would still exist given that the climate in this region is relatively warm year-round. The argument is made that individuals respond to heat in relative terms, as opposed to absolute (Smoyer et al., 2000). In other words, a single threshold by which we can anticipate an aggressive reaction to heat exposure is not possible for all regions. The average temperature of a place is important to consider. For example what a population considers to be 'hot' in a temperate climate such as Toronto may be considered 'moderate' in other, more tropical, regions. However, Ceccato's (2005) results still suggest that there was still a drop in the number of homicides during the winter months, supporting the notion that regardless of the range in temperature, the relationship between higher temperatures and aggressive behaviour remains true.

Few studies have observed the relationship between weather conditions and fire incidence. Chandler (1982) found a relationship between the average minimum temperatures and the number of fires at the weekly level in Great Britain. He found that severe winter conditions are positive predictors of fire incidence in the home. Conversely, Corcoran et al., (2009) note that residential fire decreases when humidity is high in South East Queensland, Australia. They speculate that this is because high levels of humidity prompt a change in individual behaviour. The findings of Corcoran et al. (2009) also found that the incidence of suspicious fires increases when conditions are dry. They speculate that this is a choice rationalized by the perpetrator in order for their crime to have a larger impact, as dry conditions are better able to support and spread fire (Corcoran et al., 2009).

Corcoran et al., (2009) also use weather data across South East Queensland, Australia to examine the variability in fire-events based on daily weather conditions. South East Queensland is a region whose regional climate does not vary much over the course of the year. They found that residential fires are more common during winter months. Chandler (1982) and Corcoran et al. (2009) suggest the relationship between colder weather conditions and fire incidence relates to the use of heating mechanisms, such as fireplaces and space heaters.

Based on previous research, there is evidence to believe that temperature has an effect on individual aggression, and therefore increase their propensity to commit various types of crime. Because the relationship between deliberately set fire events and heat wave conditions has not been explored, we aim to contribute to the body of literature by answering the question: do heat wave conditions influence the incidence of deliberately set fire events in the City of Toronto?

3.3 – Methodology

3.3.1 – Study Area

The City of Toronto (including the formerly independent municipalities of Etobicoke, York, North York East York, Scarborough and Old Toronto) is the largest city in Canada, with a population of 2.5 million people (Statistics Canada, 2010). Located in Southern Ontario, Toronto experiences significant temperature changes over the course of the year. However, being located along the north shore of Lake Ontario, Toronto experiences some of the most moderate temperatures in the country. The climate is described as continental, with cool winters and warm summers. On average, Toronto receives approximately 55-70 mm of precipitation per month (Toronto's Climate, 2011). The range in temperatures can be extreme; the highest ambient temperature reported during our study period (from late spring through early fall) is 37.9ºC, and the lowest -4.8ºC. However, on average the mean daily temperature (ambient, or measured temperature) in January is -4.5ºC and 22ºC in July (Toronto's Climate, 2011). The months of the year that experience the hottest days, and the highest frequency of prolonged episodes of heat are July and August (Pengelly et al., 2007). Therefore, we would anticipate that the highest frequency of deliberately set fire events occurs during those two months if the relationship between heat exposure and arson exists.

The City of Toronto is ideal for studying the relationship between heat and criminal activity. This is because the range of temperatures experienced by individuals in the city is great, especially once wind chill and humidex are factored in. Though we are only focusing on heat aggression resulting from periods of excess heat exposure, the psychological and physiological responses resulting from changes in temperature over the course of the year can be amplified as individuals respond to temperature in relative, not absolute, terms (Smoyer et al., 2000).

3.3.2 – Data

Fire Data

The data used in this analysis were acquired from the Ontario Office of the Fire Marshal (OFM). The original dataset includes events from 1983 through 2007. Weather data availability only allows us to use the years 1998 through 2007. Only the events occurring during the warm period of the year were of interest to us, cutting the data down to the study period of May 15th through September 30th, 1998-2007. The City of Toronto Public Health Department considers this time period during which they are on alert for extreme episodes of heat, as they relate to acute health issues in the population (Heat Alerts, 2011). Therefore, this is the same period for which we will monitor for prolonged episodes of heat.

The Toronto Fire Department (TFD) classifies deliberately set fire events in four ways: arson, vandalism, youth vandalism, and riot/civil commotion. Fire events are classified as arson when some element of planning can be identified on the part of the perpetrator by fire personnel during investigation. Planning can include the consideration of time, persons absent or present, or materials used to ignite a fire (Slade, March 14, 2011, Personal Communication). Fire events are classified as vandalism (including youth vandalism) when they are deliberately set and the fire department cannot identify any level of planning on in the part of the offender, where the only apparent motivation is the destruction of property. Riot fires are classified as fire events that occur during civil demonstrations (Slade, July 29, 2010, Personal Communication). For the purposes of this study, we only distinguish between loss and no loss fire events. Fires that result in no monetary loss are referred to as no loss events, whereas loss fire events have resulted in monetary loss. Fires classified as arson by the fire department are generally those which have resulted in loss; vandalism fires are more often no loss events (Figures 2 & 3). We distinguish between fire events based on estimated damages because the process for classifying an event as either arson or vandalism can be difficult. It has been suggested that the investigation and reporting of fire events is a skill continually being developed by fire personnel. The decision is at the discretion of the responding captain and is dependent on their level of experience (Slade, March 15, 2010, Personal Communication; Hershbarger and Miller, 1978). The reporting of physical damages is a less ambiguous process, and therefore we consider our events by this definition. During our study period, we analyze a total of 4 511 fire events over 1 391 days. Loss events account for a slightly larger proportion, with 2 340 events; 2 171 are no loss events.

