Static or shifting: Quantifying the relationship between income and green space in urban Halifax, Nova Scotia (2001-2016)

Environmental Science Undergraduate Honours Thesis

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April 2019

Table of Contents

Table of Figures

List of Tables

Acknowledgements

First, I would like to express my gratitude for my supervisor, Dr. Christopher Greene, for his continual guidance, knowledge, and support throughout this year. I would also like to thank the honours course coordinator, Dr. Tarah Wright, for her kind words of encouragement and feedback throughout the entirety of this process. I also thank Dr. Daniel Rainham for sharing his knowledge during various brainstorming meetings during the past semester. Finally, I thank my peers for their endless encouragement and moral support.

Abstract

Urbanization can have damaging effects on many cities by exacerbating existing social and environmental inequalities. Income inequality can have implications on urban environments particularly if it leads to strong physical polarization of income groups within the physical limits of a city. As cities become increasingly polarized with respect to income, there is evidence to suggest the inequitable distribution of environmental amenities (e.g., urban forest, lakes etc.) may follow. This outcome is an important sustainability issue given the known environmental and health benefits associated with green space access. In this study, the spatial distribution of median household income in urban Halifax was evaluated using local indicators of spatial autocorrelation (LISA) to estimate the degree of polarization of income groups from 2001-2016. Over 15-years, spatially distinct regions in Halifax were identified that have remained predominately high- and low-income, with other areas emerging with the expansion of high-income into new suburban developments. In this study PlanetScope (4-band VIS-NIR) satellite imagery was used to quantify *% tree canopy* and *% short vegetation* features which are important aspects of green space. Tree canopy was unevenly distributed with low-income neighbourhoods having less availability during the 15-year study-period. The results of this study suggest there is some relationship between income and distribution of green space in Halifax.

1.0 Introduction

1.1 Motivation

While global human population growth rates are on the decline, there has been a shift from rural to urban regions in greater numbers as the Global South continues to undergo rapid urbanization (United Nations, 2018a). Currently 55% of the world's population resides in urban regions; by 2050 it is predicted that this percentage will rise to 68% (United Nations, 2018a). While there are benefits to urbanization, rapid urbanization can also carry negative implications for cities due to the constant demand for development, public amenities, and housing (Fillion, Bunting, Pavlic & Langlois, 2010). For example, critical agricultural land providing sustenance for human populations is often developed to provide infrastructure and living space for expanding populations (Alig, Kline & Lichtenstein, 2004). In 2001, roughly half of Canada's twelve-thousand square kilometers of urban areas was prime agricultural land which had been subsumed by growing cities (Hofmann, 2001). Urban environments are complex due to the interconnection of social structures, economics, ecology, and biophysical factors (Heynen, Perkins & Roy, 2006). The complexity of dense urban environments leads to a common problem related to distributional inequalities, especially in regards to the provision of income and environmental amenities (Erkip, 1997; Bunting & Filion, 2001; Heynen et al., 2006; Glaeser et al., 2009). Internationally, income inequality has emerged as an important topic for many countries within the Organisation for Economic Co-operation and Development (OECD) after it was established that most countries, such as the United States and United Kingdom, have high levels of inequality in their cities (OECD, 2014; Breau, Shin & Burkhart, 2018). Inequalities within cities can also directly influence changes to the urban form (i.e., the physical and non-physical characteristics) leading to a city that has regions that experience intensification (Filion et al., 2010), low-density sprawl (Delmelle, Zhou & Thill, 2014), and polarization (Zwiers, Kleinhans & van Ham, 2015) all within different parts of the same city. More frequently, cities are becoming increasingly polarized in relation to income, education, and political views (Glaeser, Resseger & Tobio, 2009; Zwiers et al., 2015). In Canadian cities, income polarization appears to be increasing since the 1970s, but at differing rates (Walks, 2013).

The collective trends of income polarization are important because, in many cases, the unequal distribution of environmental amenities has been tied to socioeconomic status; in other words higher income earners often have disproportionately greater political power and economic gain (Erkip, 1997; Banting & Myles, 2013). Many studies often look at underlying socioeconomic variables, in an effort to understand the factors that may be related to environmental amenity distribution (Berland et al., 2015; Kedron, 2016). Within the literature, median household income is frequently used to evaluate inequality regarding the distribution of amenities within urban regions (e.g., Shanahan, Lin, Gaston, Bush & Fuller, 2014; Breau, Shin & Burkhart, 2018). Many studies have suggested that urbanization in Canadian cities has been associated with inequalities when it comes to availability of green space (Barbosa et al., 2007; Astell-Burt et al., 2014; Wolch et al., 2014). This thesis quantifies historical income polarization over a 15-year timespan (from 2001 to 2016) and its relationship with existing green space within Halifax, Nova Scotia. The results of the study will demonstrate that due to income polarization there is an uneven availability of green space to Halifax residents.

1.2 Background

More than half of global human populations reside in urban areas, as the societal effects of industrialization favour urban living away from a historically agrarian dominated society in rural regions (Scott, 1986; United Nations, 2018a). It is important to note that rates of urbanization are not equal globally; countries in the Global South in the past twenty years have experienced a more rapid increase in urbanization in comparison to North America (United

Nations, 2018b). There are many opportunities associated with dense urban living including accessibility to health care facilities (United Nations, 2018a), but often urban areas become void of features from the natural environment (Vemuria et al., 2011).

The compounding effect of urbanization and heterogeneity of the urban environment can lead to the polarization of income groups within a city (Walks, 2013; Greene, Robinson & Millward, 2018). Income polarization refers to the spatial divergence of high- and low-income groups, and in some cases the decline of the middle-class (Dinca-Panaitescu & Walks, 2015; Breau et al., 2018). Therefore, a city with income polarization would have geographically distinct neighbourhoods of high- and low-income.

Green space has various definitions throughout the literature, however a strong definition is provided by the Environmental Protection Agency (EPA) stating that green space is "land that is partly or completely covered with grass, trees, shrubs, or other vegetation" (Environmental Protection Agency, 2017, para. 1). Thus, green space is undeveloped naturalized areas within an urban environment such as urban parks, community gardens, and greenways. A considerable amount of research has shown green space contributes to the economic value of land, societal benefits, environmental integrity, and human well-being (Barbosa et al., 2007; Kabisch & Haase, 2014; Anguluri & Narayanan, 2017).

Both income polarization and green space have been widely studied from a Canadian perspective (e.g., Walks, 2013, Duinker et al., 2015), but less frequently are these topics studied together (e.g., Pham et al., 2012; Greene et al., 2018). In many Canadian cities, such as Toronto, Montreal, Vancouver, and Calgary, income polarization has been identified and shown to be increasing (Walks, 2013; Breau et al., 2018). More recent studies have started to expand beyond more basic concepts of inequality and examine green space from the more complex concept of environmental justice (Erkip, 1997; Heynen et al., 2006). Income has become a primary focus in these studies because this attribute has been identified to have an influence on the abundance of green space (e.g., Barbosa et al., 2007, Shanahan et al., 2014) and because higher income neighbourhoods tend to have greater economic and political power (Heynen et al., 2006). Simultaneously, green space has been found to be under-supplied or lacking in lower income neighbourhoods (Wolch et al., 2014). Furthermore, there has been a growing interest in the literature to determine whether income has an influence on availability of green space (Barbosa et al., 2007; Wüstemann et al., 2017). This study will provide further insight for current research of green space distributional inequalities by incorporating the spatial distribution of income.

1.3 Summary of Literature

There is a growing body of literature discussing income polarization in Canada, with a suite of studies focused on larger urban centers such as Toronto, Montreal, and Vancouver (MacLachlan & Sawada, 1997; Hulchanski, 2010; Walks, 2013; Breau et al. 2018). Walks (2013) and Breau et al. (2018) provided evidence of strong to moderate income polarization in most large Canadian cities. One seminal study considering income polarization recognized that there was increased income polarization over a 25-year period (1980-2005) in Toronto (Hulchanski, 2010).

While there appears to be a data gap regarding income polarization in mid-sized Canadian cities, studies in mid-sized cities in the United States such as Milwaukee, Wisconsin have shown evidence of income polarization (Heynen et al., 2006). Preliminary research in Halifax, a mid-sized Canadian city with a population of approximately 400,000 people in 2016 (Statistics Canada, 2017), has started to examine income inequality and polarization (Prouse et al., 2014a; Prouse et al., 2014b; Grant & Gregory, 2016; Ramos & McNabb, 2018). Initial studies (e.g., Prouse et al., 2014a; Ramos & MacNabb, 2018) in Halifax have found weak evidence of income polarization, however, since Halifax is a growing city it can be postulated that this location could align with national trends of high-income polarization in the near future (Prouse et al., 2014a; Ramos & MacNabb, 2018). Weak evidence of income polarization could be related to various factors including the delineation of the study area as the Halifax Regional Municipality (HRM) and/or the geographic unit of analysis. Using the HRM as a study area may have contributed to the detection of weak income polarization due to amalgamation in 1996 (Prouse et al., 2014a). Several municipalities with mixed urban form were made into one unit, and as such a large proportion of the geographic extent is predominantly classified as rural (City of Halifax, 2014b). An area of improvement indicated by Prouse et al. (2014b) is to use a geographic unit of analysis that is a finer scale (i.e., each unit represents a smaller geographic area) like a dissemination area (DA) rather than the larger census tracts (CT). Furthermore, to build upon studies conducted in Halifax, new methodologies including local indicators of spatial autocorrelation (LISA), are used to conclude whether there is evidence of income polarization in Halifax. A LISA incorporates the influence of spatial dependency with the goal of identifying geographically distinct regions of high- and low-income (i.e., income polarization) in Halifax.

With regards to green space, many green space inequality studies are conducted in the United States (Dai, 2011; Vemuri et al., 2011; Schwarz et al., 2015), Europe (Barbosa et al., 2007; Wüstemann et al., 2017), and Australia (Astell-Burt et al., 2014). Several studies have demonstrated the relationship between income and the availability of green space including the urban forest, where individuals with high-income had greater access to the urban forest in Milwaukee (e.g., Heynen et al., 2006) and those with low-income had less access to green space in Australia (e.g., Astell-Burt et al., 2014). While few studies have analyzed the relationship between income polarization and green space in Canada, even fewer studies have examined the relationship in mid-sized cities in Canada (Harvey, 2014). This thesis will add to the body of literature regarding the relationship between distributional inequalities of income and green space.

1.4 Introduction of Study

The objective of this study is to detect historical income polarization over a 15-year period (2001-2016) to determine whether it is tightly coupled to existing green space within urban Halifax, Nova Scotia. Since there is evidence of weak income polarization in Halifax (Ramos & MacNabb, 2018), it is possible that incorporating recently established methodology in income polarization studies (see Breau et al., 2018 and Greene et al., 2018) will further quantify income inequality in Halifax. Using similar techniques as Greene et al. (2018), median household income (MHI) is tested to determine whether there has been polarization over a fifteen-year timespan from 2001 to 2016. If there is income polarization, this study will then test the strength and significance of relationship with existing green space in order to detect distributional inequalities. From this point on, when referring to green space it will include two distinct entities of land cover including tree canopy and short vegetation. These categories of green space will be operationalized by using *% tree canopy* and *% short vegetation* as indicators of fractional coverage (or percent cover) of green space.

Research Question:

Is there detectable income polarization in urban Halifax, Nova Scotia? If so, does the present pattern of green space also exhibit a strong correlation with income?

Hypotheses:

a. There is income polarization in the Halifax Regional Municipality over a 15-year period (2001-2016).
b. If this evidence of a: there is a spatial correlation between income polarization and green space in the Halifax Regional Municipality.

The spatial limits of this study were delineated based on a population density criterion of 400 or more people per km^2 as defined by Statistics Canada's definition of an urban area (Statistics Canada, 2011). This longitudinal analysis will evaluate the spatial polarization of median household income from 2001 to 2016 using Canadian census data at five-year intervals. A cross-sectional snapshot of green space will establish if there is a relationship with income polarization.

1.5 Summary of Approach

To address this research question and subsequent hypotheses, local indicators of spatial autocorrelation (or LISA) were applied to test the relationship between median household income (MHI) and green space at the dissemination area (DA) with the use of geographic information systems software (GIS) specifically ESRI's ArcGIS™. To quantify a relationship between MHI and green space variables, the DA will be used as a geographic unit of analysis to which Statistics Canada uses to disseminate MHI data collected by the Canadian census (Statistics Canada, 2015a). A bivariate Moran's I test was used to test temporal pairs of MHI at five-year intervals throughout the fifteen years to detect areas remaining consistently high- and low-income. Classified remotely sensed imagery (PlanetScope 4-band VIS-NIR) of urban Halifax was then evaluated to identify and aggregate green space (e.g., tree canopy and short vegetation) to the DA level of geography. To quantify the relationship between income polarization and green space, a LISA was utilized to detect significant similar clusters at the DA level of high- and low-income polarization and green space with the use of ESRI's ArcGIS (e.g., ArcMap™). For example, the LISA finds clusters of low income and low green space. The overall objective of this thesis is to identify the historic polarization of income over fifteen years (2001-2016) in relation to existing green space within urban Halifax, Nova Scotia.

2.0 Literature Review

This literature review provides an overview of research regarding income polarization and green space in urban environments. This review focused on recent primary research with a North American focus, however, studies examining cities in Australia and Europe were also considered. Relevant literature was identified from several databases, including: Scopus and Environment Complete. Research articles were identified in a range of publications including *Landscape and Urban Planning*, *Canadian Geographer,* and *Urban Forestry and Urban Greening*. This literature review takes the following approach: first, inequalities brought forth by urbanization are addressed. Then, the value and importance in the spatial distribution of green space within the urban environment are explored. Income polarization is given a global, national and municipal context within Canada. Further review of literature focuses on using these concepts in application for Halifax, Nova Scotia. Finally, literature identifying the relationship between income polarization and green space is presented. During this review, key knowledge gaps are identified arising from each of the applicable research fields. The review identifies and discusses relevant topics within the primary literature regarding income polarization and green space in urban environments.

2.1 Urbanization and inequality

Rapid development in cities has led to structural changes in the urban form such as intensification, sprawl, and polarization (Filion et al., 2010; Delmelle et al., 2014; Zwiers et al., 2015). Growth of global human populations puts pressure on the urban environment and infrastructure due to increased demand for limited natural resources and space (Alig et al., 2004; Newman, 2006). Several studies have suggested that the urban form of cities is being decentralized as populations sprawl outwards towards suburban communities (Filion et al., 2010; Delmelle et al., 2014). Decentralization is supported by the convergence hypothesis proposed by

Filion et al. (2010), stating that cities tend to follow similar trends of sprawl following periods of rapid development of low-density, vehicle dominated cities. On a regional-scale, some areas within a city experience intensified population density despite showing trends of sprawl and decentralization (Filion et al., 2010). In an analysis of neighbourhoods within four Dutch cities, there was socio-spatial polarization of employment, education, and income within each city center (Zwiers et al., 2015). As a result of urbanization, urban forms of cities are changing causing regions to become intensified, sprawled, and polarized (Filion et al., 2010; Delmelle et al., 2014; Zwiers et al., 2015).

In urban environments, inequalities occur frequently some of which include sociodemographic, biophysical, and economic inequalities (Bunting & Filion, 2001; Luck, Smallbone & O'Brien, 2009; Beach, 2016). Several studies have demonstrated urban sociodemographic inequalities pertain to class, income, and race/ethnicity (Bunting & Filion, 2001; Walks & Bourne, 2006). A common example of high income inequality is Manhattan because it exhibits nearly double the level of inequality present in suburban Chicago (Glaeser et al., 2009). Patterns of vegetation cover vary within urban environments partially due to underlying biophysical characteristics influencing vegetation distribution (Luck et al., 2009). Overall, inequalities are commonly present in urban regions affecting social aspects, demography, the biophysical environment, and economy within a city (Bunting & Filion, 2001; Luck et al., 2009; Beach, 2016).

2.2 Income polarization in Canada

The identification of income polarization at international, national, and municipal levels has changed since the 1970s due to development of economic and spatial detection methodologies (Walks, 2013). Initial studies in the field of income polarization focused primarily on income inequality and polarization at the international level (Walks, 2013; Boulant et al., 2016). The majority of Organisation for Economic Co-operation and Development (OECD) countries show increasing trends of inequality and polarization (Breau et al., 2018). In Canada, Bourne (1989) was one of the first researchers to identify income polarization at the municipal-level within 27 Canadian cities from 1971 to 1981. Preliminary studies of income inequality in economics and geography have often used the Gini coefficient to describe growing income inequalities and polarization (Bourne, 1989; MacLachlan & Sawada, 1997). The Gini coefficient is an economic statistical measure used to measure income inequality by expressing deviation of income from a hypothetical equal distribution of income (OECD, n.d.). Using the Gini coefficient, MacLachlan & Sawada (1997) identified increasing income inequality in cities throughout North America. Despite being frequently used in income inequality studies in the 1980s and 1990s, there are many weaknesses of the Gini coefficient to detect polarization, given its inability to detect inequalities that do not pertain to income (de Maio, 2007). Limitations of the Gini coefficient led to other forms of inequality detection including Hulchanski's (2010) study of income polarization in Toronto, Ontario. Hulchanski (2010) was one of the first researchers to visually represent income polarization at the neighbourhood level (using the census tract) in Canada over a period of time from 1980 to 2005. However, a weakness associated with previous measures of income polarization is that they did not incorporate spatial dependency leading to the use of local indicators of spatial autocorrelation (i.e., LISA). A LISA detects income polarization at the neighbourhood level, the strength of which is that it incorporates spatial distribution and dependency of variables (Breau et al., 2018). A LISA is a spatial analytical technique, developed to be used in conjunction to geographic information systems (GIS), that visually quantifies the extent of significant clusters of a variable (Anselin, 1995). A LISA identifies areas (high-high and low-low) of positive spatial autocorrelation meaning variables with similar values are clustered in space (Anselin, 1995). Due to the strength of these spatial analytical tools, this study intends to use the novel methodological approaches used by Breau et al. (2018) and Greene et al. (2018). The economic and spatial methodology used to identify income polarization has progressed from the 1970s to incorporate spatial analytical techniques such as local indicators of spatial autocorrelation (Walks, 2013).

Canadian trends suggest sociodemographic inequalities have become expressed in the spatial polarization of income since the 1970s (Beach, 2016). In his analysis of income in Canadian Metropolitan Areas, Walks (2013) suggested that polarization of income at the household and neighbourhood level was increasing from 1970 to 2005. Increasing income polarization is supported by evidence from Toronto where there is an indication of increasing and decreasing income levels in separate distinct regions in the city (Hulchanski, 2010). Similarly, Vancouver showed strong trends of increasing income polarization expressed as a gradient between low and high-income neighbourhoods (Breau et al., 2018). Montreal also has a trend of income polarization, although in comparison to Toronto and Vancouver it has an overall weak trend (Rose & Twigge-Molecey, 2017). Since the 1970s, Canada has experienced an increase in income polarization in large metropolitan areas (Beach, 2016).

More recently, research has commenced on income polarization in Halifax, Nova Scotia (Prouse et al., 2014a; Ramos & MacNabb, 2018). In Halifax, early studies of income polarization used Hulchanski's (2014) 'Three Cities' model as a basis for detecting whether income polarization was present (Prouse et al., 2014a). The results of this study were relatively inconclusive indicating there was not strong evidence of income polarization (Prouse et al., 2014a). Ramos & MacNabb (2018) further described the results, stating that there are weak trends of income polarization within Halifax. Improvements in existing income polarization studies, therefore include, further spatial analytical techniques to detect trends of income polarization (Breau et al., 2018). Despite inconclusive results in this particular Halifax study, subsequent research by Prouse et al. (2014b) suggested that earlier inconclusive results may be related to their use of a coarser geographic unit (e.g., census tract), and suggested that future research should use a finer scale (e.g., dissemination areas). Therefore, recent literature has commenced regarding the examination of income polarization in Halifax, Nova Scotia (Prouse et al., 2014a; Ramos & MacNabb, 2018).

2.3 Value and distribution of green spaces

Green spaces within the urban environment provide a plethora of ecosystem services including air filtration (Nowak et al., 2006), microclimate regulation (Bouland & Hunhammar, 1999), and carbon sequestration (Nowak & Crane, 2002; Mexia et al., 2018). Air can be filtrated by vegetative biological processes that are able to filter pollutants and particulate matter produced from anthropogenic activity (Boland & Hunhammar, 1999; Nowak et al., 2006; Wolch et al., 2014). Nowak et al. (2006) used a model to predict total anthropogenic pollutants (e.g., ozone, sulphur dioxide, nitrogen dioxide, and particulate matter) removed by the urban forest in the continental United States and estimated 711,300 tonnes of pollutants are removed annually. Microclimate regulation is the capability of natural ecosystems to maintain temperature and climate in urban environments (Bolund & Hunhammar, 1999). Often, urban environments are significantly warmer than surrounding regions due to the production of anthropogenic heat from vehicles and heat absorbing materials (Bolund & Hunhammar, 1999). For example, the abundance of vegetation in rural Stockholm has resulted in an annual temperature that is 0.6°C lower than downtown Stockholm (Bolund & Hunhammar, 1999). Several studies, for instance Nowak et al. (2002) and Mexia et al. (2018), have conducted studies to measure the capability of urban forests and vegetation to sequester carbon dioxide. Abundance and variability of vegetation was revealed to be crucial for carbon dioxide sequestration in urban parks in Portugal (Mexia et al., 2018). Green spaces have an important role in the urban environment, due to the ecosystem services they provide, such as air filtration, microclimate regulation, and carbon sequestration (Bouland & Hunhammar, 1999; Nowak el., 2002; Wolch et al., 2014).