Weather Data

Environment Canada keeps an online archive of weather data from various weather stations across the country (Weather Office, 2011a). We acquired all weather data for the years 1998 through 2007 from the weather station at Toronto's Pearson International Airport. We do not consider years prior to 1998, as some important weather information was incomplete for those years, such as daily maximum and minimum temperature readings. Consistently reported weather data is important for this project, as we require consecutive daily weather information in order to develop a classification scheme for heat wave conditions. Additionally, though this airport is considered to be Toronto's, it is actually located in Mississauga, just outside of the Toronto city boundary. We chose this weather station because it offered the most consistent weather data for the city, and is the main source of weather information for the Greater Toronto Area. The weather station at Pearson International Airport monitors daily temperature (ambient, high and low), precipitation (rain or snow), humidex (apparent temperature) and more.

Though the weather data downloaded from Environment Canada (Weather Office, 2011a) includes a wealth of information, we are predominantly concerned with the Humidex reading for each day. Humidex is a measure indicating apparent temperature, or the 'feels like' temperature, as opposed to the ambient measured temperature. Humidex is calculated using several weather indicators, the most important of which are ambient temperature and relative humidity. The combination of ambient temperature and humidity creates conditions that feel hotter, and more uncomfortable, than what would be experienced with dry-heat. When humidity is high, the body's physiological responses to heat occur at lower ambient temperatures. The excess moisture in the air inhibits the body's ability to sweat and regulate temperature appropriately, subsequently building up stress hormones in the body (Weather Office, 2011b).

The reorganization of our data was necessary to answer our research question. We are seeking to determine if there is a relationship between prolonged heat wave conditions and the incidence of arson. A heat wave, as defined by Environment Canada, is a string of three or more days where apparent temperature is equal to, or in excess of, 32ºC (Atmospheric Hazards, 2010). Therefore, when we identify potential days as part of a heat wave, we are looking for those days where apparent (Humidex) temperature equals or exceeds 32. We chose to use the Humidex values when preparing our heat wave index because it is thought to affect the body's physiological response to heat the same way as ambient temperatures (measured, actual temperatures), however the response occurs at lower ambient temperature values. Therefore, we needed to create a new variable identifying periods of heat wave conditions. We identify periods where the Humidex reaches or exceeds 32 for three (or more) consecutive days. When two heat waves are separated by two or fewesr days, they are identified as one extended heat wave. Finally, we added a lag of one day to all identified heat waves (including the extended heat waves). Therefore, the minimum number of days our heat wave variable measures is four days. This is model variable HEAT.

Another weather variable we include in our model is precipitation. Precipitation is included in the model as an additional mechanism for predicting how short term weather events affect fire-setting behaviour. We use millimetres of rain instead of creating a dichotomous variable for precipitation/no-precipitation, as the quantity of precipitation is important in predicting fire setting behaviour. A greater quantity of rain may influence individuals to change their behaviour, or hamper the fire setting process. Wet conditions, intuitively, are less conducive to fire setting than drier conditions. Corcoran et al. (2009) found that the drier conditions are better predictors of fire events. They rationalize that this is a conscious choice by offenders in order for their event to have a greater impact. Conversely, wetter conditions may deter fire setting behaviour. This becomes the model variable PRECIP.

Additional Data

We compiled a list of all statutory holidays in Ontario during our study period, and added those to our analysis as a dichotomous variable for the date of the holiday. While visually browsing through our data, we noticed that there were a considerable number of arson events occurring on holidays in the City of Toronto. These statutory holidays are often accompanied by celebration with the use of widely available pyrotechnics. The defined study period has four statutory holidays (one in each May, July, August, September). Though holidays are not weather related phenomena, the variable controls for behaviours that might be associated with holidays, such as alcohol consumption and the exposure to fireworks and like-materials. This becomes model variable HOLIDAY.

We use YEAR in the model to control for the fact that we are using longitudinal data. YEAR will help us to understand the overall trend in deliberately set fire events for the City of Toronto. We also include a time lag in our model (LAG). LAG is an autoregressive variable that controls for temporal clustering of events. Arson has serial tendencies and is therefore likely to exhibit temporal clustering (Prestemon and Butry, 2005). This lag represents the role that one day's number of arson events plays in determining the number of arson events on the next day.

Finally, we create dichotomous variables for the months in our study period, May through September. We use these in the model to understand whether some months experience arson differently than others. These become model variables MAY, JUNE, JULY and AUGUST. SEPTEMBER is the reference month in our model.

3.3.3 – Analysis

First, we illustrate the relationship between deliberately set fire events according to temperature (Figure 4). This was important to determine whether a trend between temperature and fire event activity exists. In order to accomplish this we need to control for temperature. Toronto has a continental climate where there are many days in the year that have moderate temperatures. We used all fire events (loss and no loss) and weather data for January 1998 through 2007 for this portion of the analysis. In order to control for the fact that there were more days at moderate temperatures, it was necessary to sum the number of days at given temperatures, as well as the number of events reported on days with given temperatures. The number of events was then divided by the number of days to produce an average number of events per day with specific temperatures.

We use a Poisson regression model to determine the relationship between the incidence of deliberately set fire events and excess exposure to high temperatures while controlling the other independent variables noted above. We assume a Poisson distribution of arson events per day because deliberately set fire events are discrete and rare. Poisson regression is suitable for modelling discrete events as a function of independent predictor variables. We hypothesize that heat and arson have a positive relationship, where excess exposure to heat or hot weather conditions will result in a higher than expected incidence of arson

The main-effects model used in this analysis is

$$\log(\lambda_i) = \alpha + \beta_{year}YEAR_i + \beta_{may}MAY_i + \beta_{june}JUNE_i + \beta_{july}JULY_i + \beta_{august}AUGUST_i + \beta_{heat}HEAT_i + \beta_{precip}PRECIP_i + \beta_{holiday}HOLIDAY_i + \beta_{lag}LAG_i$$

where

$\log(\lambda_i) =$	log of the dependent variables
$\alpha =$	fixed intercept
$\beta =$	coefficient of the independent variables
$i =$	date

Poisson regression assumes that events are random and independent of one another. We know that in the case of deliberately set fire events in the City of Toronto, between 1998 and 2007, there has been evidence of serial occurrences (Cherry, 2007). Serial fire setting by one individual violates the assumptions of independence. We attempt to control for the problem of temporal autocorrelation by using the lag variable above. Two-day and three-day lag variables were also included, but they were not statistically significant and therefore excluded from the final model.

Statistical modeling for this chapter was completed using SAS (SAS Institute Inc., 2009). Before completing the model, we first investigated the individual relationships between the independent variables and the dependent variables (both loss and no loss events). We added month-heat wave interaction terms to our main-effects model. The literature suggests that populations respond to heat in relative, not absolute, terms (Smoyer et al., 2000). That is to say that exposure to heat early in the warm season (i.e. May) is more likely to produce a physiological response than heat exposure later in the season, after populations have had the opportunity to adjust to warmer temperatures (Smoyer et al., 2000). Only significant interaction terms are included in the model.

3.4 – Results

The initial investigation into the application of routine activity theory and the negative affect escape model suggests that a relationship between fire events and temperature is possible. Figure 4 suggests that there is a positive association between temperature and the average number of fire events per day. The 2nd order polynomial trend line suggests a positive curvilinear relationship between arson and temperature. This positive relationship is true up to about 10-15ºC. Beyond this point the curve begins to flatten. At approximately 30ºC the relationship begins to turn negative. In an effort to answer our query regarding the relationship between deliberately set fire events and their relationship to extended heat wave conditions, we use bivariate and multivariate regression analysis. Additionally we investigated which month we should expect the greatest number of days included as part of heat wave during out study period. Based on our weather data and using Environment Canada's definition for identifying heat waves, July has the greatest number of heat wave days over the entire study period (1998-2007) (Figure 5).

3.4.1 – Bivariate Regression Results

In terms of loss fire events (Table 1), bivariate Poisson regression results indicate that YEAR, MAY, AUGUST, SEPTEMBER, and PRECIP are significant at the p=0.05 level. YEAR shows that over time, the trend in fire events resulting in monetary loss is decreasing. MAY and AUGUST have positive coefficients, supporting a significant positive relation to loss fire events. SEPTEMBER has a statistically significant negative relationship to loss fire events.

PRECIP also has a negative statistically significant relationship to loss fires, where p=0.001. JUNE, JULY, and HEAT are not statistically significant.

The bivariate Poisson regression models for no loss fire events (Table 2) show similar results to those of loss fire events. MAY, AUGUST, SEPTEMBER, and PRECIP are all statistically significant at p=0.05. MAY, AUGUST and SEPTEMBER all have negative coefficients. In comparison to loss fire events, the direction of the relationship between fire events and AUGUST changes; AUGUST has a positive relationship with loss fire events, and a negative relationship with no loss fire events. The direction relationship in MAY and SEPTEMBER remains the same for both types of events. PRECIP is statistically significant with a negative relationship to no loss fire events. The direction of this relationship is the same for both loss and no loss fire events. HEAT is not statistically significant for either type of fire event. The coefficient is a weak positive for both loss and no loss fire events.

Though not all variables explored in the univariate analysis are statistically significant, many are still included in our final model. For example, only MAY, AUGUST and SEPTEMBER produce statistically significant results in both bivariate models, but the inclusion of JUNE and JULY is also necessary to control for all months in our study period. HEAT is not statistically significant in our univariate analysis. YEAR is only significant with respect to loss fire events, however it is included in the final model because we include summer periods for a number of years (1998 through 2007). The variables included in our final regression analysis are YEAR, MAY, JUNE, JULY, AUGUST, HEAT, PRECIP, HOLIDAY, LAG and MAY*HEAT. SEPTEMBER is not included because it is the reference month for all other month variables, and the results will be compared to SEPTEMBER. The interaction terms for JULY, AUGUST, AND

SEPTEMBER with HEAT were not significant, and therefore only MAY*HEAT was included in the final regression analysis.