Human health is positively influenced by the presence of green space within a city (de Vries, Dillen, Groenewegen & Spreeuwenber, 2013). When urban residents were asked to rate their perceived general health those that lived in close proximity to green space, especially seniors and youth, tended to give a higher health rating (Maas et al., 2006; de Vries et al., 2013). There are inconclusive results regarding the direct relationship between the improvement of physical health and the availability of green space (Völker et al., 2018). Though, some studies have demonstrated individuals believe that their physical health is improved by living in close proximity to green space (de Vries et al., 2013; Völker et al., 2018). The role of green space for the improvement of mental health and stress levels is more conclusive, where contact with natural environments has shown to help mitigate stress and cortisol levels (Thompson et al., 2012). Individuals perceive that their mental, physical, and overall health is improved from green space within their city (Mass et al., 2006; de Vries et al., 2013; Völker et al., 2018).

The literature demonstrates green space distribution within urban environments is often uneven (Luck et al., 2009; Shanahan et al., 2014). For example, the urban landscape in Brisbane, Australia is heterogeneous due to uneven distribution of infrastructure and the biophysical environment (Shanahan et al., 2014). The same study sought to understand whether the heterogeneity of the urban landscape had resulted in an unequal distribution of green space (Shanahan et al., 2014). Their findings suggest green space distribution is largely uneven especially in socio-economically disadvantaged neighbourhoods (Shanahan et al., 2014). Several studies have highlighted differences between private versus public green space and their influence on the provision of green space (Barbosa et al., 2007; Shanahan et al., 2014). The unevenness of urban regions is attributed to the distribution of natural resources within the preexisting biophysical environment (Luck et al., 2009). Within the urban environment, research suggests green space is often not equally distributed within a city (Barbosa et al., 2007; Luck et al., 2009; Shanahan et al., 2014).

Research of environmental amenities indicates uneven distribution of amenities is often an issue regarding race/ethnicity, education, and/or income (Heynen et al., 2006; Glaeser et al., 2009). In the literature, several examples of disparities regarding the availability of environmental amenities are found to be a result of race and ethnicity (Heynen et al., 2006). Hispanic populations in Milwaukee had less urban forest canopy cover, while non-Hispanic White populations had more (Heynen et al., 2006). Evidence from their study was used to support an argument to broaden the scope of environmental justice literature to focus on ecological injustices experienced in urban environments (Heynen et al., 2006). Education-based inequalities are also a concern for green space and urban forest distribution (Shanahan et al., 2014; Wüstemann et al., 2017). Inconsistencies regarding the distribution of green space based on varying household education levels were identified in Germany (Wüstemann et al., 2017). Recent literature suggests median household income is used as a common indicator of income inequality in cities (Shanahan et al., 2014; Greene et al., 2018). Greene et al. (2018) quantified inequality between median household income and the urban forest canopy cover in Toronto, Ontario, and identified a relationship. The unequal distribution of environmental amenities in a city is commonly associated with sociodemographic variables such as race/ethnicity, education, and/or income (Heynen et al., 2006; Glaeser et al., 2009; Wüstemann et al., 2017).

2.4 Income and green space

Contemporary literature is becoming more focused on the relationship between income and availability of green space (Astell-Burt et al., 2014; Shanahan et al., 2014). In five of Australia's most populous cities, green space was significantly less abundant for low-income households than high-income households (Astell-Burt et al., 2014). Similarly, individuals with a higher socioeconomic status had more access to tree cover in Australia (Shanahan et al., 2014). Preliminary studies in Halifax, Canada support the hypothesis that income influences the presence of green space (Harvey, 2014). A series of interviews in Halifax identified historical inequalities influenced the perception and placement of green space (Harvey, 2014). The role of income in relation to the availability of green space is an increasing area of focus amongst academic literature (Astell-Burt et al., 2014; Shanahan et al., 2014).

2.5 Knowledge gaps

There is significant literature supporting the relationship between green space and inequalities (e.g., Astell-Burt et al., 2014; Shanahan et al., 2014) however, there are gaps in research regarding the polarization of income (Breau et al., 2018). Few studies have considered the role of increasing income polarization on green space (Astell-Burt et al., 2014). Many studies used techniques that do not incorporate spatial dependence in the quantification of income polarization. Therefore, this study will integrate spatial analytical techniques as indicated as an area of future study by Breau et al. (2018) and Greene et al. (2018). Even though a similar study has been completed in Halifax (Prouse et al., 2014a), there is still room to build upon previous income polarization techniques by using spatial statistical analysis established by Breau et al. (2018) as well as applying the green space variable. Additionally, Prouse et al. (2014b) hypothesized using a finer scale (like dissemination areas) might result in more conclusive results. This literature review indicates that there is a need for more research regarding the relationship between green space and income polarization especially using a longitudinal approach in Halifax.

2.6 Conclusion

Inequalities introduced or exacerbated by urbanization has led to research regarding the unequal distribution of green space in cities, which is of concern because of its relationship with income inequality (Bunting & Filion, 2001; Shanahan et al., 2014). Urbanization has led to structural changes in cities resulting in income polarization within a city (Zwiers et al., 2015). This literature review identified the importance of green space in cities, especially due to highlighted inequalities regarding their distribution (Heynen et al., 2001; Astell-Burt, 2014). Knowledge gaps were identified relating to geographic and temporal range of existing studies (Prouse et al., 2014b). As well, this review highlighted that identifying income polarization using spatial statistical analytical methods is an area for future studies in Halifax, Nova Scotia (Prouse et al., 2014b). This study will seek to fill in knowledge gaps found in this literature review, by using spatial analytical statistics from ESRI's ArcGIS™ to determine if there is a relationship between income polarization and availability of green space.

3.0 Methods

3.1 Overview of Methods

This study seeks to detect and quantify any historical relationship(s) between green space and income over a fifteen-year timespan (2001-2016) for a portion of the Halifax Regional Municipality (HRM), Nova Scotia. Using the geographic information systems (GIS) (e.g., ArcGIS™ and GeoDa), this study detected changes in median household income (MHI) at the dissemination area (DA) level from 2001 up until 2016. ESRI's ArcGIS™ environment were utilized to ensure consistency of DA between the time points, while a bivariate Local Moran's I quantifies areas that remained significantly high- and low-income. The DA is a geographic boundary containing a population of 400-700 people used by Statistics Canada to disseminate census data (Statistics Canada, 2015a). Then, using remotely sensed imagery, green spaces were identified, and fractional coverage of the DA was calculated to provide a common geographic unit in which to test the relationship with median household income (MHI) for the region. Before testing the spatial relationship between the two variables, an inferential statistical test was applied to examine the strength of continuous relationships (e.g., Geographic Weighted Regression) between the variables. To determine spatial correlation, specialized local indicators of spatial autocorrelation (or LISA) were applied to examine the strength and significance in the relationship between MHI and green space. By quantifying the spatial relationship between income level and green space, this study could be used to inform policy decisions related to future green space placement and expansion in the HRM.

3.2 Study area

Halifax is the capital city of Nova Scotia, a province located on the east coast of Canada (City of Halifax, 2014a). In 2016, the city's population of 403,131 represented approximately 43% of the province's total population (Statistics Canada, 2017). Because large rural areas were amalgamated with more urban areas in 1996, this study focused on a subset of Halifax, selected using Statistics Canada's definition of urban areas including a population density of 400 or more people per km^2, at the neighbourhood scale using the DA (Figure 1; Statistics Canada, 2011). Halifax is the urban center of the Halifax Regional Municipality (HRM); the geography of Halifax is important consideration because the peninsula representing the core of the municipality is also surrounded by water (City of Halifax, 2014a). The natural landscape and geology of the area has imposed limitations on where development can occur due to the location of the harbour, irregular coastline, and topography (City of Halifax, 2014a). Population growth has been somewhat limited by cultural practices and development projects on the Halifax peninsula resulting in the dispersion of population outward toward other regions in the HRM (Stantec, 2013; City of Halifax, 2014a). However, studies conducted by the City of Halifax have shown room for further densification to accommodate for population and economic growth (e.g., Stantec, 2013, City of Halifax, 2014a). Halifax's natural landscape is highly variable based on underlying land-use such as residential, commercial, and institutional areas (Steenberg, Duinker & Charles, 2013).

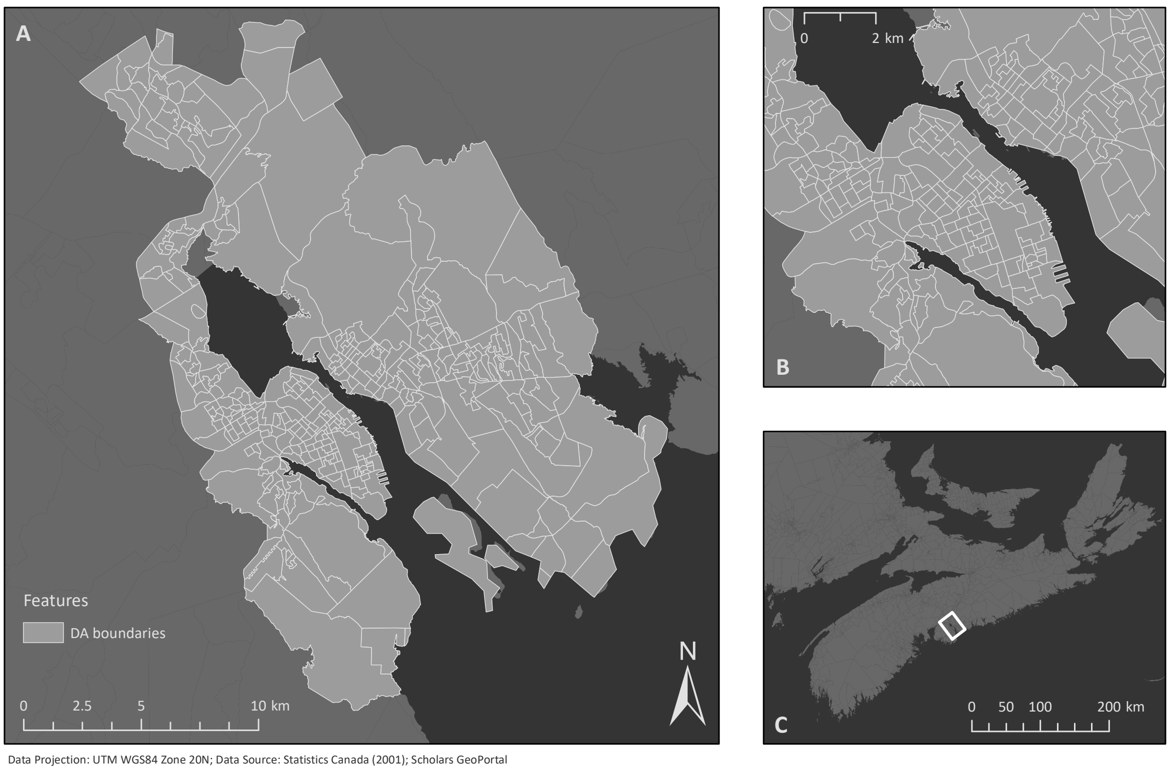


Figure 1. The geographic location and extent of urban Halifax (A), Nova Scotia with dissemination area boundaries indicated (see inset for reference of the Halifax peninsula (B) and Nova Scotia (C)).

3.3. Data Processing and methods

3.3.1 Census data

Canadian census data was used to establish median household income (MHI) levels in urban Halifax following techniques employed by Greene et al. (2018) to evaluate the extent of distributional inequalities of MHI in Toronto, Ontario. Canadian census data from 2001, 2006, 2011, and 2016 at the dissemination area (DA), that was initially gathered by Statistics Canada in Halifax, was obtained from the University of Toronto database, CHASS (Computing in the

Humanities and Social Sciences). Cartographic boundaries for the DA boundaries in each census year (2001, 2006, 2011, and 2016) were acquired from Scholars GeoPortal. For this study, the DA was selected to obtain a sufficient sample size for subsequent inferential data analysis and to build upon previous recommendations from income polarization studies in Halifax, Nova Scotia (Prouse et al., 2014a; Ramos & MacNabb, 2018). Due to differences in cartographic boundaries over time, all MHI data were processed to be contained within boundaries existing in 2001, so that all census years had consistent spatial boundaries. As populations grow, DA boundaries are rezoned making comparison over time difficult because geographic locations of some DAs differ. Using consistent DA boundaries is a necessary component for longitudinal analyses. Considering that MHI had changed over time, proportional income was calculated for any inconsistent DAs ensuring MHI was comparable across the suite of time points. For visual and analytical comparison, since the Canadian dollar has fluctuated over time, MHI inputs were standardized by using z-scores (see Figure 2). A z-score is a statistical measure representing how many standard deviations an observation is from the mean of the distribution (Longley, 2010).

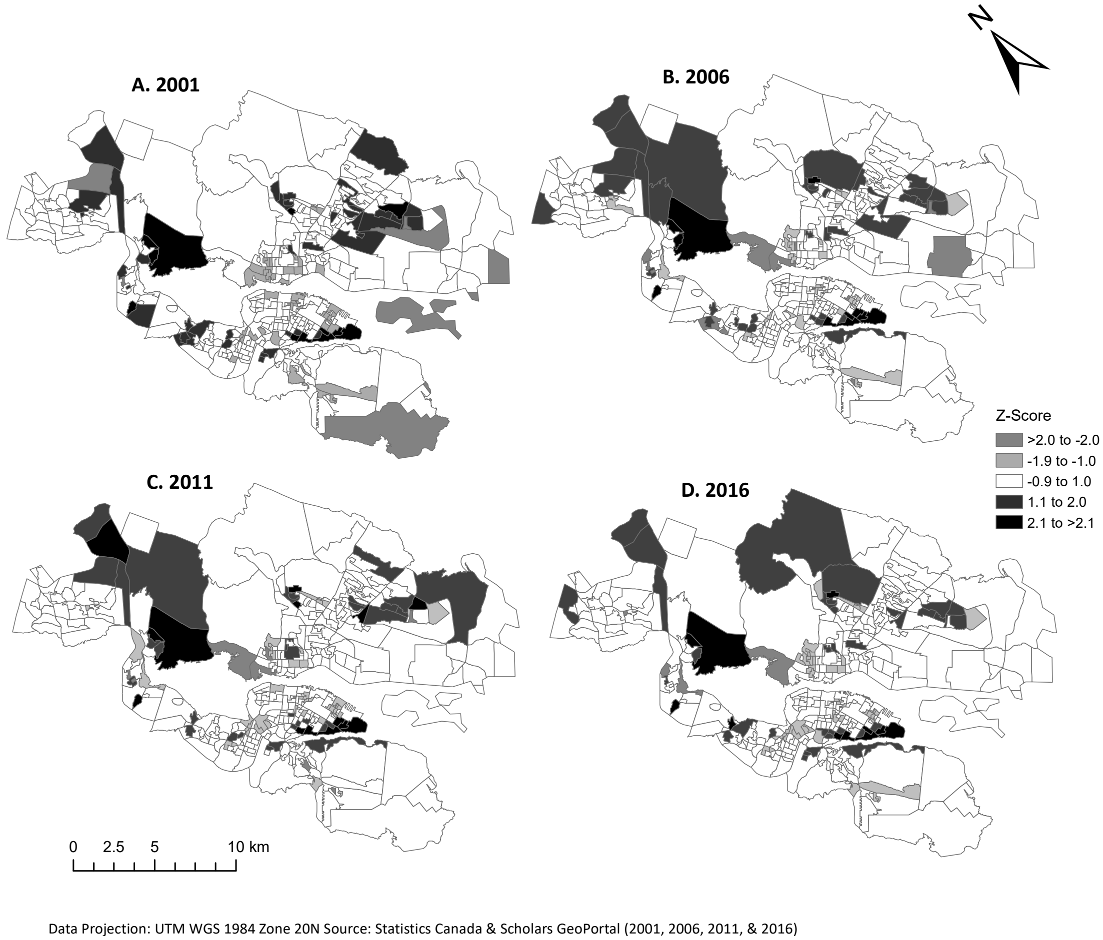


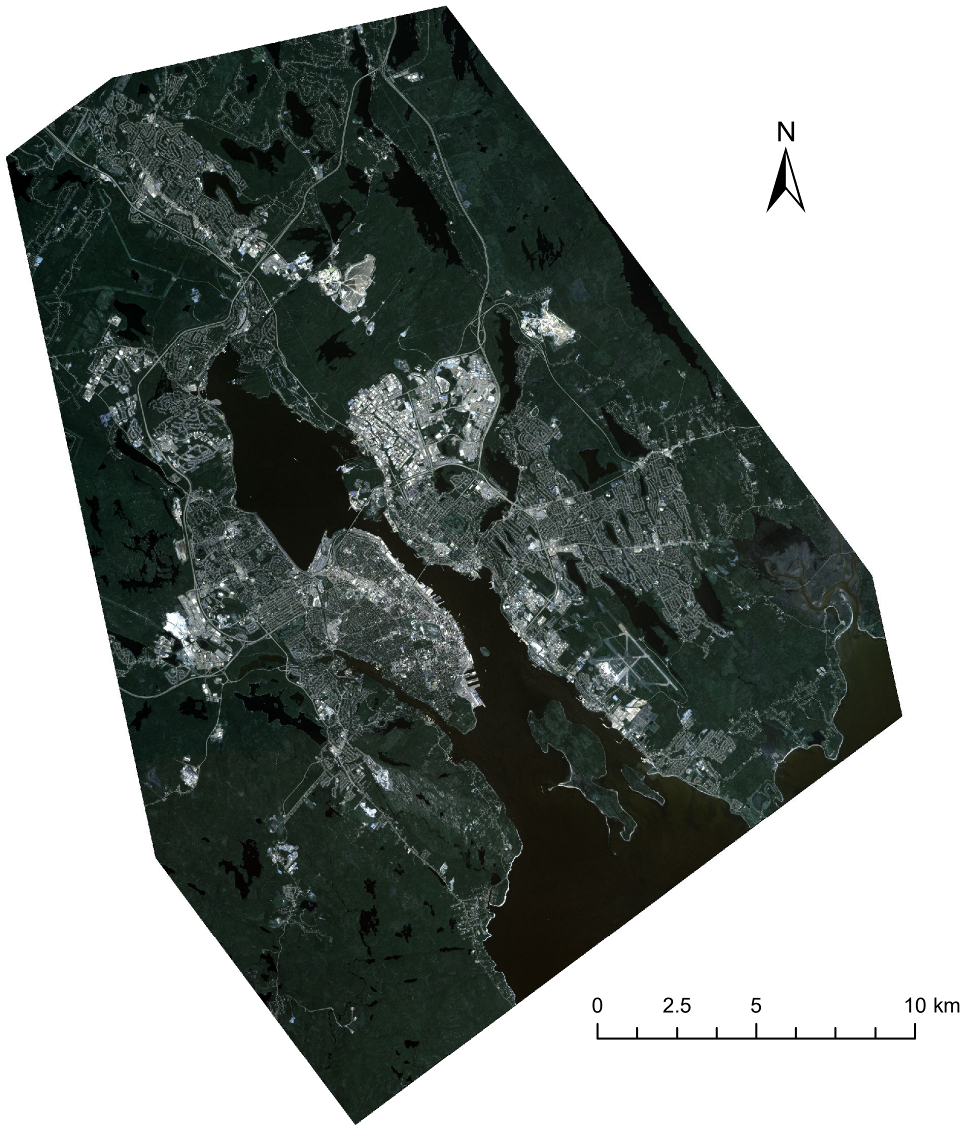
Figure 2. Median household income at the dissemination area (DA) in 2001 (A), 2006 (B), 2011 (C), and 2016 (D) in urban Halifax, Nova Scotia. Median household income is represented by z-scores.

3.3.2 Mapping median household income data

Areas of significant high- and low-income that remained static for the entirety of the fifteen-year study were identified by comparing sequential five-year time point pairs. A bivariate local indicator of spatial autocorrelation (LISA) was used to test spatial clustering of MHI between the endpoints 2016 and 2001 to identify areas (or clusters) of high-high and low-low income. In this research, the specific LISA used was a bivariate Moran's I with the intention of detecting clusters of positive autocorrelation (Lloyd, 2010). Positive spatial autocorrelation is the clustering of similar extreme values, in this case, areas of high and low income (e.g., high in 2016 and 2001 or low in 2016 and 2001). Then, sequential temporal bivariate tests were performed, for example between 2001 to 2006, 2006 to 2011, etc., to detect changes in the spatial distribution of MHI high- and low-income neighbourhoods throughout the fifteen-year period. To quantify the extent of cluster area changes in the bivariate Moran's I results, descriptive statistics regarding the proportion of DAs with high and low income for each sequential temporal pair were performed. The mean center of significant clusters was identified for each sequential time point pair so that the directional movement of clusters could be visualized.