3.4.2 – Multivariate Regression Results

Table 3 summarizes the results of our final Poisson regression model with respect to loss fire events. The independent variables that have a statistically significant relationship (at p=0.05) with loss deliberately set fire events are: YEAR, MAY, JUNE, AUGUST, PRECIP and HOLIDAY. YEAR is highly statistically significant (p=<0.0001) with a negative coefficient. MAY, JUNE, and AUGUST each have a positive statistically significant relationship with loss fire events, relative to SEPTEMBER. PRECIP is statistically significant where p=0.0057 and has a negative coefficient. HOLIDAY is highly significant (p=<0.001) with a positive coefficient. Neither HEAT nor MAY*HEAT are significant for loss fire events. These variables are included to measure the influence of excess heat conditions on the incidence of deliberately set fire events. HEAT is almost significant at p=0.1 level (with a significance of 0.1104) and LAG is significant at p=0.1.

Table 4 summarizes the no loss fire event regression results. Fewer variables prove to be statistically significant with respect to no loss fire events. MAY, PRECIP, HOLIDAY and MAY*HEAT are significant at the p=0.05 level. No other variable are significant at p=0.1. MAY is significant with a relatively large positive coefficient, relative to SEPTEMBER. PRECIP has a negative relationship with respect to no loss fire events, as is the case with loss fire events. HOLIDAY also produces the same relationship to no loss fire events as loss fire events, with a positive coefficient.

3.5 – Discussion

We set out to explore the relationship between episodes of excess heat exposure and deliberately set fire events. More specifically, we hypothesized that with extended heat wave conditions, the incidence of deliberately set fire events would increase. Figure 4 illustrates the relationship between fire events and temperature, and suggests that increases in temperature influence increases in fire setting. Figure 4 also provides visual support for two theories highlighted in this study: routine activity theory and the negative affect escape model. Arguably, Figure 4 provides more support for routine activity theory than the negative affect escape model. The shape of the relationship in Figure 4 is curvilinear, which would suggest negative affects has a stronger relationship with fire-setting in Toronto. However, there is a more dramatic change in behaviour from cold to moderate, which suggests that changes in social behaviour are a greater driver of deliberately set fire events as opposed to aggressive responses to heat, supporting routine activity theory. A motivated offender may be willing to wait if conditions are unfavourable. Likewise, property owners maintaining their position at home do not provide an appealing environment for an offender to commit their crime, as guardianship of the property is a factor. In order for a crime to occur there must be a willing offender, a vulnerable target and a lack of guardianship (Cohen and Felson, 1979).

Given the climatic conditions in Toronto (with a large range in temperature between winter and summer), there is a weak effect of extreme heat on fire incidence, producing a curvilinear inverted-U shaped relationship. A possible explanation for why we do not see a more pronounced reduction in fire events at high temperatures is very likely due to the fact that Toronto does not get hot enough in the summer to warrant dramatic changes in behaviour or enough to cause aggressive physiological responses. However, the changes we see over all seasons suggest that residents of Toronto are not as averse to heat as they are cold. The increases in fire event activity above zero degrees are not as dramatic as below zero degrees.

Though Figure 4 illustrates the relationship we would expect to see with the negative affect escape model, the results from our regression analysis do not provide strong support for the relationship between excess exposure to heat and fire-setting behaviour. Our regression analysis, however, provides better support for routine activity theory as an explanation for arson behavior in Toronto. The multivariate analysis confirms a relationship between May fire-setting behaviour, identifying a highly significant (p=<0.0001) positive relationship. May is the beginning of the warm season in Toronto, which provides more opportunity for individuals and families to spend time outdoors. The increase in the number of daylight hours increases the amount of activity individuals can participate in outside of the home as well. The incentive to spend more time outside of the home and in contact with other individuals, results in a lack of guardianship around properties, which, according to Routine Activity Theory, is one of the factors that influences the incidence of crime (Cohen and Felson, 1979). A lack of guardianship around properties provides convenient opportunities for offenders to commit their crimes without fear of detection. The significance of MAY therefore provides support for the applicability of routine activity theory to fire-setting behaviour.

Based on the results of our regression analysis, we conclude that changing weather conditions may affect the incidence of arson in Toronto. Though we are only interested in the relationship between arson and heat wave conditions, one finding from our regression analysis supports that routine activity theory is applicable to fire-setting behaviour in Toronto. We considered the months May through September in our final analysis, using September as the reference month. Relative to September, loss fire events are significantly more likely to occur in

May, June, and August. Loss fire events are more often those targeted specifically by individuals (largely classified as arson by the TFD). Conditions are conducive to fire setting during the warm season, which can influence offenders with the hope that their fires will have a large impact. In the case of no loss fire events, they are more likely to occur in May relative to September. No other month is significant. June and August experience approximately the same number of heat wave events, with May and September experiencing the least. Changes in temperature produce changes in behaviour and routine activities, which may be responsible for the significance of May in our regression model. The literature has suggested that individuals respond to heat in relative, not absolute terms (Smoyer et al., 2000). Exposure to elevated temperatures, but not necessarily excessively hot temperature, can result in heightened physiological responses relative to those later in the summer season, before individuals have a chance to adapt to hot temperatures. HEAT is not significant at $p=0.05$ for either loss or no loss events, suggesting that the relative change in temperature is a more important factor in considering response to changes in season.

If we consider the interaction between May and heat waves, we find that it is only significant for no loss fire events. The significance of this interaction provides support that individuals respond to heat in relative terms. In this case, individuals have not yet had a chance to adapt to warmer temperatures, and the resulting fluctuation in body temperature from cold to warm can affect the hormonal responses related to aggressive behaviour. The significance of this relationship for only no loss events also supports that premeditated fire events (often those resulting in loss) are less affected by temperature. In other words, heat wave conditions early in the season are positive predictors for fire events resulting from spontaneous decision making on the part of the offender, as no loss events are often those resulting from vandalism. Though the interaction between May and heat is not significant for loss fire events, May alone is, and heat waves approaching significance at p=0.1. This suggests that though loss fire events are no more likely to occur during heat waves in May, they are more like to occur in the month of May or during periods of excess exposure to heat.

Though precipitation and holidays are not variables used to answer our research question, they are possible confounding factors influencing the relationship between arson and heat exposure. Wet weather produces a wet environment, making lighting and spreading fire more difficult. Our results are consistent with this intuition. However, we cannot know whether rain deters fire setting behaviour, or whether the offender is unsuccessful in carrying out their crime. We observe the same relationship for no loss and loss fire events. Similar to these findings, Corcoran et al. (2009) concluded that the incidence of suspicious fires was greater when conditions were dry, suggesting that a perpetrator would rationalize their behaviour in order for the crime to have greatest impact.

Holidays are highly statistically significant (p=<0.0001) for both loss and no loss fire events. There are four holidays occurring during the months in our study period (May through September). Each of these events is associated with some form of celebration, and generally includes the use of widely available fireworks. It is difficult to conclude whether it is the responsibility of these widely available pyrotechnics that contribute to the incidence of deliberately set fire events, or whether it is the additional free time having been given an additional day free of obligation. The literature has suggested that most violent crime and criminal offences occur in later hours of the day, during individual free time (Ceccato, 2005). Ceccato (2005) also said that longer days put individuals into contact for longer periods of time, which increases the exposure of target populations to potential offenders. Holidays offer individuals significantly more free time, which potentially puts them at risk on such days. A greater amount of free time, and the opportunity to spend this time away from the home, is consistent with routine activity theory.

The literature suggests that criminal events tend to cluster both spatially and temporally. LAG is a variable included in our model to control for serial or 'copycat' behaviour by offenders. Copycat crime refers to criminal events committed by separate offenders but affect a similar group or community, just as serial crime would. The near-repeat hypothesis suggests that a burgled home in one neighbourhood increases the likelihood that other homes in the same neighbourhood have a higher probability of being burgled soon after the initial event than those in other neighbourhoods (Townsley et al., 2003). If the LAG were statistically significant, it would suggest that fire events on one day have an influence on the following days events. However, because LAG is not significant in either model, it leads us to conclude that the events of one day have little effect on the events of subsequent days. Though it is understood that Toronto has experience serial fire setting behaviour during our study period (Cherry, 2007), the lack of significance of the LAG variable suggests that fire events are not influenced at the daily level. We examined the effect of longer lags in our model, but these were also not significant.

3.5.1 Contributions

The effect of temperature on arson rates has not previously been explored in the literature. Our initial contribution is to the body of knowledge with respect to arson, and specifically to the relationship arson has with excessive heat. Few studies have had appropriate access to detailed weather data and daily fire incident data in order to successfully explore the influence of weather conditions on fire incidence at the local level, and daily time-scales (Corcoran et al. 2009). This study satisfies this identified gap in the literature by using disaggregated fire event data for the City of Toronto, while considering a specific type of weather event (heat wave).

Our study also differs from others in two ways, with particular focus on Ceccato (2005) and Corcoran et al., (2009). First, we examine a region where the climatic extremes are very different from those in the previously mentioned studies. Toronto experiences average daily temperatures ranging from about -4.5°C in January to 22°C in July (ambient temperature, not including wind-chill or humidex factors) (Toronto's Climate, 2011). In South East Queensland, Australia the temperature ranges are approximately 20°C through 30°C (Brisbane and South East Queensland, Australia, 2011), and in Sao Paulo, Brazil about 16°C through 22°C, on average (A Guide to Sao Paulo, 2007). The range in temperature in Toronto is much greater than in Sao Paulo and Queensland. Secondly, we are focusing our attention deliberately set fire events, not violent crime or the general incidence of fire. Depending on motive arson can have violent motivations, however it is more than just a general fire event caused by accident; it is one carried out intentionally by an individual.

We also hope to contribute knowledge to the Toronto Fire Services. Having a better understanding of the processes that drive crime and criminal activity will help produce more effective and efficient emergency services. Additional knowledge of some of the mechanisms that drive arson and fire setting behaviour will aid in planning and allocation of services based on acute weather events, which can be forecasted days in advance (such as excess heat, or precipitation). Calendar events (holidays) are also known ahead of time. Allocating extra resources on holidays, which have shown to be significant predictors of fire events, can also prevent unnecessary damages. More efficient scheduling can improve response time and prevent a considerable amount of damage. It may also improve the ability of the emergency services to apprehend those responsible for the event, as they may still be in close proximity to the fire.

3.5.2 Limitations

There are a number of limitations to our study. The most important limitation is the lack of consistent weather data. We have 25 years worth of fire incident data for the City of Toronto. Our study was limited to 10 years (1998-2007) because the source of weather data available for the City was incomplete. There were gaps in temperature measurements for some days prior to 1998. In order to appropriately complete this study, it was necessary for us to have consistent temperature and humidex measurements for consecutive days, in order to develop a variable identifying heat wave conditions.