3.3.3 Green space remote sensing imagery

The following methodology used in this study is similar to the methods applied in Greene et al. (2018) that provided a framework for quantifying the distribution of environmental amenities. A mosaic of five-tiles was created to cover the extent of the study area using four-band, visible and near-infrared remotely sensed imagery with a 3m resolution (Figure 3). Analytical Level 3B PlanetScope imagery was provided courtesy of Planet Labs, Inc. acquired on August 1, 2018.



Data Projection: UTM WG1984 Zone 20N Data Source: Planet Labs: PlanetScope- 4-band VIS-NIR (acquired: 2018-08-01)

Figure 3. Geographic extent of the five-tile mosaic PlanetScope (4-band VIS-NIR) imagery in urban Halifax, Nova Scotia. Date of acquisition: 2018-08-01.

Land cover was isolated into four distinct classes including tree canopy, short vegetation, water, and built areas, using a rule-based supervised classification (Figure 4). A supervised classification using object-based image analysis (or OBIA) was used to incorporate the geometry of identified pixel clusters (or "features"), along with their spectral properties, to classify land cover. Classification of tree canopy was further refined using rule-based classification where mean NDVI >0.3 was considered tree canopy. An accuracy assessment based on 300 random points was performed after the classification to quantify the accuracy of the supervised classification (Tables A1 and A2). These points were used to identify image segments that would be included as a part of the accuracy assessment.

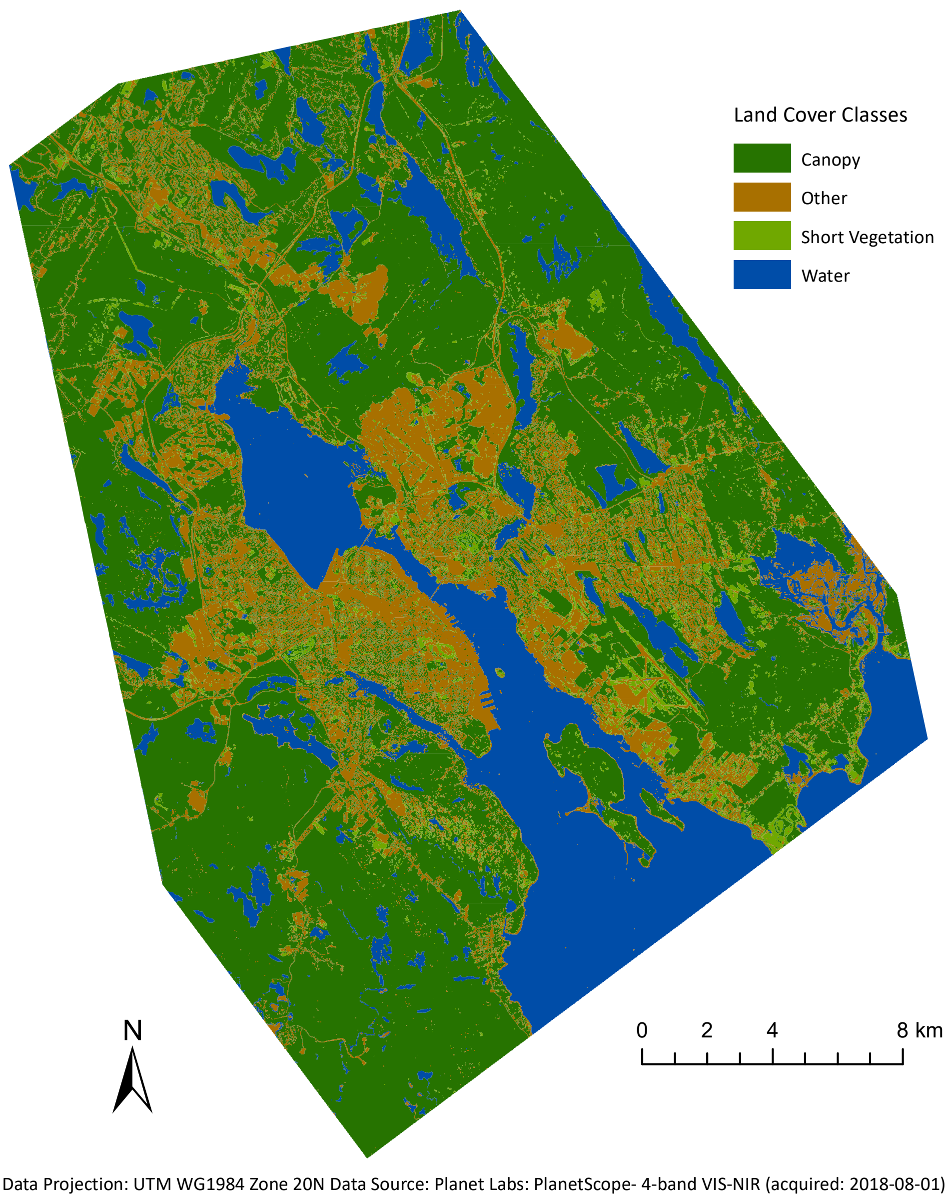


Figure 4. Tree canopy, short vegetation, water, and other land cover classified using supervised, rule-based object-based image analysis (Mean NDVI >0.3 = tree canopy) in urban Halifax, Nova Scotia.

Classified segments were isolated into individual green space components to generate fractional coverage (or percent cover of the class) for each DA. Percent cover of green space was defined by two land cover classes generated from the image classification: *% tree canopy* and *% short vegetation*. These percentages were derived through the generation of summary statistics where the proportional area of green space in a DA was compared to the total area of the DA (Figure 5). A univariate LISA, specifically a Local Moran's I, using queen's contiguity, was applied to identify the extent of significant high-high and low-low green space. Therefore, neighbourhoods that have high and low abundance of green space are identified using the LISA. Refer to Figure 6 for an overview of methodology used in this study.

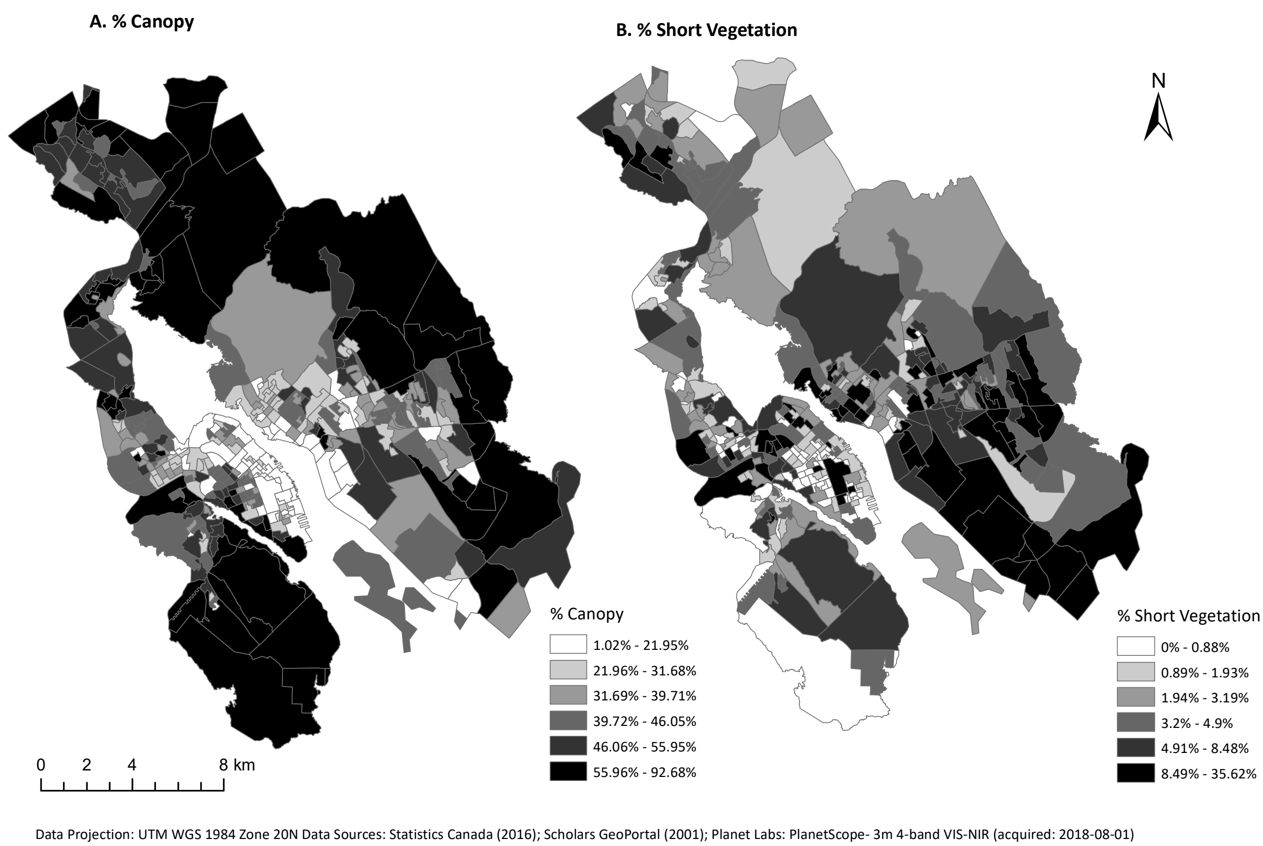


Figure 5. Percent cover of green space separated into *% tree canopy* (A) and *% short vegetation* (B) by dissemination area in urban Halifax, Nova Scotia.

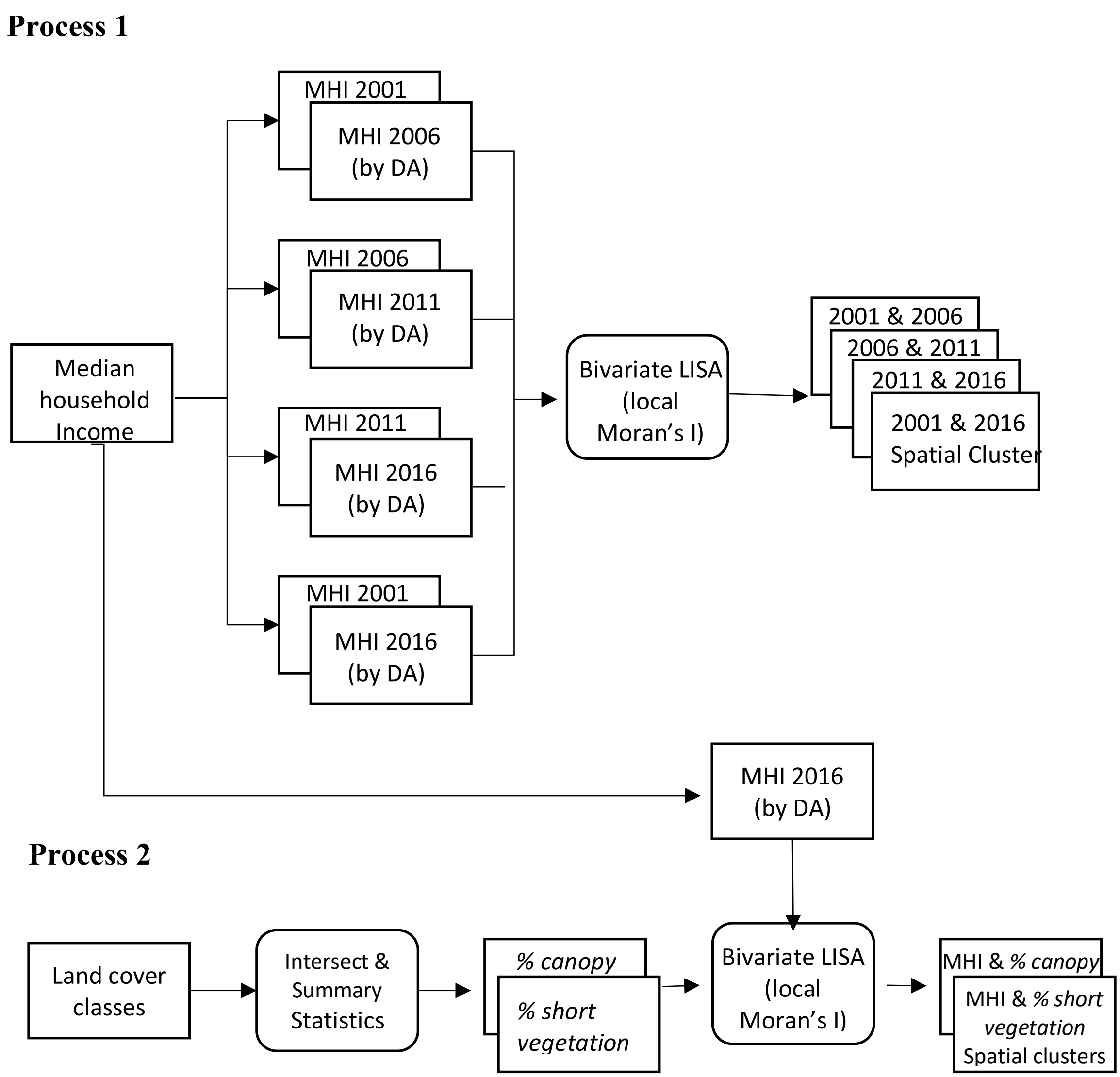


Figure 6. Overview of analysis of income polarization and green space data to produce bivariate local indicators of spatial autocorrelation (LISA) Local Moran's I. Process 1 outlines income polarization methods and process 2 outlines green space methods.

3.4 Data analysis

The strength of the continuous variables were first quantified using geographic weighted regression (GWR). This spatial analytical technique, used for non-stationary variables, uses an adaptive linear equation to detect whether a dependent variable is influenced by an independent variable(s) (Lloyd, 2010; Rogerson, 2015).

Low correlation strength or coefficients of variation do not exclude the possibility of strong spatial dependence between variables, so a local indicator of spatial autocorrelation will be applied to identify any spatially significant clusters of spatial autocorrelation (Lee, 2001; Greene et al., 2018). That is, clusters were identified having significant similar relationships. For this work, bivariate Local Moran's I will be employed to measure the extent of significant areas that have low MHI and low green space, and high MHI and high green space. Along with areas of significant high/low MHI and green space, dissimilar areas were also identified including low MHI and high green space, and high MHI and low green space. For this study, the spatial weights matrix was defined as queen's contiguity, where a DA was considered a neighbour if it shared an edge or a corner. A bivariate Local Moran's I was used because it has been applied in recent environmental amenity distributional studies pertaining to MHI and tree canopy in Toronto, Ontario (e.g., Greene et al., 2018). A benefit of using the Local Moran's I test is that it measures low-low and high-high clusters for all DA's in the study area. Although, it is important to acknowledge that there is underlying temporal dependence of MHI between census years violating the assumptions of independence amongst variables for a Local Moran's I.

3.5 Limitations

3.5.1 Census data

There are identifiable limitations regarding the census data related to the nature of the initial data collection by Statistics Canada. The primary limitation of the methodology has to do with the changes in DA boundaries over time in the census data collected. The dissemination area boundaries have changed because Statistics Canada has had to split zones based on changes in the population within DAs once they moved outside of the preferred 400-700 people (Statistics Canada, 2015a). To make boundaries consistent, they were matched to the geographic DA boundaries from the 2001 census. Even though geographic boundaries were made consistent with the 2001 boundaries, the original populations were retained by calculating and ascribing proportional income based on population to the centroid of the DA. Proportional income data from subsequent census years were assigned to 2001 DAs based on centroids that fell within the DA.

Another limitation of the census data is related to the intermittent nature of the MHI data collected. Due to the extensive data collection required, the Canadian census occurs only every five years. Moreover, income data is collected via the long-form census which is only distributed to around 25% of Canada's population and generalized to the population. Historically, Canadian census data has varied considerably because of changes in methodology, processes, and questions (Statistics Canada, 2015b). Methodology changes in the collection of Canadian census data are worth noting because in 2011 Canada replaced the long-form survey to the National Household Survey leading to a large non-response rate potentially impacting observed results in this research (Statistics Canada, 2015b).

A potential problem of this study is related to the use of DA cartographic boundaries over census tracts (CT). Using DAs as a geographic unit of analysis could result in the modifiable areal unit problem (i.e., MAUP) a phenomenon related to variance in analytic output if different zones or scales are used (Lloyd, 2010). Therefore, underlying trends could be considered to be weak or not be detected at all based delineation of zones (Flowerdew, 2011).

3.5.2 Remote sensing imagery

The primary limitation regarding the remote sensing imagery relates to the cross-sectional green space data. This study used a single time-point of higher spatial resolution (i.e., 3m) of PlanetScope satellite imagery. To perform a longitudinal analysis of green space, the imagery would be preferred to be the same resolution, but imagery available for this study include Landsat (30m spatial resolution) and Sentinel-2 (10m spatial resolution). Therefore, green space is limited to a temporal snapshot. Aggregating green space attributes to the DA level leads to a problem referred to as an ecological fallacy. This problem arises when inferences are made about an individual based on the group characteristics found in the aggregated zones (Lloyd, 2010).

4.0 Results

4.1 Income polarization

4.1.1 Detection of polarization: Bivariate Moran's I

Distinct geographic locations exhibiting significant clusters of high (high-high clusters) and low (low-low clusters) of median household income (MHI) are indicative of income polarization in urban Halifax (Figure 7). As a proportion of the total number of dissemination areas, high-high clusters comprise 11.38% of the DAs in urban Halifax between 2001 and 2016, while low-low income clusters comprise 16.34% of the total (Table A1). Though the majority of DAs in the Halifax area did not contain significant clusters of high-high and low-low MHI (Figure 7) making up 72.28% of the DAs in urban Halifax (Table A1). A high, positive spatial correlation between MHI from each census year indicates a strong relationship between MHI over the fifteen-year study period (Figure 8). These results are supported by a visual comparison of significant high-high and low-low income clusters where the geographic location of these clusters remained fairly static over time (Figure 7).

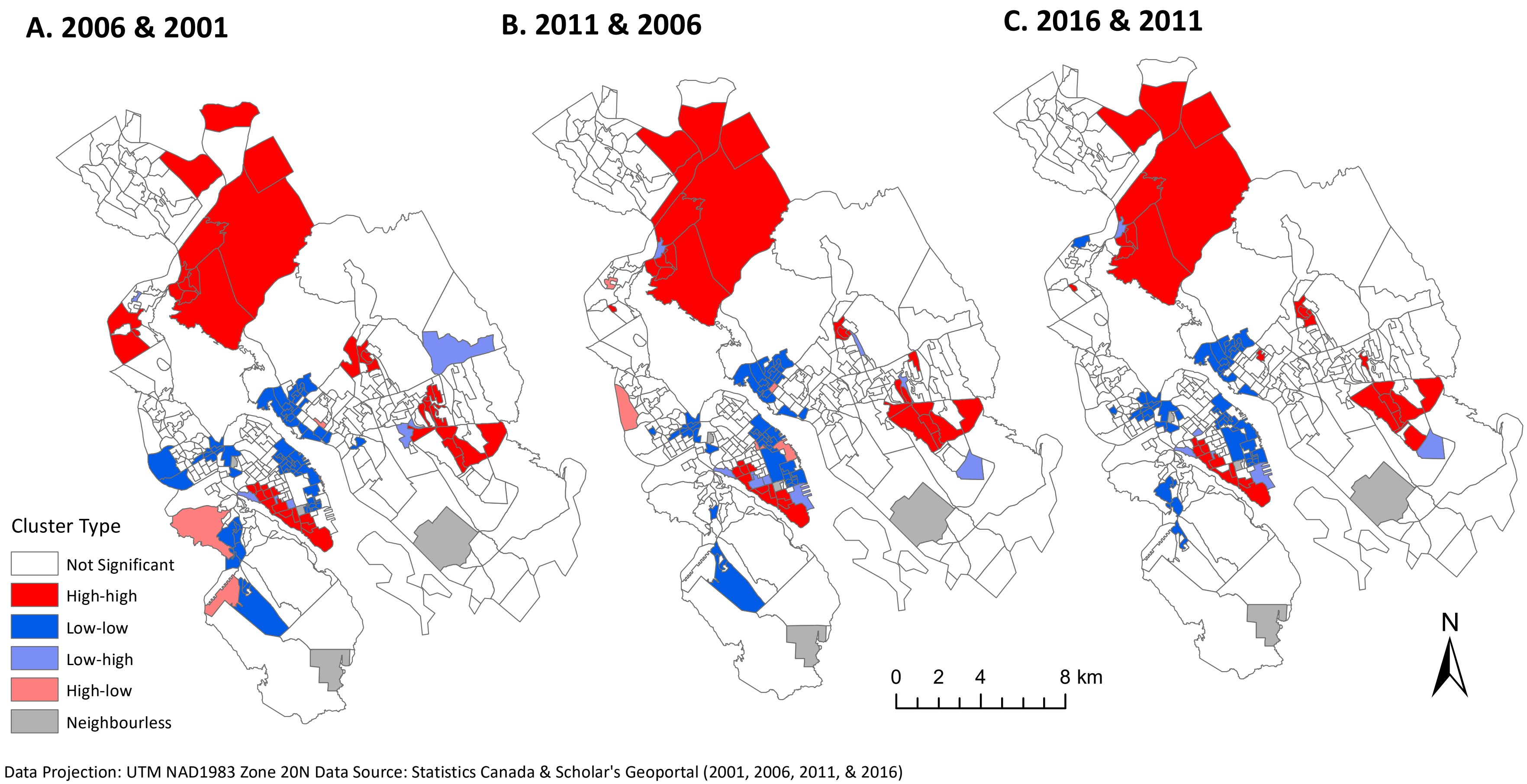


Figure 7. Bivariate local indicators of spatial autocorrelation of median household income at the dissemination area between census years 2006 and 2001 (A), 2011 and 2006 (B), and 2016 and 2011 (C) in urban Halifax, Nova Scotia.