Another limitation of this study is the definition of a heat wave. Formally, we use the definition for heat waves defined by Environment Canada, three consecutive days in excess of 32ºC using apparent temperature (Humidex). However, we subjectively modified this definition in order to create a variable describing extended heat wave condition. We accomplished this by allowing for two days between heat waves to be included, effectively creating one heat wave, as well as adding a one-day lag to all heat waves. It can be argued that the two-day allowance between heat waves is too much, or too little. Additionally, despite the fact that this is the temperature regarded by Environment Canada as the lower cut-off for identifying heat wave conditions, we feel that it may be too high for the model to be able to identify a relationship between excessive heat and fire-setting behaviour. The weather station begins to identify humid conditions beginning at 27ºC. Perhaps if we were to lower the threshold for HEAT our regression results would support our hypothesis.

Further, we know that individuals respond to heat in relative, not absolute, terms. Relative physiological responses by individuals to heat can vary from one individual to another, and the psychological influence of the physiological effects will also vary. Not every individual will be influenced by heat as easily as others, and that influence may not always result in aggression or aggressive behaviour. Additionally, not all aggressive responses will result in fire setting behaviour.

Finally, in order to define the period for which we will monitor for heat waves, we turned to Toronto Public Health (Heat Alerts, 2011). The City of Toronto monitors for excessive heat between May 15th and September 30th of every year in order to provide warnings to the public for health related concerns. We used this period to identify heat wave conditions as they may influence fire-setting behaviour. Because we only use half of the month of May in our analysis, it may impact the quality of our findings, as the month is not entirely comparable to the other four included in our analysis.

3.6 – Conclusion

Overall, we are not able to find adequate evidence to support a relationship between deliberately set fire events and heat wave conditions. However, for no loss fire events, heat waves early in the warm season (May) have proved to be a significant predictor of fire events, which can be explained by relative physiological responses by individuals to changes in temperature. For loss fire events, the general incidence of heat waves has a weak statistically significant relationship, and vaguely suggests that fire events resulting in loss are likely to occur during heat waves. We were better able to find support that changes in routine activities by individuals resulting from changing weather conditions have a stronger influence on fire-setting behaviour in Toronto.

Future research can investigate the combination of weather factors and how they influence crime in general, and arson in particular. This type of knowledge can help aid the staffing and efficiency of fire and emergency service personnel in order to improve quality of service and response times. Future work might also consider including various other weather factors to build upon this study. We were particularly interested in excessive exposure to heat and its' influence of fire setting behaviour. The literature has shown that short-term weather conditions have an effect, both physiologically and psychologically, on individuals and groups. A deeper understanding of this influence will aid in preparing populations as climates continue to grow warmer.

3.7 – Tables and Figures

Figure 1: Shapes illustrating possible relationships between temperature and aggressive behaviour

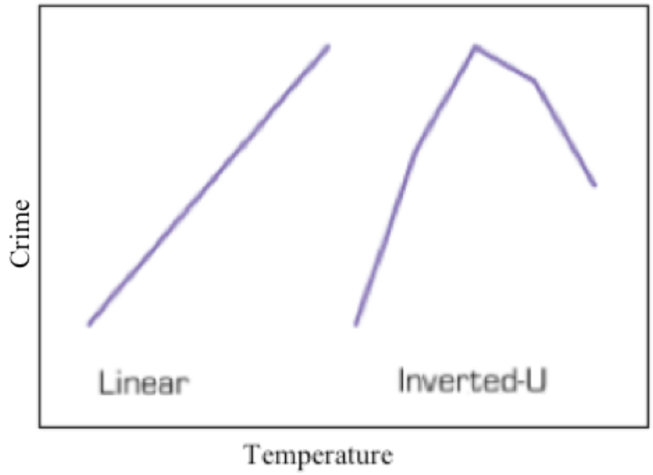


Figure 2: Number of no loss fire events by day classified by possible cause

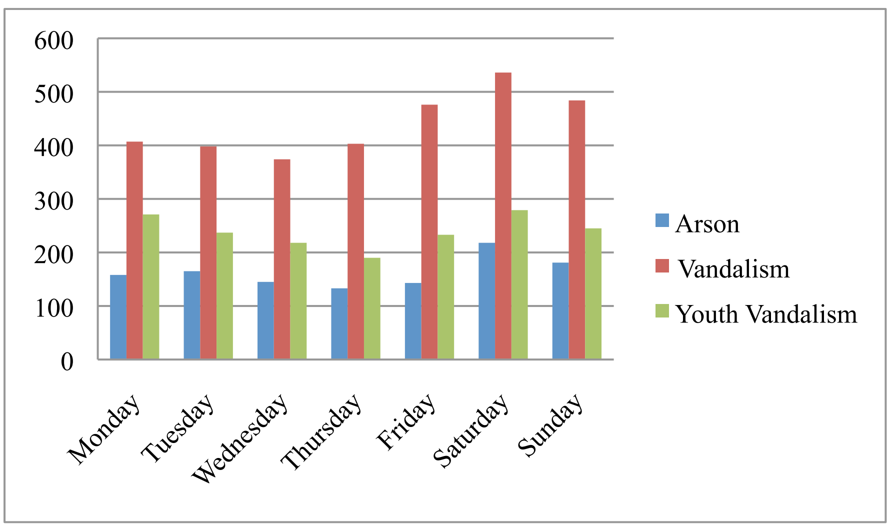


Figure 3: Number of loss fire events by day classified by possible cause.