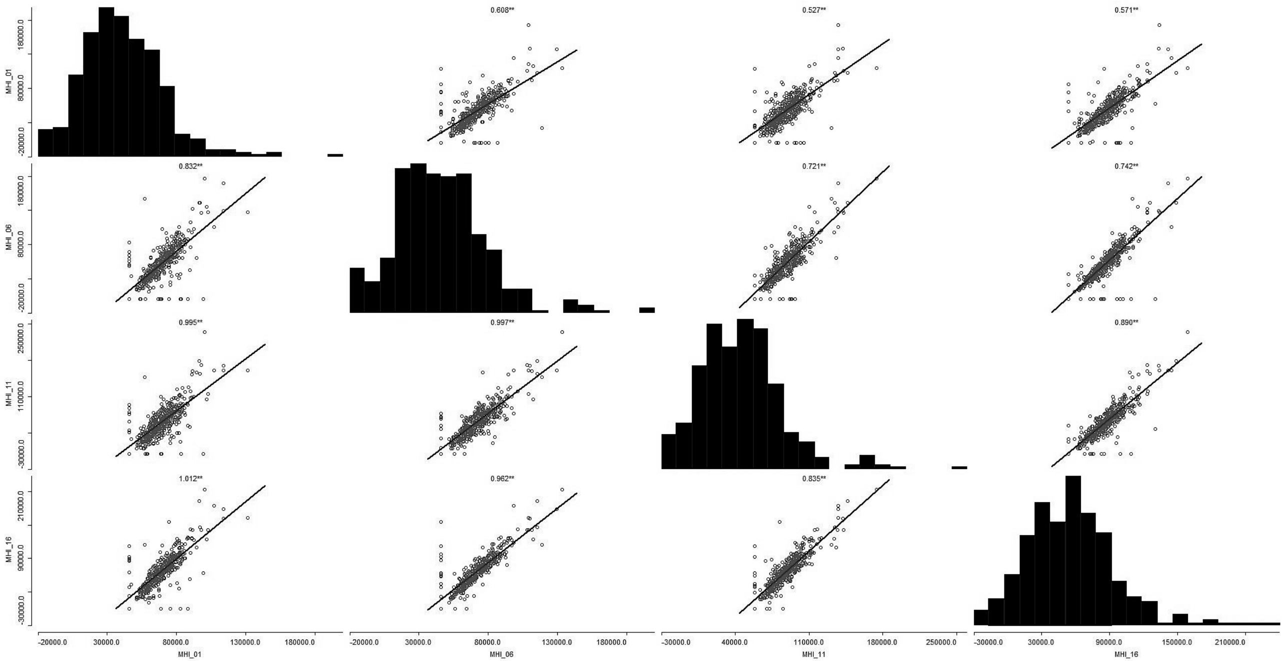


Figure 8. Correlation between median household income obtained from each census year (2001, 2006, 2011, and 2016) in urban Halifax, Nova Scotia, represented by scatterplots and histograms. Scatterplots include linear trend line and correlation coefficient.

Three distinct locations exhibited consistently high-high income between the census years included neighbourhoods such as the ‘South End’ (cluster H-1), Bedford (cluster H-2), and Portland Estates (cluster H-3; Figure 9). The ‘South End’ neighbourhood (cluster H-1) is located along the northern shoreline of the Northwest Arm and south of Chebucto Road. Cluster H-1 remained in a similar position throughout the fifteen-year study time period (Figure 9). Cluster H-2 remained the most geographically expansive high-high cluster across all temporal pairs, with the perimeter of the cluster(s) extending northward from Admiral’s Cove and Eaglewood towards Lakeview and Waverley (Figure 10). Throughout the fifteen-year time-period, Cluster H-2 moved northeast (Figure 10). Cluster H-3 had the smallest areal extent, including neighbourhoods like Portland Estates and Portland Hills, and was slowly moving eastward (Figure 10).

Three consistent significant clusters of low-low income neighbourhoods were observed, including Fairview (cluster L-1), the north end of Dartmouth (cluster L-2), and downtown Halifax (cluster L-3; Figure 9). The limits of the Fairview area (cluster L-1) has remained relatively static throughout the fifteen-year timeframe and generally covered a smaller extent (Figure 9) than the other described clusters. Cluster L-2 covered the north end of downtown Dartmouth and over time migrated further northward; this cluster includes neighbourhoods like Highfield Park, Tuft's Cove, and Shannon Park (Figure 10). The last significant low-low cluster (L-3) covered a comparatively large area and is located south of Young Street in a neighbourhood known as the 'North End' in downtown Halifax.

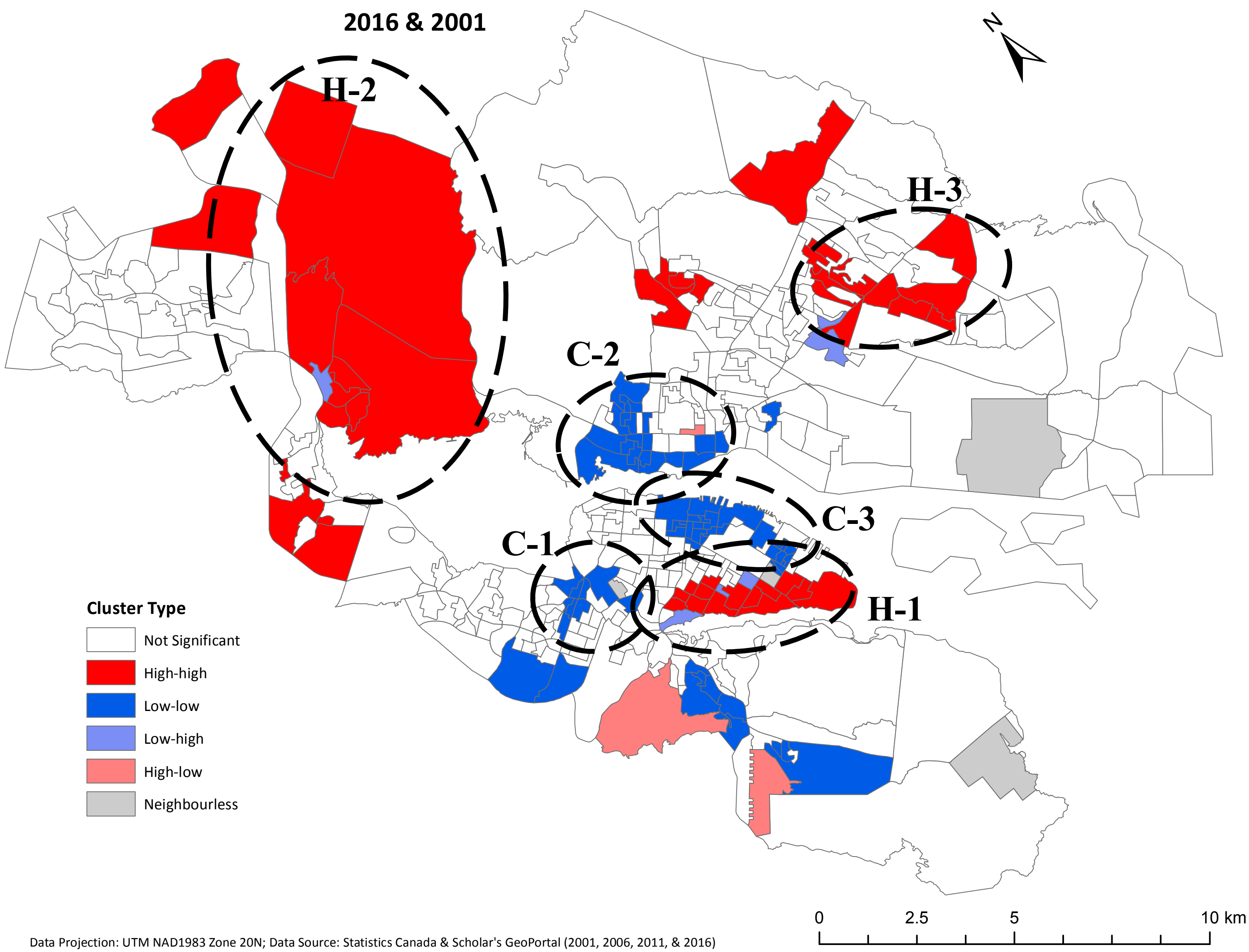


Figure 9. Bivariate local indicators of spatial autocorrelation of median household income in 2001 and 2016 in urban Halifax, Nova Scotia. Black circles indicate key areas of significant high- and low-income.

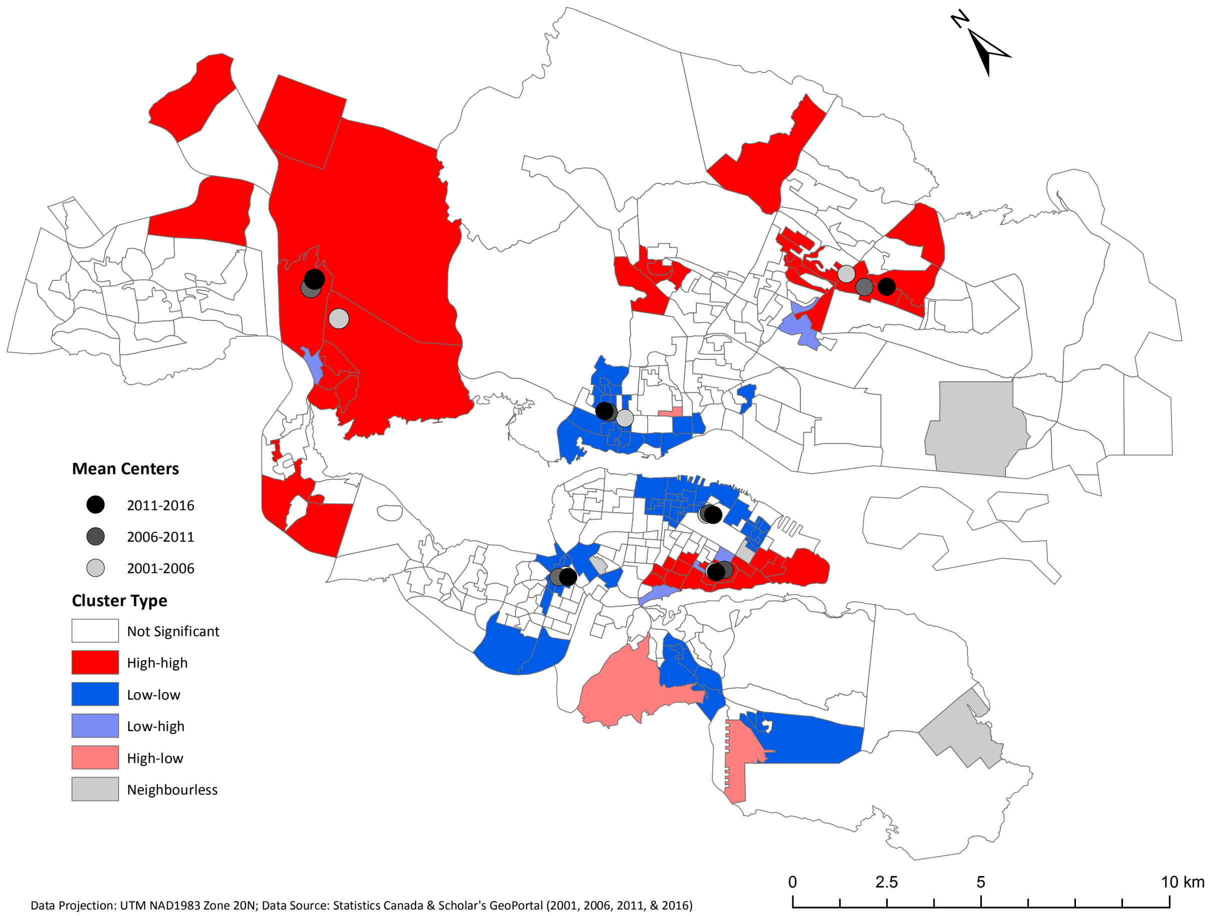


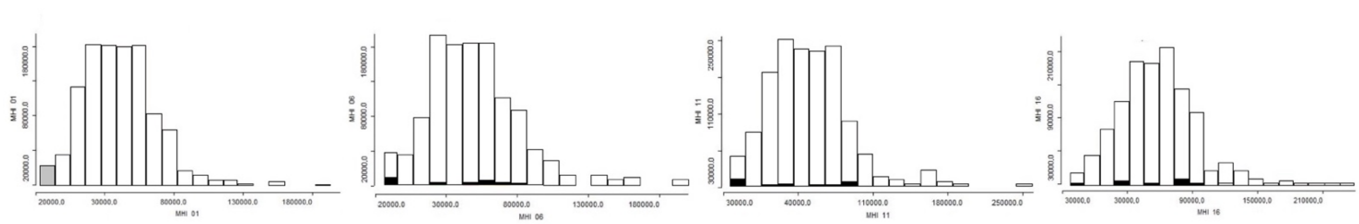
Figure 10. Mean centers of high-high and low-low clusters of median household income (MHI) from 2001 & 2006, 2006 & 2011, and 2011 & 2016. Overlain on a bivariate local indicator of spatial autocorrelation of MHI in 2001 and 2016 in urban Halifax, Nova Scotia.

Despite the apparent stability of significant clusters of high -high and low-low income, there were marginal decreases in the proportion of high-high and low-low incomes dissemination areas in urban Halifax from 2001 until 2016 (Table A2). Though the proportion of low-low clusters increased between two temporal pairs. There was a small increase of 0.89% between 2006-2011 and 2011-2016 (Table A2). As a result of overall decreases in high-high and low-low over the fifteen-years, there were increases in the proportion of median cluster types, high-low, low-high, and non-significant (Table A3).

4.1.2 Redistribution of income

Historically low-income DAs in 2001 appear to be displaced by medium-higher income neighbourhoods in subsequent census years (Figure 11). Conversely, neighbourhoods that were traditionally high-income in 2001 remained high-income throughout the fifteen-year period with little displacement by lower-income neighbourhoods (Figure 11). The displacement of low-income by high-income neighbourhoods seems to be disproportionate given that high-income neighbourhoods remained in the same geographic region. This displacement was limited to select DAs throughout the study area without a clear occurring pattern. It is possible that low-income groups are not being displaced due to relative proportions of low- to middle-income groups from population growth. Influxes of middle-income groups could inflate overall MHI while low-income households still remain in the DA.

Low-MHI



High-MHI

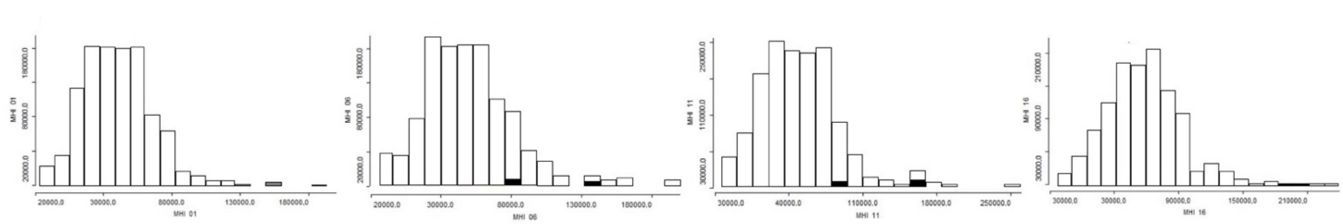


Figure 11. Displacement of low- and high-median household income groups by dissemination area (DA), as indicated by bars highlighted on the histogram, from 2001 onwards in urban Halifax, Nova Scotia. Grey bar indicates high- and low- income DA in 2001 while black bars indicate displacement of the DAs in subsequent years.

4.2 Green space distribution

A high *% tree canopy* cover was observed on the periphery of urban Halifax and areas with low *% tree canopy* cover on the Halifax peninsula (Figure 12). Significant large areas of high *% tree canopy* cover (high-high) were present in DAs at the limits of the study area. Low *% tree canopy* covered DAs (low-low) were located on the Halifax peninsula (Figure 12). Short vegetation was distributed more irregularly with pockets of high *% short vegetation* located near Shearwater and Eastern Passage (Figure 12). Significant areas of low *% short vegetation* were located in the Halifax peninsula, that seemed to overlap with areas of low *% tree canopy* cover (Figure 12). Based on the distribution of green space in urban Halifax, it appears that there is a greater abundance of green space in neighbourhoods that are located on the periphery of the urban center. Areas that have reduced cover by tree canopy and short vegetation are largely contained within the Halifax peninsula.

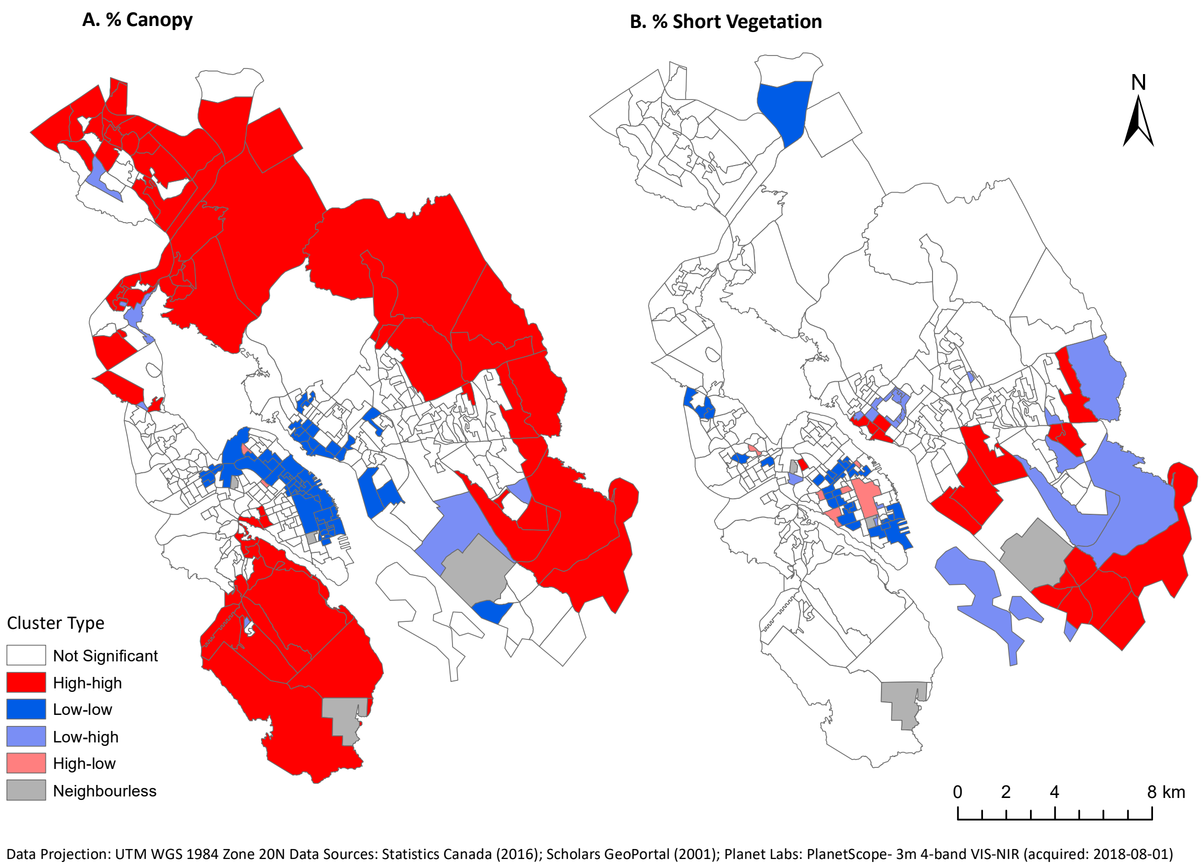


Figure 12. Univariate local indicator of spatial autocorrelation (LISA) of *% tree canopy* (A) and *% short vegetation* (B) in urban Halifax, Nova Scotia.