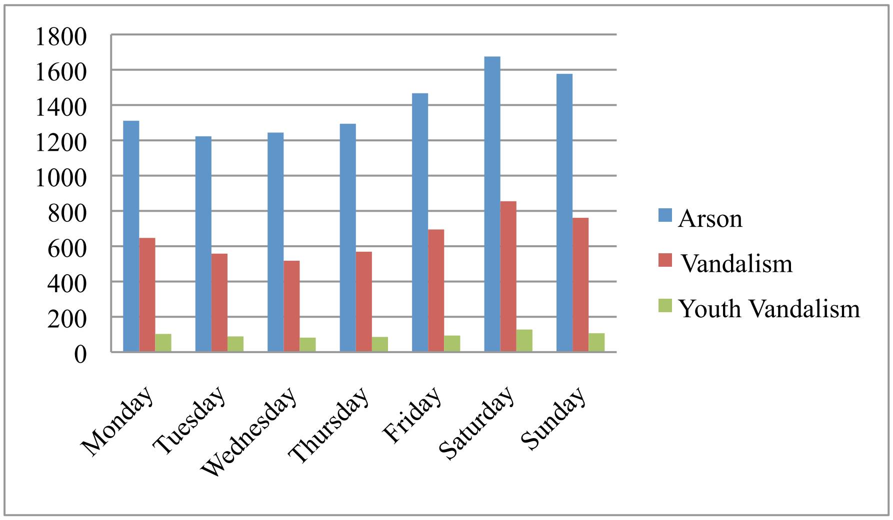


Figure 4: Average number of fire events (all events) per day, at a given temperature (ambient)

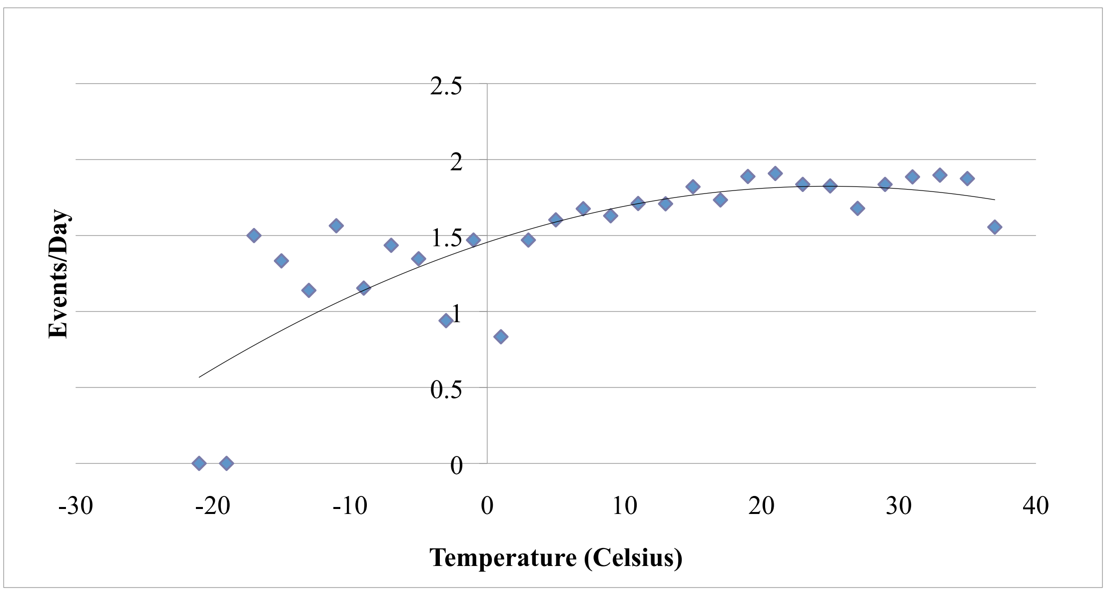


TABLE 1: Univariate Results, Loss Events

Dependent	Independent	Estimate	Significance
Loss Fire Events	YEAR	-0.0241	<.0001
	MAY	0.2303	<.0001
	JUNE	-0.041	0.3241
	JULY	-0.0638	0.1242
	AUGUST	0.0997	0.0138
	SEPT	-0.1668	0.0002
	HEAT	0.0556	0.1344
	PRECIP	-0.0088	0.0143

TABLE 2: Univariate Results, No Loss Events

Dependent	Independent	Estimate	Significance
No Los Fire Events	YEAR	-0.0057	0.2511
	MAY	0.3434	<.0001
	JUNE	-0.0543	0.2391
	JULY	0.0051	0.9078
	AUGUST	-0.1001	0.0287
	SEPT	-0.1313	0.0066
	HEAT	0.0289	0.4737
	PRECIP	-0.0173	0.0001

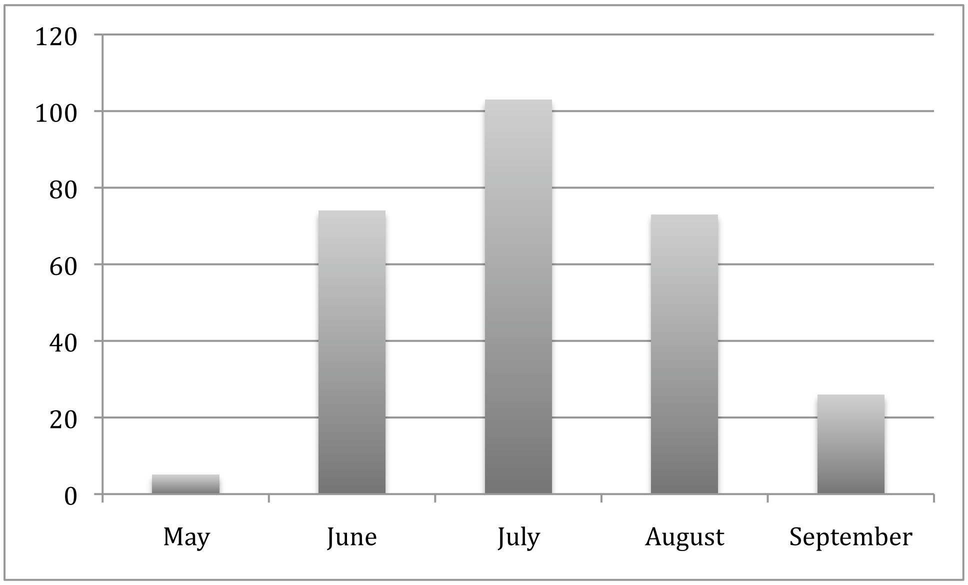
TABLE 3: Model 1, Loss Fire Regression Results

Dependent	Independent	Estimate	Significance
Loss Fire Events	INTERCEPT	0.8547	<.0001
	YEAR	-0.026	<.0001
	MAY	0.2981	<.0001
	JUNE	0.1101	0.0466
	JULY	0.0572	0.3057
	AUGUST	0.1786	0.0011
	HEAT	0.0645	0.1104
	PRECIP	-0.01	0.0057
	HOLIDAY	0.487	<.0001
	LAG	-0.0179	0.0724
	MAY×HEAT	0.0998	0.5158

Table 4: Model 2, No Loss Fire Regression Results

Dependent	Independent	Estimate	Significance
No Loss Fire Events	INTERCEPT	0.6984	<.0001
	YEAR	-0.0054	0.2784
	MAY	0.3357	<.0001
	JUNE	0.0932	0.1269
	JULY	0.0921	0.1231
	AUGUST	0.026	0.6694
	HEAT	0.0303	0.4936
	PRECIP	-0.0191	<.0001
	HOLIDAY	0.6638	<.0001
	LAG	-0.0009	0.9337
	MAY×HEAT	0.3041	0.0289

Figure 5: Number of heat wave days per month over study period



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CHAPTER FOUR: Conclusion

4.1 – Summary and Conclusion

This thesis uses multivariate regression analysis in order to explore the relationship between the anthropogenic environment and the physical environment on the incidence of deliberate fire-setting behaviour in Toronto, Canada. We sought to answer two questions:

I. Does street network permeability influence the incidence of fire-setting behaviour in Toronto?

II. Does exposure to extended episodes of heat influence the incidence of fire-setting behaviour in Toronto?

In the case of our first objective, we hypothesized that neighbourhoods with high levels of street network permeability would experience a higher incidence of arson. For both loss and no loss fire events there appears to be a relationship between permeability and the rate of fire incidence in Toronto neighbourhoods. Though permeability in itself was not statistically significant, the density of laneways, alleys or trails in a neighbourhood have a positive and statistically significant relationship with arson. Figures 7, 8 and 9 of Chapter 2 show the density of laneways and with the density of fire events across the city, illustrating the results of our regression analysis, where the concentration of fire events is spatially very similar to the concentration of highly accessible routes. We cannot determine the causal relationship between laneway density and the incidence of deliberately set fire events, as we may not have considered all factors. We included many socioeconomic variables to control for factors previously considered throughout the literature, including income status, family structure, housing value and housing density. We have not, however, included variables that describe the concentration of various types of activity occurring in Toronto's neighbourhoods, specifically recreational activities. Future research might consider including this in some capacity.

In the case of our second objective, we hypothesized that the incidence of fire-setting behaviour would increase with exposure to extended period of heat based on the Negative Affect Escape Model and Routine Activity Theory. What we were able to conclude from our regression analysis is that extended heat wave conditions in Toronto do not positively influence the incidence of arson. Heat is only relevant for particular times of year. Extended period of heat in May are associated with higher rates of arson, suggesting that heat aggression most contributes to criminal fire setting before individuals have the opportunity to adapt to warmer temperatures. More significant predictors of fire-setting behaviour in Toronto include precipitation and statutory holidays. Precipitation is intuitively a factor in determining the impact of fire. The causal relationship may not be clear however. Perhaps the offender was not successful in starting a fire producing a significant impact, or the fire was extinguished by falling rain. Conversely, the offender may have made the conscious decision to wait for more favourable conditions. The significance of holidays in predicting fire setting behaviour may relate to the activities individuals take part in on such days, including the consumption of alcohol and the use of widely-available fireworks. The significance of holidays can also speak to the notion that criminal activity occurs during individual free-time, where holidays occur four times throughout the summer and allow individuals an extra day free of obligation.

Future research might consider various perspectives in developing a more thorough understanding of the processes that drive arson, if not specifically with respect to arson of heat related aggression or permeability, than more generally with arson itself. Because arson has the capacity of being driven by violence or for the sake of property crime, it cannot be denied that it's consequences are not far-reaching. Given the lack of focus on arson throughout the literature, both in an international or Canadian context, there is a significant amount of opportunity to contribute knowledge both to literature and communities alike.