4.2 Income and green space

4.2.1 Geographic Weighted Regression

A positive relationship was observed between MHI 2016 and green space where the strongest association with MHI was *% tree canopy* (r^2=0.6876; Table C8). A weaker positive correlation was identified between MHI 2016 and *% short vegetation* (r^2=0.2466; Table C9).

4.2.2 Bivariate Local Indicators of Spatial Autocorrelation

Upon visualization of the relationship between green space and median household income in 2016, distinct significant areas of high- and low-MHI and green space were identified in urban Halifax (Figure 13). Regarding *% tree canopy*, large areas were considered high-MHI and high-*% tree canopy* especially in peripheral regions. Whereas areas with low-MHI and low-canopy covered a smaller area on the Halifax peninsula (Figure 13A). Though, a large portion of the study area did not contain significant areas of tree canopy cover (Figure 13A). Considerably less of the study area was considered to contain significant areas of high-MHI and high-green space and low-MHI and low-green space; the majority of DAs were found to be not significant (Figure 13B).

Areas of stable high- and low-income, seen in Figure 9, did not entirely align with areas highlighted as areas of high-income and high-*% tree canopy* except a few locations (Figure 13A). The entirety of cluster H-2 and one DA in cluster H-1 was identified as an area of stable high-income over time in addition to containing significant tree canopy coverage (Figure 13A). Significant areas of low-MHI and low-*% tree canopy* align more with stable areas of low-income through time with parts of all three identified clusters (L-1, L-2, and L-3) represented in significant areas of low income and tree canopy coverage (Figure 13A). Visualizing the relationship between MHI and tree canopy coverage and comparing it to stable income polarization clusters demonstrates that downtown Halifax and Dartmouth, Fairview tend to have lower income and tree canopy coverage.

Considering a majority of the study was considered to be not significant between income and short vegetation cover, there was little overlap between areas of stable high- and low-income (Figure 13B). There did however, seem to be more areas of low-MHI and low-*% short vegetation* within urban Halifax similar to the relationship between income and tree canopy.

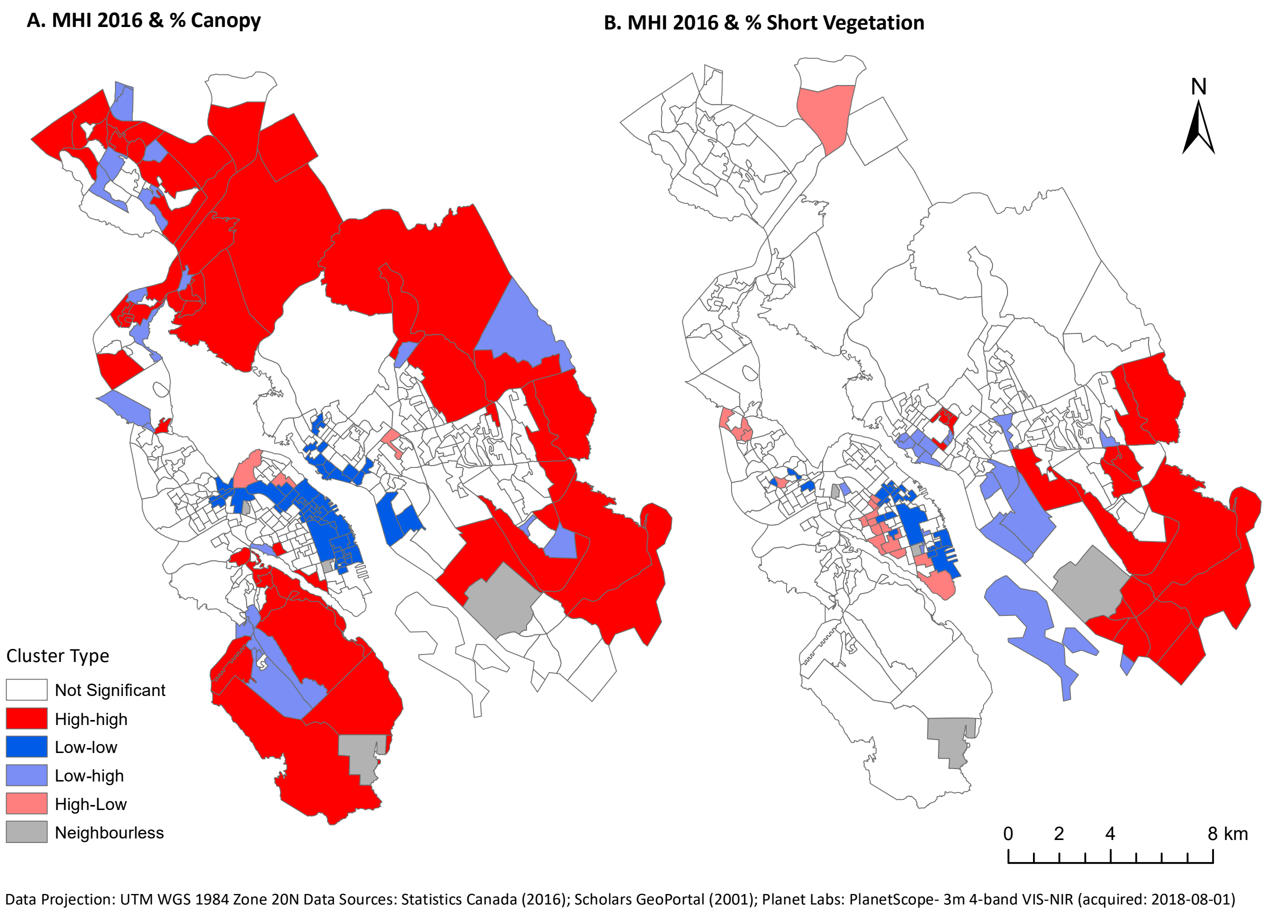


Figure 13. Bivariate local indicators of spatial autocorrelation of median household income in 2016 and green space *(% tree canopy* and *% short vegetation*) in urban Halifax, Nova Scotia.

5.0 Discussion

5.1 Suburbanization and stable clusters

Spatial analytical techniques used to understand the distribution of median household income (MHI) in the Halifax Regional Municipality from 2001-2016 show distinct neighbourhoods in urban Halifax that can be described as predominately high- and low-income. Temporally static income clusters may be explained by both social and economic processes influencing development within Halifax over time. The distribution of income within Halifax appears to be associated with historic movement of urban to suburban living that gained momentum in the mid 20th century (Fiedler & Addie, 2008). Populations relocated to the suburbs as those who could afford to leave cities were enticed by the vast properties and privacy of suburban life near the city (Fiedler & Addie, 2008). This phenomenon of suburban expansion spatially aligns with the pockets of high-income neighbourhoods (clusters H-1, H-2) identified outside of the Halifax peninsula and on the peri-urban fringe (Figure 9). Moreover, downtown Halifax has experienced a population decrease of 25,000 people to suburban communities in the past three decades (City of Halifax, 2014b).

An area that appears to be inconsistent with this suburban expansion narrative, however, is the 'South End' neighbourhood (cluster H-3) located along the southern part of the Halifax peninsula (Figure 9). This incongruity can be explained simply by the fact that the 'South End' (cluster H-3) is an area of strong historical affluence that has remained in same geographic location throughout the 20th and 21st century (Prouse et al., 2014). Large estates were developed in the 'South End' in the mid-1800s largely due its close proximity to attractions like the shore of the Northwest Arm and Point Pleasant Park (Millward, 1983). At this time, the 'South End' was far removed from industrial areas located in the northern part of the peninsula, further concentrating its location in a belt along the Northwest Arm (Millward, 1983). Low-income neighbourhoods more often tended to be concentrated in the urban center of Halifax and Dartmouth. This tendency towards low-income areas in city centers can be explained by the decentralization of populations outwards and labour market shifts as higher income populations left city centers (Walks, 2013). Urban centers have become a central hub for business, political, and institutional sectors providing insight regarding slight fluctuations of high- and low-income groups in central Halifax. For example, Halifax has eight higher-education institutions leading to an abundance of non-resident, renting university students that do not contribute to overall MHI distribution (Prouse et al., 2014).

5.2 Urban development densification

Income distribution in Halifax does not reflect extreme polarization emerging in other Canadian cities, such as Toronto or Montreal (e.g., Hulchanski, 2010, Walks, 2013, and Breau et al., 2018), but the results of this study suggests that there is some degree of socioeconomic polarization. One explanation is that historic effects of income polarization in Halifax are fixed and embedded within the urban in form. Therefore, the fifteen-year study period may not be able to detect more long-term historical polarization. Another possible explanation why the spatial pattern of polarization is not increasing in Halifax could be credited to the development of urban planning and economic strategies by the city of Halifax (i.e., *Regional Plan, Economic Growth Plan- 2006-2011* and *Downtown Halifax Secondary Municipal Planning Strategy*). To maintain sustainable economic growth, planning strategies have targeted densification within the urban center of Halifax as a major objective (City of Halifax, 2014b; City of Halifax, 2016). Development strategies focusing on densification have increased the prevalence of condominiums and mixed-use buildings in the urban centre. These units, when constructed with the existing clusters, tend to further concentrate high- and low-income within the cluster rather than expand the extent of the cluster. For example, traditional wealthy neighbourhoods are often associated with large properties that have single-detached dwellings (Millward, 1983). But the prevalence of apartments and expensive condominiums leads to a smaller areal extent of high- and low-income groups.

5.3 Displacement of Income Groups

Slight decreases in the overall extent of polarized income areas in Halifax does not necessarily equate to an absence of income inequality, as demonstrated by the displacement of low-income neighbourhoods by high-income neighbourhoods in Halifax. In fact, historic effects of income polarization could be fixed and embedded within the urban form over decades to centuries (Hulchanski, 2010).

While not observed in this study, this methodology could be useful for identifying areas of gentrification as these results appeared to show displacement of low-income groups. Gentrification is a process whereby a traditionally lower-income neighbourhood is 'revitalized' and developed favouring middle-class resettlement (Walks & Maaranen, 2008). Effects of gentrification are variable, depending on local policies and planning, however it frequently changes the sociodemographic and economic composition of a neighbourhood (Bourne, 1993). Detection of gentrification could be useful because, at present day, gentrification is an area of discussion with Halifax citizens due to concern over the displacement of individuals from the 'North End' (Prouse et al., 2014). Even though the results of this paper do not attest gentrification in specific regions in Halifax, they provide a basis for displacement of individuals disproportionately favouring low-income neighbourhoods that is applicable to many Canadian cities (Walks & Maaraneen, 2008). The geographic unit of analysis, the dissemination area, was unable to detect changes of income distribution experienced within neighbourhoods. Therefore, further analyses at a finer-scale would be necessary to provide further evidence of gentrification in Halifax.

5.4 Green space distribution

Unequal distribution of green space was not evident for all categories of green space in this study, where tree canopy is more abundant in the periphery of Halifax, and short vegetation is more sporadic. This distribution could be related to the area available for green space on the Halifax peninsula, but it could also be influenced by differences in strength of the relationship between income and green space. The strength of the relationship between income is variable in the study area, therefore it is expected to influence where green space is visualized. For example, in urban regions, a short supply of green space increases the desirability and demand for the amenity (Barbosa et al., 2007). Alternatively, areas on the peri-urban fringe have an abundance of green space and will remove vegetation for development. Therefore, a greater relationship between income and green space is anticipated in urban regions compared to the peri-urban fringe. Due to the variation in the strength of the relationship, a geographic weighted regression (i.e., GWR) was necessary to capture differences in the fit of the regression model based on a local subset rather than the overarching pattern (Lloyd, 2010; Rogerson, 2015).

Another possible explanation is that dense development on the Halifax peninsula and downtown Dartmouth limits area available for natural vegetation and parks. Therefore, a greater abundance of tree canopy is expected to be present around the border of the study area. Short vegetation does not appear to follow the same trend as the majority of the study area is considered non-significant. This interpretation raises an important issue regarding the differences in the type of vegetation based on their ecological, health, and social benefits (LaPaix & Freedman, 2010). Literature suggests that trees are more effective at sequestering carbon and providing health benefits than grassy parks (Shanahan et al., 2014; Mexia et al., 2018). Results from this study suggest there is comparatively less tree canopy cover than short vegetation within downtown Halifax and Dartmouth. As Halifax considers open space and green belt development within the city, emphasizing tree canopy should be an important factor in consideration in planning their placement.

5.5 Relationship between income and green space

Stable areas of high-income during the fifteen-year study period are not consistent with areas identified with a relationship between high MHI in 2016 and tree canopy. Development practices in newer suburban development tends towards removing mature tree canopy thereby replacing existing canopy coverage with young, less dense trees (Steenberg et al., 2013). Planting younger trees in new, higher-income suburban developments could explain why these neighbourhoods do not coincide with areas of historic high-income. There are two exceptions to the previous explanation: Bedford (cluster H-2) and a small part of the 'South End' (cluster H-1). Both spatial clusters and neighbourhoods are long standing communities in urban Halifax that have retained many of the historic, older trees and had more time for trees to reach maturity (Steenberg et al., 2013). As mentioned previously, the 'South End' is an area of historic affluence existing since the 1870s contributing to its small pockets of high-income and high-tree canopy coverage (Milward, 1983). Whereas Bedford was historically a separate region with a different development history, prior to the amalgamation into the Halifax Regional Municipality (HRM) in 1996 (City of Halifax, 2014). Though some research suggests that there is a relationship between high-socioeconomic status and green space (e.g., Astell-Burt et al., 2014; Shanahan et al., 2014), not all studies have found a strong relationship (e.g., Heynen & Lindsey, 2003; Greene et al., 2018).

Areas of stable low-income during the fifteen-year study period are generally consistent with areas identified as having a relationship between low MHI in 2016 and tree canopy. Therefore, the unequal distribution of tree canopy disproportionately affects areas of low-income. Considering the stability of income areas for fifteen-years, it can be inferred that areas of low-income have experienced less tree canopy coverage throughout the duration of this study period. Green space and tree canopy inequalities have been observed in many other cities raising a widespread issue regarding environmental justice within urban environments (e.g., Heynen et al., 2006; Luck et al., 2009). Acknowledging green space distributional inequalities is important for future urban planning and management plans especially considering that the identified low-income areas appear to have persisted for fifteen-years. Incorporating underlying socioeconomic factors (e.g., the Canadian Marginalization Index) for green space placement would be a step in the right direction, however it is vital to acknowledge the various other social, cultural, and political pressures and biases that contribute to green space placement (Anguluri & Narayanan, 2017). For example, other areas of concern for green space placement includes race and ethnicity, education-level, home ownership, etc. (Steenberg et al., 2013; Shanahan et al., 2014; Greene et al., 2018). Additionally, it is important to recognize the impact of green space development in low-income communities as in some cases poorly planned green spaces can increase property values (Anguluri & Narayanan, 2017).

Other than the previously identified areas of unequal green space, the overarching relationship between MHI in 2016 and green space in Halifax is of moderate strength and could be explained in part by the implementation of the *Urban Forest Master Plan* in 2013 during the latter portion of the study period (Halifax Regional Municipality, 2013). This plan outlines preventative forest management techniques that aim to ensure equal availability of the urban forest by incorporating stakeholders' opinions and knowledge (Halifax Regional Municipality, 2013). The City of Halifax has also recently developed the *Halifax Green Network Plan* with one of its main objectives is to incorporate more 'open space' (or green space) and green belts in Halifax (Halifax Regional Municipality, 2018). The *Halifax Green Network* and the *Halifax Regional Plan* outlines strategic outlines for the protection and management of green space in

Halifax Regional Municipality. Recognizing environmental, social, health benefits from green space, these plans share similar goals to increase connectivity and availability of green space in Halifax (Halifax Regional Municipality, 2018). In the analysis for green space placement, there were many variables for placement, however the Green Network working group did not consider any form of income factors into their decision. Therefore, since results of this study show the emerging trend of green space distributional inequalities in Halifax, it is recommended that the city of Halifax considers income data when determining the placement of quality green space.

6.0 Conclusion

This study quantified the spatial relationship between median household income from 2001 to 2016 and existing green space in urban Halifax. Most notable significant findings of this study include: relatively static geographic regions of high- and low-income neighbourhoods indicating some degree of income polarization, displacement of low-income dissemination areas by middle-income groups, and unequal distribution of tree canopy disproportionately effecting low-income neighbourhoods.

Disproportional distribution of green space, specifically tree canopy, is an important indicator for environmental justice issues in Halifax. These results demonstrate that income inequalities are related to a neighbourhood's availability of green space. Therefore, future green space placement and policy decisions are essential considering the shortage of tree canopy that coincides with low-income neighbourhoods. Results of this study can aid decision-makers to minimize inequality and environmental justice issues raised by considering income data in future green space placement. Considering the seemingly static nature of income neighbourhoods in Halifax, environmental and income inequalities could persist in the future if they are not addressed through future green space placement and policy decisions. Median household income was used as an area of focus for environmental justice issues, therefore future studies could integrate other important socioeconomic variables such as race/ethnicity, education-level, home ownership, etc.

This study incorporated novel methodology in the income polarization and environmental justice fields, therefore this somewhat unique approach to quantifying income polarization in relation to environmental inequalities can be used in future studies. Understanding the relationship between income polarization and environmental amenities is important for identifying environmental justice issues in any geographic location. Therefore, methodology used in this study can be used for the identification of environmental inequalities with the goal of providing a framework for decision, and policy-makers to address these environmental justice issues.

7.0 Literature cited

Alig, R., Kline, J. K., & Lichtenstein, M. (2004). Urbanization on the US landscape: Looking ahead in the 21st century. *Landscape and Urban Planning*, *69*, 219–234. doi:10.1016/j.landurbplan.2003.07.004

Anguluri, R., & Narayanan, P. (2017). Role of green space in urban planning: Outlook towards smart cities. *Urban Forestry and Urban Greening*, *25*, 58–65. doi:10.1016/j.ufug.2017.04.007

Anselin, L. (1995). Local Indicators of Spatial Association-LISA. *Geographical Analysis*, *27*(2), 93.

Astell-Burt, T., Feng, X., Mavoa, S., Badland, H. M., & Giles-Corti, B. (2014). Do low-income neighbourhoods have the least green space? A cross-sectional study of Australia's most populous cities. *BMC Public Health*, *14*(1), 19–21. doi:10.1186/1471-2458-14-292

Banting, K., & Myles, J. (2013). *Inequality and the Fading of Redistributive Politics*. Vancouver: UBC Press.

Barbosa, O., Tratalos, J. A., Armsworth, P. R., Davies, R. G., Fuller, R. A., Johnson, P., & Gaston, K. J. (2007). Who benefits from access to green space? A case study from Sheffield, UK. *Landscape and Urban Planning*, *83*, 187–195. doi:10.1016/j.landurbplan.2007.04.004

Beach, C. M. (2016). Changing income inequality: A distributional paradigm for Canada. *Canadian Journal of Economics*, *49*(4), 1229–1292. doi:10.1111/caje.12248

Berland, A., Schwarz, K., Herrmann, D.L., & Hopton, M.E. (2015). How environmental justice patterns are shaped by place: Terrain and tree canopy in Cincinnati, Ohio, USA. *Cities and the Environment (CATE)*, *8*(1), 1–15.

Boone, C. G. (2008). Environmental justice as process and new avenues for research. *Environmental Justice*, *1*(3), 149–153. doi:10.1089/env.2008.0530

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, *29*, 293–201.

Boulant, J., Brezzi, M., & Veneri, P. (2016). *Income Levels And Inequality in Metropolitan Areas: A Comparative Approach in OECD Countries*. https://doi.org/10.1108/10610421011068559

Bourne, L. S. (1989). Are new urban forms emerging? Empirical tests for Canadian urban areas. *Canadian Geographer*, *33*(4), 312–328. doi:10.1111/j.1541-0064.1989.tb00918.x

Bourne, L. (1993). The myth and reality of gentrification; a commentary on emerging urban forms. *Urban Studies*, *30*(1), 183–189.

Breau, S., Shin, M., & Burkhart, N. (2018). Pulling apart: New perspectives on the spatial dimensions of neighbourhood income disparities in Canadian cities. *Journal of Geographical Systems*, *20*(1), 1–25. doi:10.1007/s10109-017-0255-0

Bunting, T., & Filion, P. (2001). Uneven cities: Addressing rising inequality in the twenty-first century. *Canadian Geographer*, *45*(1), 126–131. doi:10.1111/j.1541-0064.2001.tb01176.x

Bunting, T. E., Filion, P., Hoernig, H., Seasons, M., & Lederer, J. (2007). Density, size, dispersion: Towards understanding the structural dynamics of mid-size cities. *Canadian Journal of Urban Research*, *16*(2), 27–52.

City of Halifax. (2014a). *Regional municipal planning strategy*. Retrieved from https://www.halifax.ca/sites/default/files/documents/about-the-city/regional-community-planning/RegionalMunicipalPlanningStrategy-02Jun2018-Case21281.pdf

City of Halifax. (2014b). *Downtown Halifax secondary municipal planning strategy*. Retrieved from https://www.halifax.ca/sites/default/files/documents/transportation/transportation-projects/Cogswell-DowntownHalifax_MunicipalPlanningStrategy.pdf

Dai, D. (2011). Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene? *Landscape and Urban Planning*, *102*(4), 234–244. doi:10.1016/j.landurbplan.2011.05.002

de Maio, F. G. (2007). Income inequality measures. *Journal of Epidemiology and Community Health, 61*(10), 849–852.

de Vries, S., van Dillen, S. M. E., Groenewegen, P. P., & Spreeuwenberg, P. (2013). Streetscape greenery and health: Stress, social cohesion and physical activity as mediators. *Social Science and Medicine, 94*, 26–33. doi:10.1016/j.socscimed.2013.06.030

Delmelle, E. C., Zhou, Y., & Thill, J. C. (2014). Densification without growth management? Evidence from local land development and housing trends in Charlotte, North Carolina, USA. *Sustainability (Switzerland), 6*(6), 3975–3990. doi:10.3390/su6063975

Dinca-Panaitescu, M., & Walks, A. (2015). Income inequality, income polarization, and poverty: How are they different? How are they measured? University of Toronto. Toronto. Retrieved from http://neighbourhoodchange.ca/documents/2015/12/inequality-polarization-poverty-definitions.pdf

Duinker, P. N., Ordóñez, C., Steenberg, J. W. N., Miller, K. H., Toni, S. A., & Nitoslawski, S. A. (2015). Trees in Canadian cities: Indispensable life form for urban sustainability. *Sustainability (Switzerland)*, *7*(6), 7379–7396. doi.org/10.3390/su7067379

Environmental Protection Agency. (n.d.). *Learn more environmental justice*. Retrieved from https://www.epa.gov/environmentaljustice/learn-about-environmental-justice

Environmental Protection Agency. (2017). *What is open space / green space?* Retrieved from https://www3.epa.gov/region1/eco/uep/openspace.html

Erkip, F. (1997). The distribution of urban public services: The case of parks and recreational services in Ankara. *Cities*, *14*(6), 353–361. doi:10.1016/S0264-2751(97)00026-7.

Fiedler, R., & Addie, J.-P. (2008). Canadian cities on the edge: Reassessing the Canadian suburb. Occasional Paper Series (Vol. 1).

Filion, P., Bunting, T., Pavlic, D., & Langlois, P. (2010). Intensification and sprawl: Residential density trajectories in Canada's largest metropolitan regions. *Urban Geography*, *31*(4), 541–569. doi:10.2747/0272-3638.31.4.541.

Flowerdew, R. (2012). How serious is the Modifiable Areal Unit Problem for analysis of English census data? *Population Trends*, *145*, 106–118. doi.org/10.1057/pt.2011.20

Glaeser, E. L., Resseger, M., & Tobio, K. (2009). Inequality in cities. *Journal of Regional Science*, *49*(4), 617–646. doi:10.1111/j.1467-9787.2009.00627.x

Grant, J. L., & Gregory, W. (2015). Who lives downtown? Neighbourhood change in central Halifax, 1951-2011. *International Planning Studies*, *21*(2), 176–190. doi:10.1080/13563475.2015.1115340

Greene, C. S., Robinson, P. J., & Millward, A. A. (2018). Canopy of advantage: Who benefits most from city trees? *Journal of Environmental Management*, *208*, 24–35. doi:10.1016/j.jenvman.2017.12.015

Halifax Regional Municipality. (2013). *Urban Forest Master Plan.* https://www.halifax.ca/sites/default/files/documents/transportation/streets-sidewalks/HALREG%201246%20UrbanForestReport_HighRes_SINGLEPAGE_Mon20_Combined.pdf

Halifax Regional Municipality. (2018). *Halifax Green Network Plan*. https://www.halifax.ca/sites/default/files/documents/about-the-city/regional-community-planning/HGNP-Final%20Report_20180726_updated.pdf

Harvey, B. J. (2014). *North of North Street: Green Spaces, Identity, and the Middle Class*. Dalhousie Univerity.

Heynen, N., Perkins, H.A., and Roy, P. (2006). The political ecology of uneven urban green space: The impact of political economy on race and ethnicity in producing environmental inequality in Milwaukee. *Urban Affairs Review*, *42*(3), 3–25. doi:10.1177/1078087406290729.

Heynen, N. C., & Lindsey, G. (2003). Correlates of urban forest canopy cover: Implications for local public works. *Public Works Management & Policy*, *8*(1), 33–47. https://doi.org/10.1177/1087724X03253604

Hofmann, N. (2001). Urban consumption of agricultural land. *Rural and Small Town Canada Analysis Bulletin*, *3*(2), 1-13.

Hulchanski, J. D. (2010). *Income Polarization Among Toronto's Neighbourhoods, 1970-2005. Social Sciences*. Retrieved from http://www.urbancentre.utoronto.ca/pdfs/curp/tnrn/Three-Cities-Within-Toronto-2010-Final.pdf

Kabisch, N., & Haase, D. (2014). Green justice or just green? Provision of urban green spaces in Berlin, Germany. *Landscape and Urban Planning*, *122*, 129–139. doi:10.1016/j.landurbplan.2013.11.016

Kedron, P. (2016). Identifying the geographic extent of environmental inequalities: A comparison of pattern detection methods. *Canadian Geographer*, *60*(4), 479–492. doi:10.1111/cag.12297

LaPaix, R., & Freedman, B. (2010). Vegetation structure and composition within urban parks of Halifax Regional Municipality, Nova Scotia, Canada. *Landscape and Urban Planning*, *98*(2), 124–135. doi:10.1016/j.landurbplan.2010.07.019

Lee, S. II. (2001). Developing a bivariate spatial association measure: An integration of Pearson's r and Moran's I. *Journal of Geographical Systems*, *3*, 369–385. doi.org/10.1007/s101090100064

Lloyd, C.D. (2010). *Spatial data analysis: an introduction for GIS users*. New York: Oxford University Press, 2010.

Luck, G. W., Smallbone, L. T., & O'Brien, R. (2009). Socio-economics and vegetation change in urban ecosystems: Patterns in space and time. *Ecosystems*, *12*(4), 604–620. doi:10.1007/s10021-009-9244-6

Maas, J., Verheij, R. A., Groenewegen, P. P., De Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity, and health: How strong is the relation? *Journal of Epidemiology and Community Health*, *60*(7), 587–592. doi:10.1136/jech.2005.043125

MacLachlan, I., & Sawada, R. (1997). Measures of income inequality and social polarization in Canadian metropolitan areas. *Canadian Geographer*, *41*(4), 377–397. doi:10.1111/j.1541-0064.1997.tb01322.x

Mexia, T., Vieira, J., Príncipe, A., Anjos, A., Silva, P., Lopes, N., … Pinho, P. (2018). Ecosystem services: Urban parks under a magnifying glass. *Environmental Research*, *160*, 469–478. doi:10.1016/j.envres.2017.10.023

Millward, H. (1983). Single-family house values in metropolitan Halifax, 1981. *Canadian Geographer*, *27*(2), 178–183. doi:10.1111/j.1541-0064.1983.tb01472.x

Newman, P. (2006). The environmental impact of cities. *Environment and Urbanization*, *18*(2), 275–295. doi:10.1177/0956247806069599

Nowak, D. J., & Crane, D. E. (2002). Carbon Storage and Sequestration by urban trees in the USA. *Environmental Pollution, 116*, 381–389.

Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry and Urban Greening*, *4*, 115–123. doi:10.1016/j.ufug.2006.01.007

OECD. (n.d.). *Income inequality*. Retrieved from https://data.oecd.org/inequality/income-inequality.htm

OECD. (2014). *Economic surveys, 2014 Canada*. OECD, Paris.

Pham, T. T. H., Apparicio, P., Séguin, A. M., Landry, S., & Gagnon, M. (2012). Spatial distribution of vegetation in Montreal: An uneven distribution or environmental inequity? *Landscape and Urban Planning*, *107*(3), 214–224. doi.org/10.1016/j.landurbplan.2012.06.002

Prouse, V., Grant, J. L., Radice, M., & Ramos, H. (2014a). *Neighbourhood change in Halifax Regional Municipality, 1970 to 2010: Applying the "Three Cities" model*. Halifax.

Prouse, V., Ramos, H., Grant, J. L., & Radice, M. (2014b). How and when scale matters: The modifiable areal unit problem and income inequality in Halifax. *Canadian Journal of Urban Research*, *23*(1), 61–82.

Ramos, H., & MacNabb, K. (2018). *Halifax: A city of 'hotspots' of income inequality*. Halifax. Retrieved from http://perceptionsofchange.ca/Hotspotsofincomeinequality.pdf

Rogerson, P. (2015). *Statistical methods for geography: A student's guide.* London: SAGE Publishing, 2015.

Rose, D., & Twigge-Molecey, A. (2013). *A city-region growing apart? Taking stock of income disparity in greater Montreal, 1970-2005*. Toronto: Cities Center, University of Toronto.

Schwarz, K., Fragkias, M., Boone, C. G., Zhou, W., McHale, M., Grove, J. M., … Cadenasso, M. L. (2015). Trees grow on money: Urban tree canopy cover and environmental justice. *PLOS ONE*, *10*(4), 1–17. doi.org/10.1371/journal.pone.0122051

Scott, A.J. (1986). Industrialization and urbanization: A geographical agenda. *Annals of the Association of American Geographers*, *76*(1), 25-37.

Shanahan, D. F., Lin, B. B., Gaston, K. J., Bush, R., & Fuller, R. A. (2014). Socio-economic inequalities in access to nature on public and private lands: A case study from Brisbane, Australia. *Landscape and Urban Planning, 130*(1), 14–23. doi:10.1016/j.landurbplan.2014.06.005

Stantec. (2013). *Quantifying the costs and benefits of alternative growth scenarios*. Retrieved from https://www.halifax.ca/sites/default/files/documents/about-the-city/regional-community-planning/HRMGrowthScenariosFinalReportJuly82013.pdf

Statistics Canada. (2001). *Cartographic Boundary Files (CBF), 2001 Census* [Shapefile]. Scholars GeoPortal, [Distributor]. Retrieved from http://geo.scholarsportal.info/#r/details/_uri@=1739082337

Statistics Canada. (2001). *2001 Profile of dissemination areas: Income of individuals, families and households earnings* [table]. 2001 Census. Statistics Canada [Producer]; University of Toronto: CHASS [Distributor]. Retrieved from http://dc1.chass.utoronto.ca/cgi-bin/census/2001/displayCensusDA.cgi?c=inc

Statistics Canada. (2006). *2006 National Household Survey: Income of households* [table]. 2006 Census. Statistics Canada [Producer]; University of Toronto: CHASS [Distributor]. Retrieved from http://dc1.chass.utoronto.ca/cgi-bin/census/2006/displayCensusDA.cgi?c=inc

Statistics Canada. (2011). *2011 Profile of dissemination areas: Income of individuals, families and households earnings* [table]. Statistics Canada [Producer]; University of Toronto: CHASS [Distributor]. Retrieved from http://dc1.chass.utoronto.ca/cgi-bin/census/2011nhs/displayCensus.cgi?year=2011&geo=da

Statistics Canada. (2011). *From urban areas to population centers*. Retrieved from https://www.statcan.gc.ca/eng/subjects/standard/sgc/notice/sgc-06

Statistics Canada. (2015a). *Dissemination area (DA).* Retrieved from https://www12.statcan.gc.ca/census-recensement/2011/ref/dict/geo021-eng.cfm

Statistics Canada. (2015b). *National Household Survey user guide*. Retrieved from https://www12.statcan.gc.ca/nhs-enm/2011/ref/nhs-enm_guide/guide_4-eng.cfm

Statistics Canada. (2016). *2016 Profile of dissemination areas: Income* [table]. 2016 Census. Statistics Canada [Producer]; University of Toronto: CHASS [Distributor]. Retrieved from http://dc1.chass.utoronto.ca/cgi-bin/census/2006/displayCensusDA.cgi?c=inc

Statistics Canada. (2017). *Census profile, 2016 census*. Retrieved from https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E

Steenberg, J. W. N., Duinker, P. N., & Charles, J. D. (2013). The neighbourhood approach to urban forest management: The case of Halifax, Canada. *Landscape and Urban Planning*, *117*, 135–144. doi:10.1016/j.landurbplan.2013.04.003

Thompson, C. W., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. *Landscape and Urban Planning*, *105*(3), 221–229. doi.org/10.1016/j.landurbplan.2011.12.015

United Nations. (2018a). *World urbanization prospects: The 2018 provision*. Retrieved from https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf

United Nations. (2018b). *The speed of urbanization around the world.* Retrieved from https://population.un.org/wup/Publications/Files/WUP2018-PopFacts_2018-1.pdf

Vemuri, A. W., Grove, J., Wilson, M. A., & Burch, W. R. (2011). A tale of two scales: Evaluating the relationship among life satisfaction, social capital, income, and the natural environment at individual and neighborhood levels in metropolitan Baltimore. *Environment and Behavior*, *43*(1), 3–25. doi.org/10.1177/0013916509338551

Völker, S., Heiler, A., Pollmann, T., Claßen, T., Hornberg, C., & Kistemann, T. (2018). Do perceived walking distance to and use of urban blue spaces affect self-reported physical and mental health? *Urban Forestry and Urban Greening, 29*, 1–9. doi:10.1016/j.ufug.2017.10.014

Walks, A., & Bourne, L. S. (2006). Ghettos in Canada's cities? Racial segregation, ethnic enclaves and poverty concentration in Canadian urban areas. *Canadian Geographer*, *50*(3), 273–297. doi:10.1111/j.1541-0064.2006.00142.x

Walks, R. A., & Maaranen, R. (2008). Gentrification, Social Mix, and Social Polarization: Testing the Linkages in Large Canadian Cities. *Urban Geography*, *29*(4), 293-326. doi:10.2747/0272-3638.29.4.293

Walks, A. (2013). *Income inequality and polarization in Canada's cities: An examination and new form of measurement*. Toronto: University of Toronto.

Wüstemann, H., Kalisch, D., & Kolbe, J. (2017). Access to urban green space and environmental inequalities in Germany. *Landscape and Urban Planning, 164*, 124–131. doi:10.1016/j.landurbplan.2017.04.002

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities "just green enough." *Landscape and Urban Planning*, *125,* 234–244. doi:10.1016/j.landurbplan.2014.01.017

Zwiers, M., Kleinhans, R., & Van Ham, M. (2015). Divided Cities : Increasing Socio-Spatial Polarization within Large Cities in the Netherlands. *IZA Discussion Paper Series*, (8882), 1–31. https://doi.org/10.1029/2011JD017186

8.0 Appendices

Appendix A: Classification

Table 1. Confusion matrix for supervised classification of land cover in urban Halifax, Nova Scotia using object-based image analysis.

	Producers					
	Classified Class	Canopy	Water	Short Vegetation	Other	**Total**
Users	Canopy	151	1	3	3	158
	Water	0	77	0	1	78
	Short Vegetation	0	0	13	1	14
	Other	0	1	1	50	52
	Total	151	79	17	55	302

Table 2. Accuracy assessment statistics for supervised classification of land cover in urban Halifax, Nova Scotia using object-based image analysis.

Class Name	Producer Accuracy (%)	Producer 95% Confidence Interval Lower (%)	Producer 95% Confidence Interval Upper (%)	User Accuracy (%)	User 95% Confidence Interval Lower (%)	User 95% Confidence Interval Upper (%)	Kappa Statistic
Canopy	100	99.668877	100	95.56963	92.04463	99.09462	0.911392
Water	97.4684	93.37146	100	98.71795	95.58026	100	0.982638
Short Vegetation	76.4706	53.365055	99.576118	92.85714	75.79497	100	0.924311
Other	90.9091	82.402306	99.415886	96.15385	89.96532	100	0.952974

Appendix B: Income data and statistics

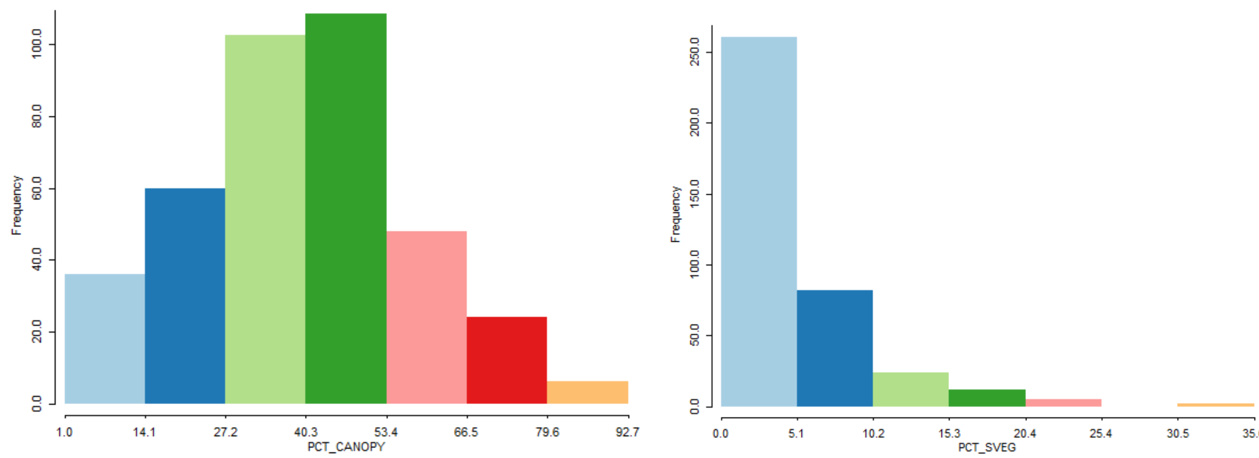


Figure 14. Frequency distribution of % tree canopy (PCT_CANOPY) and % short vegetation (PCT_VEG) by dissemination area in urban Halifax, Nova Scotia.

Table 3. Percentage of dissemination areas (DA) by cluster type between 2001 and 2016 in urban Halifax, Nova Scotia.

	High-high		**Low-low**		**Other (Non-significant; high-low; low-high)**	
Census years	# of DAs	% urban Halifax	# of DAs	% urban Halifax	# of DAs	% urban Halifax
2001 & 2016	46	11.38%	66	16.34%	292	72.28%

Table 4. Percent change in the number of dissemination areas between sequential temporal census pairs in urban Halifax from 2001-2016.

	% change in # of Das		
Census years	High-high	Low-low	Non-significant; high-low; low-high
2001 & 2006	-7.14%	-8.20%	2.66%
2006 & 2011	-4%	0.89%	0.32%
2011 & 2016			

Table 5. Percentage of urban Halifax and number of dissemination areas (DA) by cluster-type based on sequential temporal pairs of median household income.

Census years	High-high		Low-low		Non-significant; high-low; low-high	
	# of DAs	% urban Halifax	# of DAs	% urban Halifax	# of DAs	% urban Halifax
2001 2006	45	11.10%	66	16.34%	293	72.53%
2006 2011	39	9.65%	56	13.86%	309	76.49%
2011 2016	36	8.91%	57	14.11%	311	76.98%

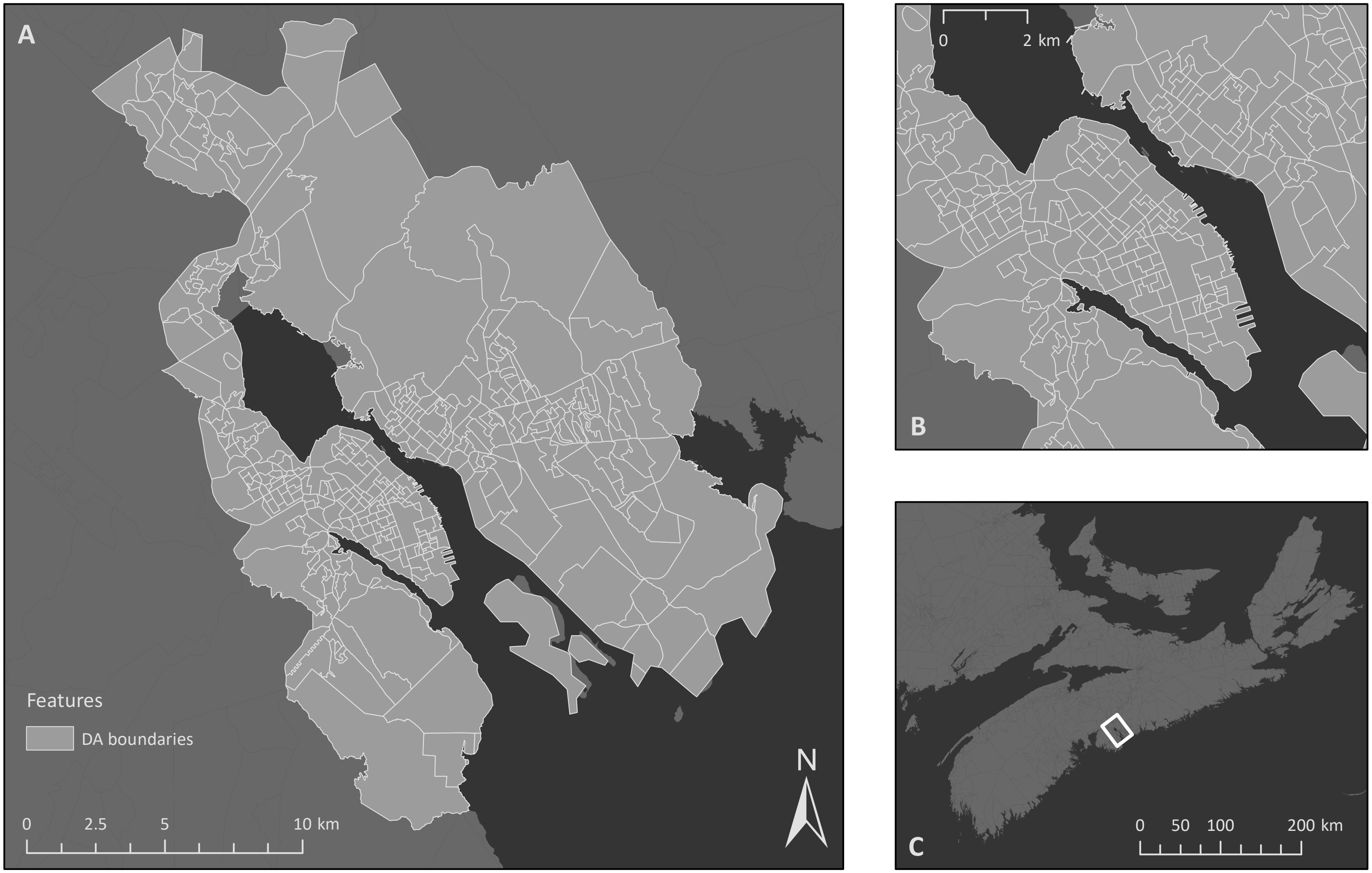
Table 6. Geographic weighted regression between median household income in 2016 and *% tree canopy* by dissemination area in urban Halifax, Nova Scotia.

GWR variables	Output
Neighbours	25
Residual squares	38216.6302
Effective number	97.512214
Sigma	11.50966
AICc	3055.35448
R^2	0.687612
Adjusted R^2	0.583104

Table 7. Geographic weighted regression between median household income in 2016 and % short vegetation by dissemination area in urban Halifax, Nova Scotia.

GWR variables	Output
Neighbours	80
Residual squares	7298.31079
Effective number	32.057339
Sigma	4.540929
AICc	2284.18145
R^2	0.246643
Adjusted R^2	0.180539

Appendix C: Maps



The

Data Projection: UTM WGS84 Zone 20N; Data Source: Statistics Canada (2001); Scholars GeoPortal

Figure 1. The geographic location and extent of urban Halifax (A), Nova Scotia with dissemination area boundaries indicated (see inset for reference of the Halifax peninsula (B) and Nova Scotia (C)).

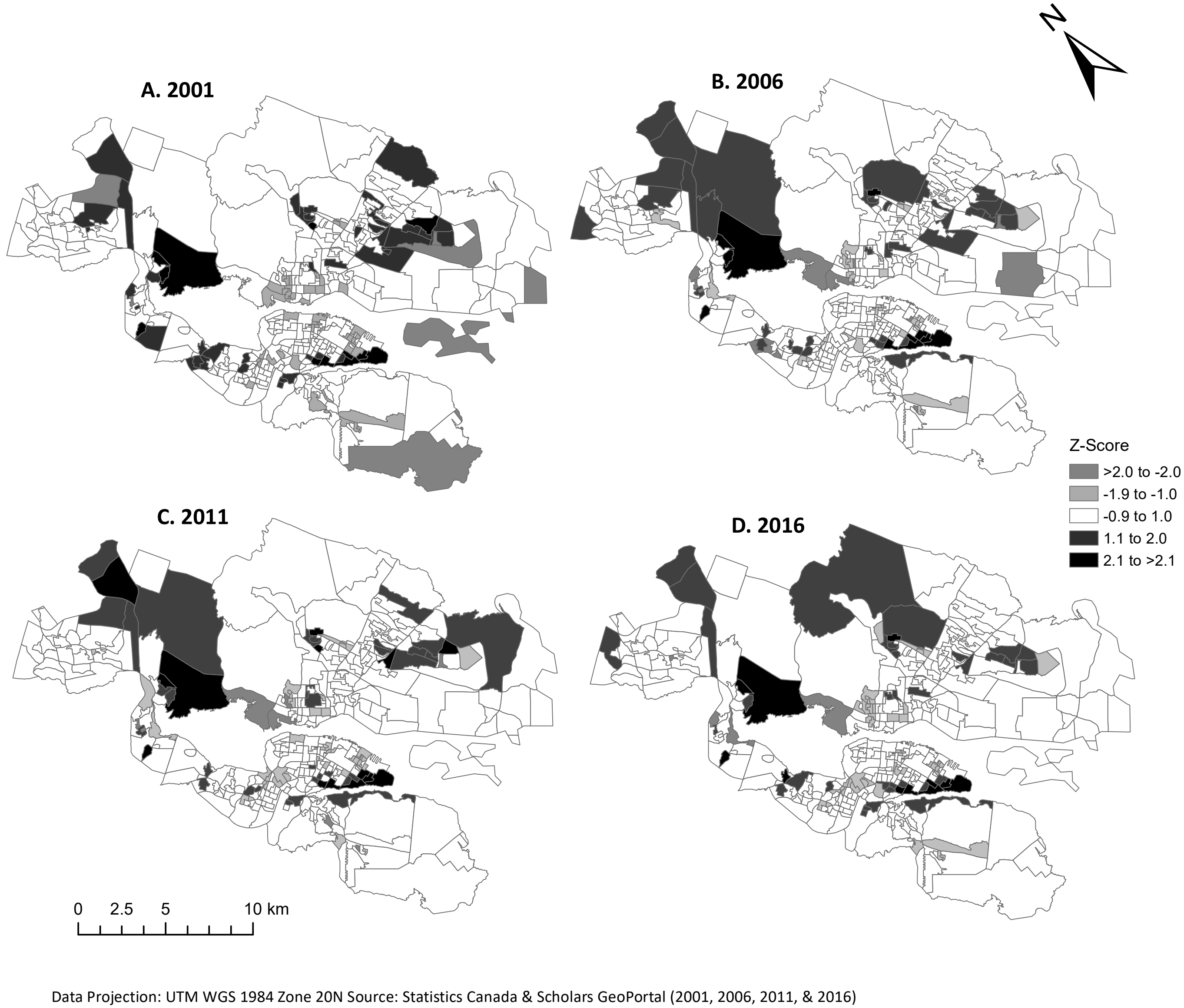
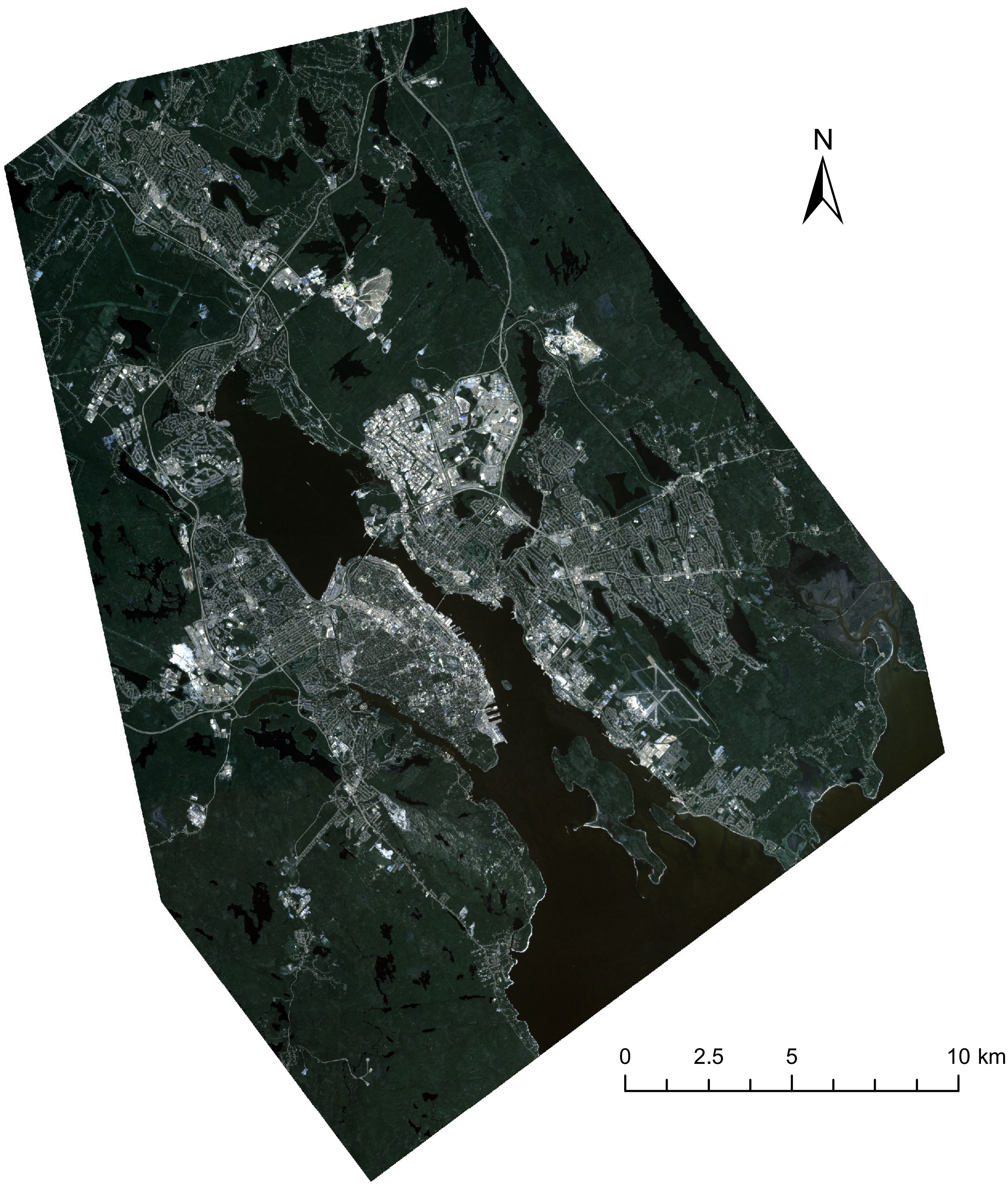


Figure 2. Median household income at the dissemination area (DA) in 2001 (A), 2006 (B), 2011 (C), and 2016 (D) in urban Halifax, Nova Scotia. Median household income is represented by z-scores.



Data Projection: UTM WG1984 Zone 20N Data Source: Planet Labs: PlanetScope- 4-band VIS-NIR (acquired: 2018-08-01)

Figure 3. Geographic extent of the five-tile mosaic PlanetScope (4-band VIS-NIR) imagery in urban Halifax, Nova Scotia. Date of acquisition: 2018-08-01

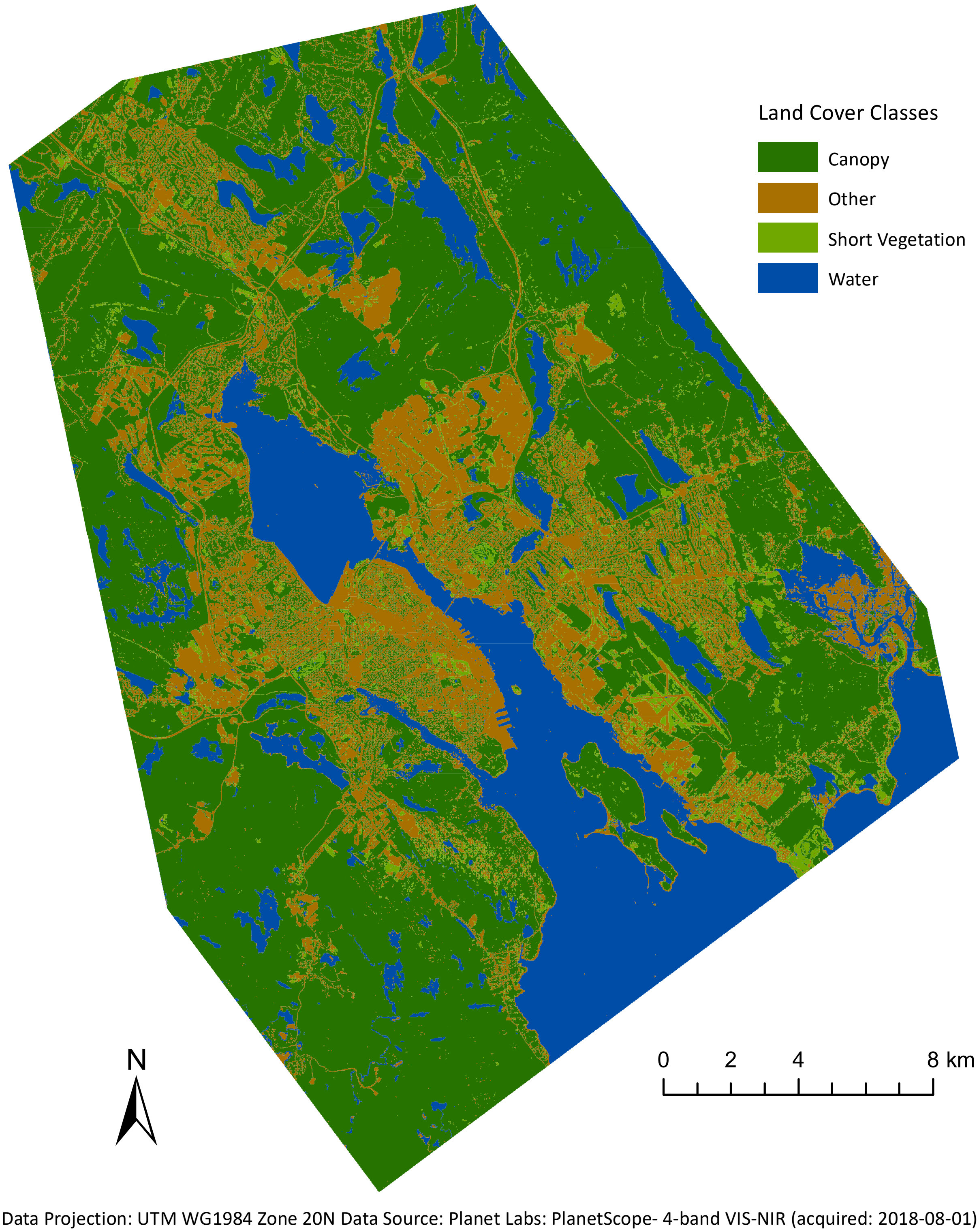


Figure 4. Tree canopy, short vegetation, water, and other land cover classified using supervised, rule-based object-based image analysis (Mean NDVI >0.3 = tree canopy) in urban Halifax, Nova Scotia.

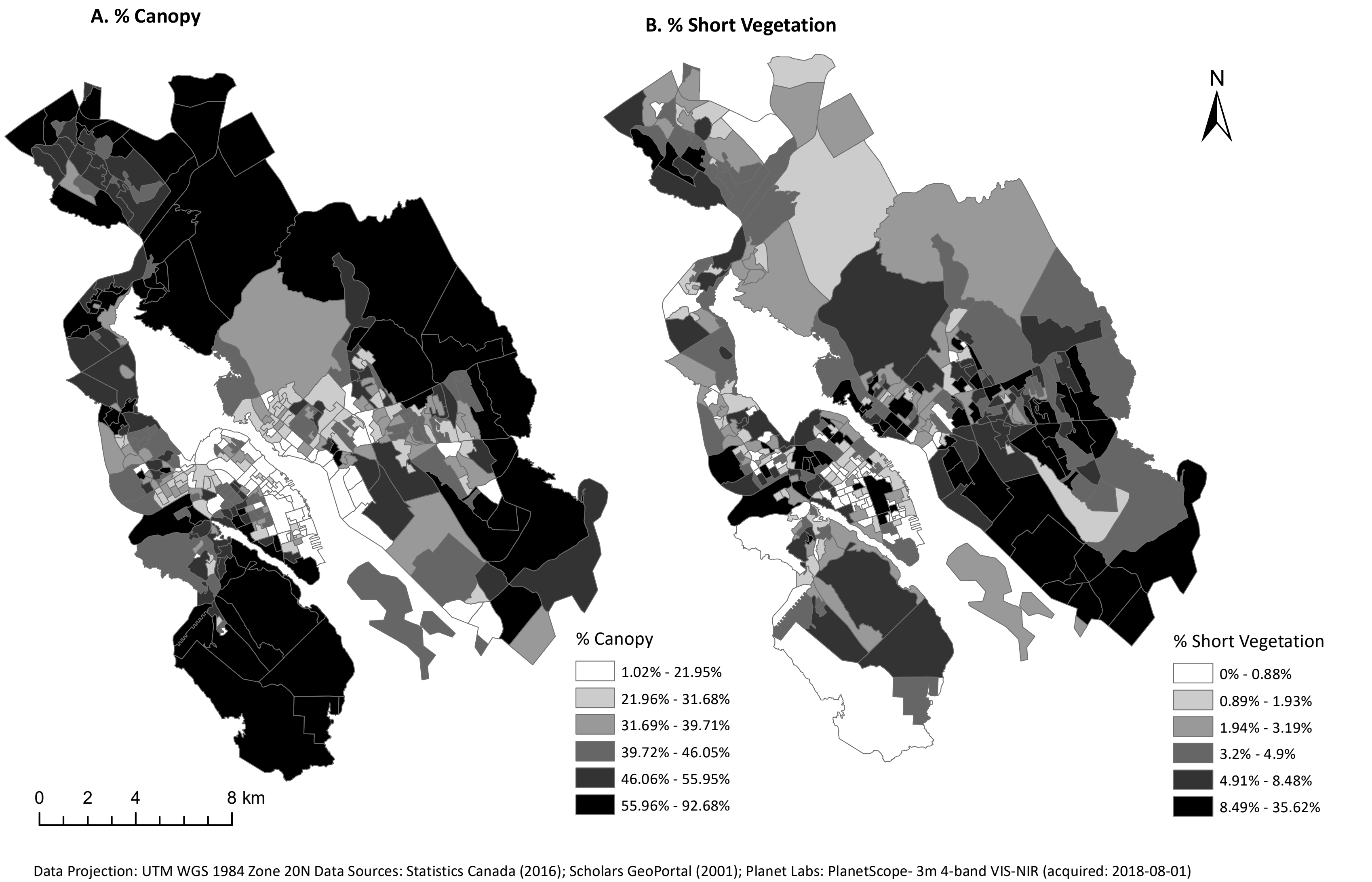


Figure 5. Percent cover of green space separated into % tree canopy (A) and % short vegetation (B) by dissemination area in urban Halifax, Nova Scotia.

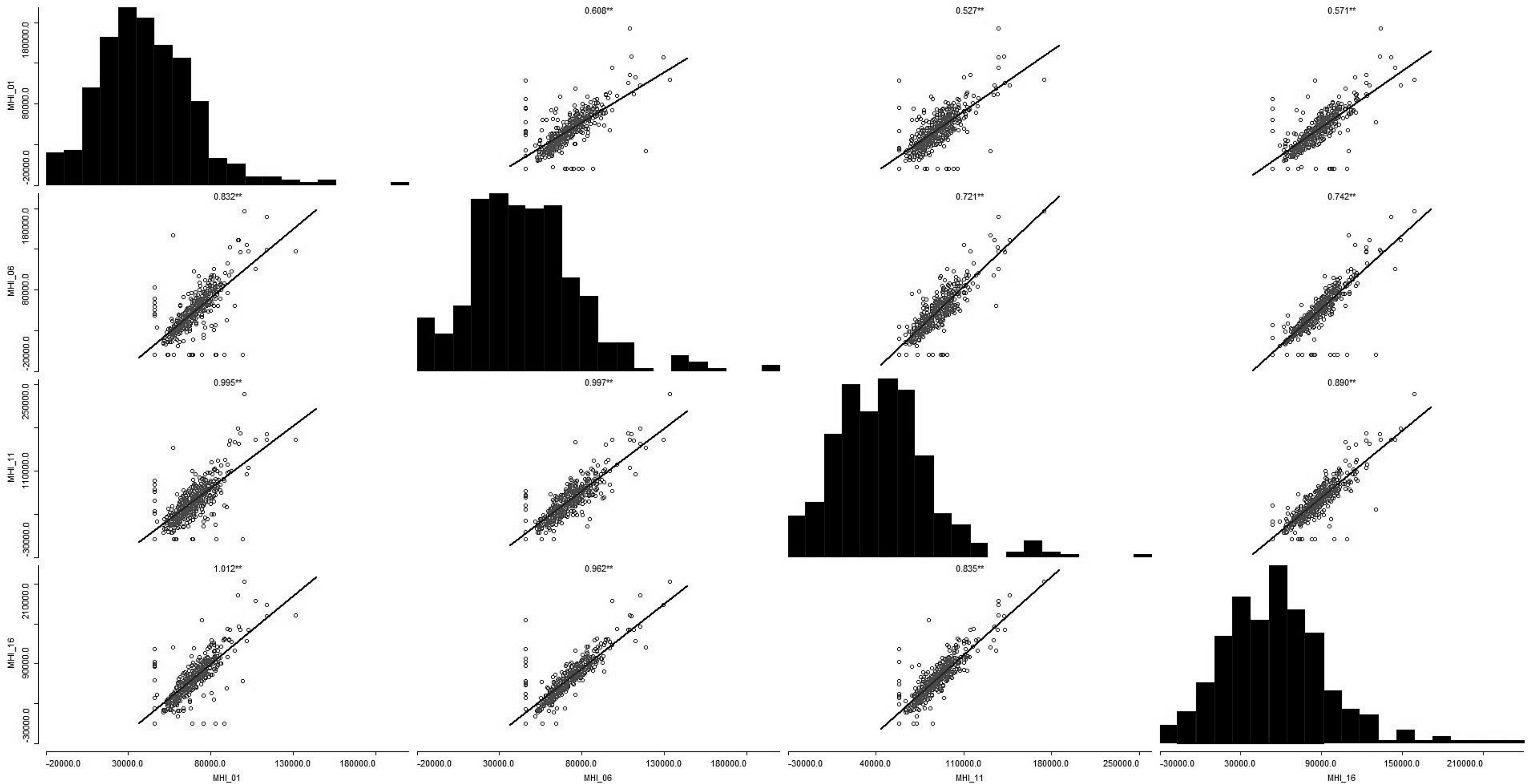


Figure 8. Correlation between median household income obtained from each census year (2001, 2006, 2011, and 2016) in urban Halifax, Nova Scotia, represented by scatterplots and histograms. Scatterplots include linear trend line and correlation coefficient.

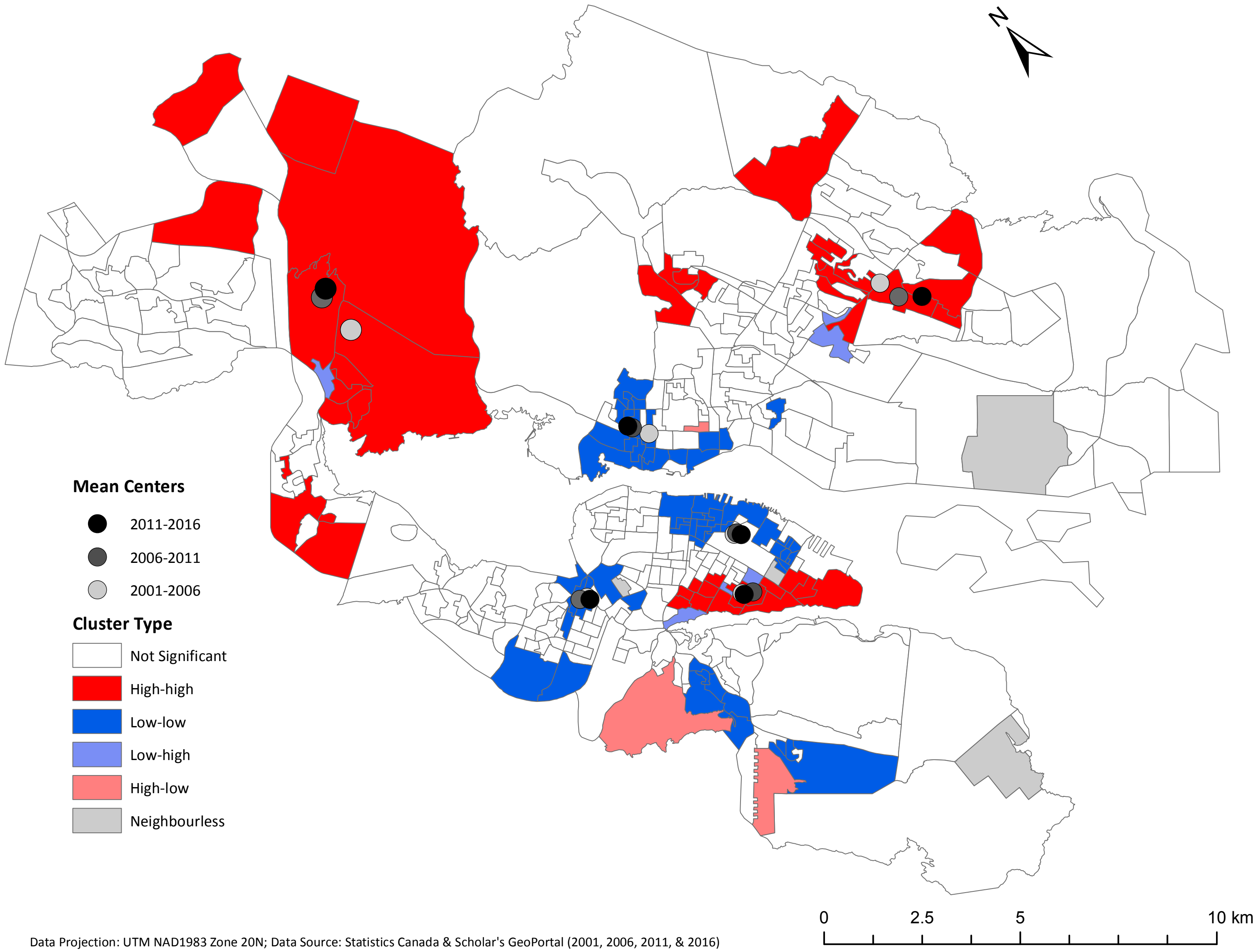
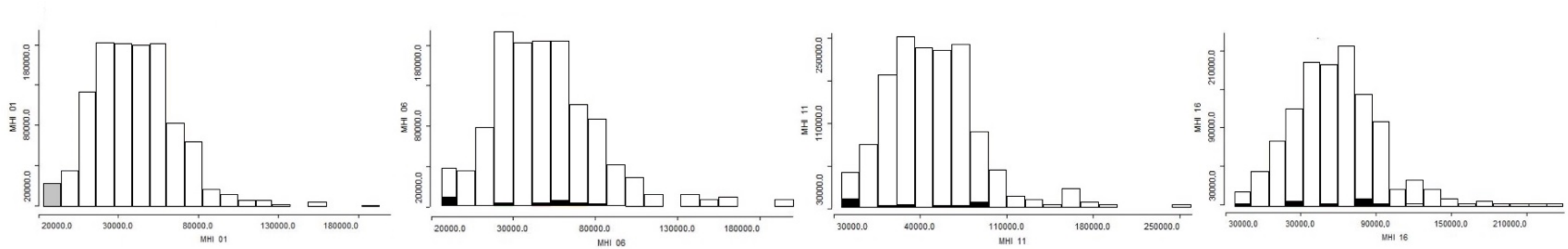


Figure 10. Mean centers of high-high and low-low clusters of median household income (MHI) from 2001 & 2006, 2006 & 2011, and 2011 & 2016. Overlain on a bivariate local indicator of spatial autocorrelation of MHI in 2001 and 2016 in urban Halifax, Nova Scotia

Low-MHI



High-MHI

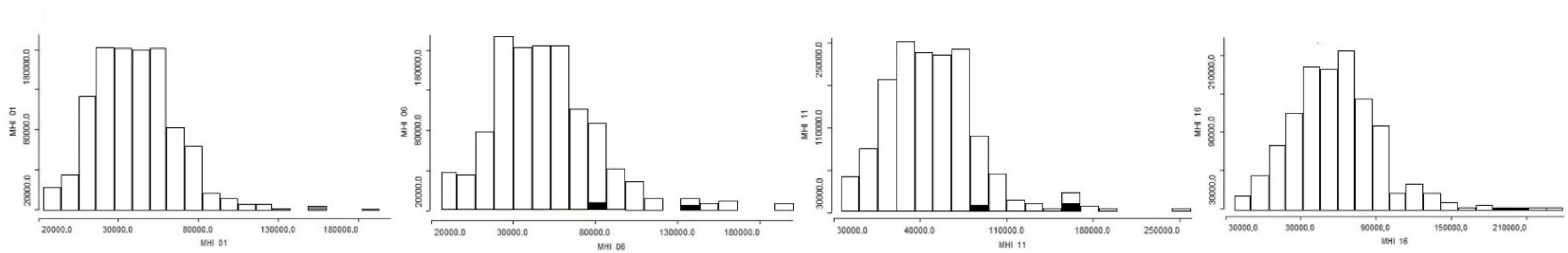
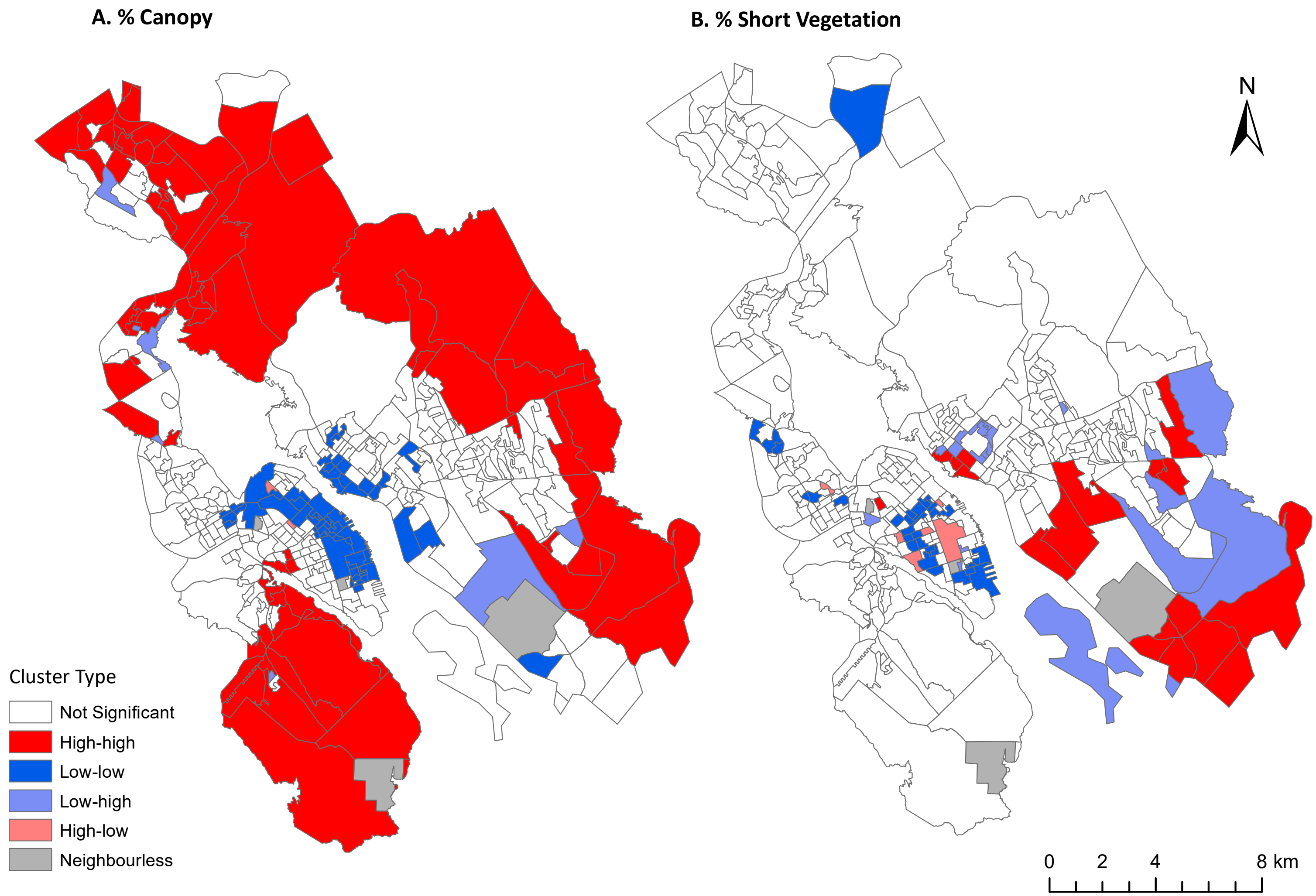
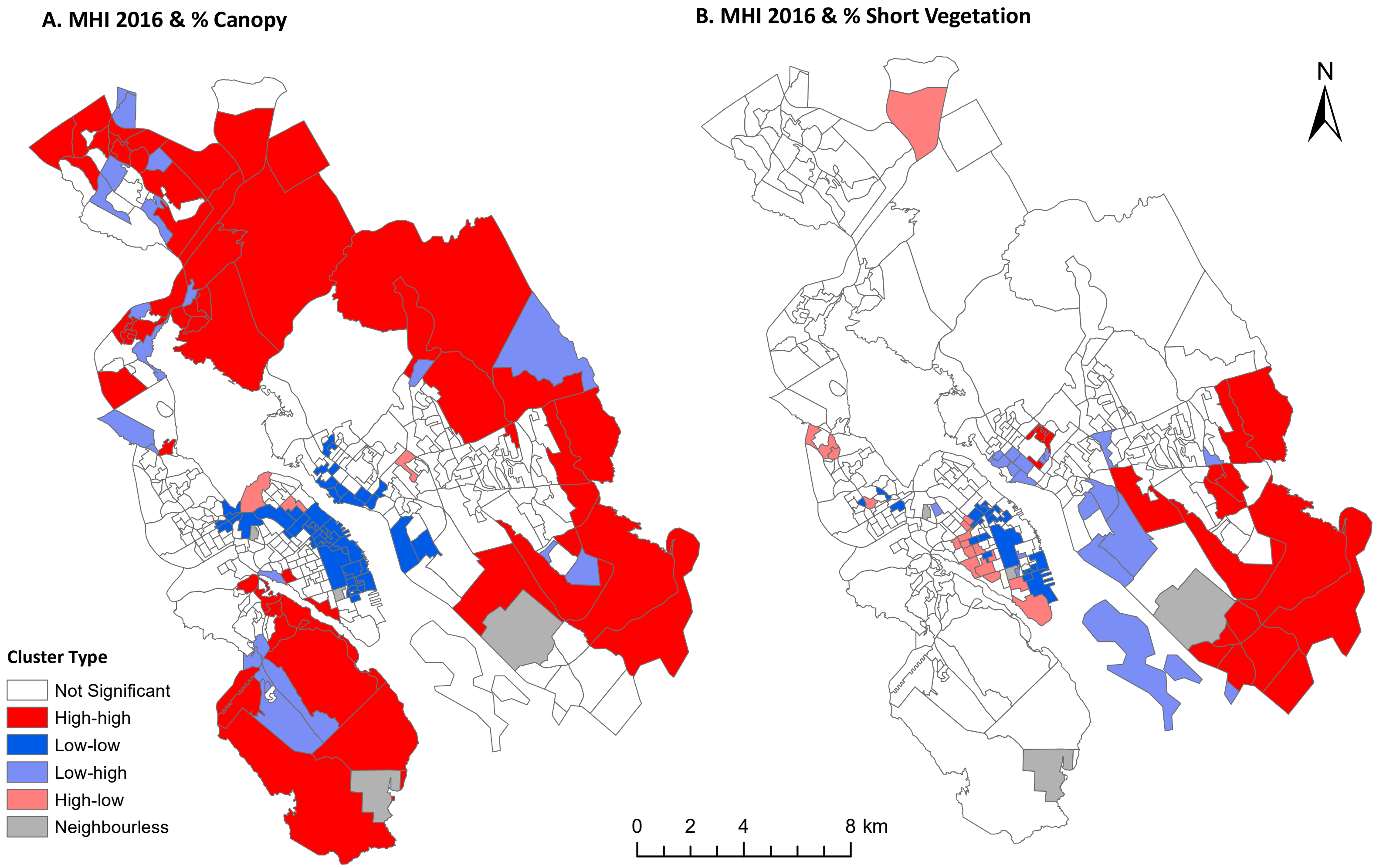


Figure 11. Displacement of low- and high-median household income groups by dissemination area (DA), as indicated by bars highlighted on the histogram, from 2001 onwards in urban Halifax, Nova Scotia. Grey bar indicates high- and low- income DA in 2001 while black bars indicate displacement of the DAs in subsequent years.



Data Projection: UTM WGS 1984 Zone 20N Data Sources: Statistics Canada (2016); Scholars GeoPortal (2001); Planet Labs: PlanetScope- 3m 4-band VIS-NIR (acquired: 2018-08-01)

Figure 12. Univariate local indicator of spatial autocorrelation (LISA) of *% tree canopy* (A) and *% short vegetation* (B) in urban Halifax, Nova Scotia.



Data Projection: UTM WGS 1984 Zone 20N Data Sources: Statistics Canada (2016); Scholars GeoPortal (2001); Planet Labs: PlanetScope- 3m 4-band VIS-NIR (acquired: 2018-08-01)

Figure 13. Bivariate local indicators of spatial autocorrelation of median household income in 2016 and green space (% tree canopy and % short vegetation) in urban Halifax, Nova Scotia.

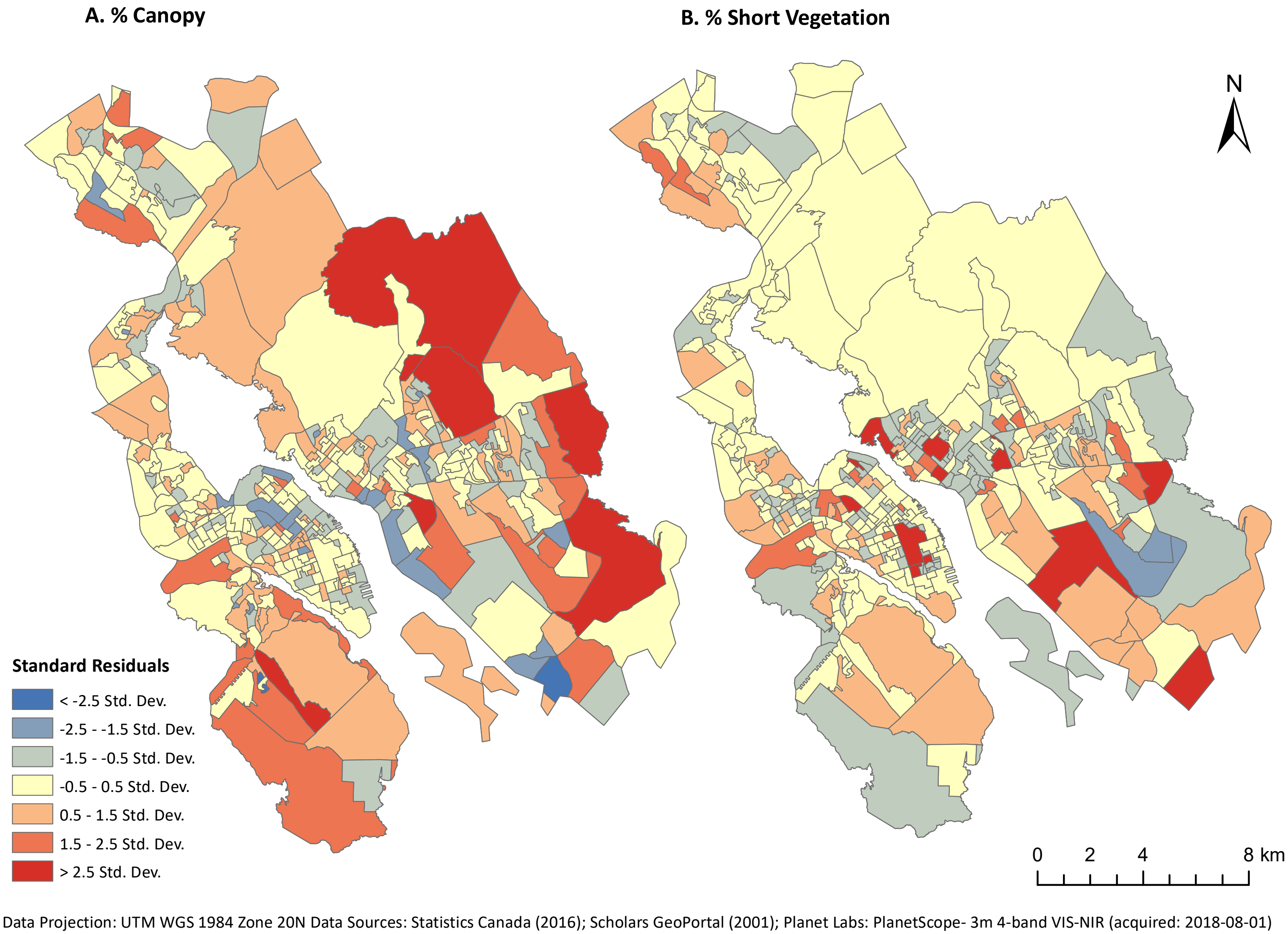


Figure 15. Standard residuals from geographic weighted regression between median household income and tree canopy (A) and short vegetation (B) in urban Halifax, Nova Scotia.