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ENVIRONMENTAL SUPPORT FOR BICYCLING IN CANADA

Association between area-based socio-economic deprivation and neighbourhood environmental

support for bicycling in nine Canadian cities

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Abstract

Previous research has found that bicycling can yield health, environmental, and social benefits. Many countries have established friendly policies and strategies to encourage bicycling behavior. However, these policies have not resulted in major shifts to bicycling, and as such, urban planners and policy makers are still looking for factors that affect people's decision in bicycling. Inequity has been found to negatively affect population health, and studies suggest that neighbourhoods with low household income tend to have less supportive infrastructure that limits residents' ability to be physically active (e.g., bicycling). This quantitative study aims to explore the association between neighbourhood socio-economic deprivation level and how supportive a neighbourhood is for bicycling (Bike Score™) in nine central metropolitan cities in Canada. In this study, neighbourhood deprivation level is measured by the Pampalon Deprivation Index, which is an index that assesses neighbourhood material and social deprivation using census data. The study has found a significant inverse relationship between neighbourhood material deprivation level and Bike Score™, and a positive relationship between social deprivation level and Bike Score™ across the study area. We recommend policy makers to allocate resources to areas with greater relative material deprivation (e.g., income inequality) and design city-specific strategies to tackle the issue.

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Background

Introduction

There has been a growing interest in studying the impact of the built environment on population health. Previous research suggests that active travel (e.g., walking and bicycling) carries various health and social benefits via increasing daily physical activity level (Kelly et al., 2014). For example, active travel modes have zero emissions, reduce community isolation, and improve mental health (Humphreys, Goodman, & Ogilvie, 2013). Therefore, it is important from a public health perspective to promote bicycling as a healthy alternative to vehicular travel and to study the potential barriers and constraints for people in accessing bicycling infrastructure. Previous research has found inequity in environmental characteristics between neighbourhoods of varying socio-economic status due to differing travel choices and physical activity levels (Kelly, Lian, Struthers, & Kammrath, 2015). We hypothesize that area-based socio-economic deprivation has an impact on residents' use of active travel, such as bicycling on a regular basis. Through the health equity approach, this study aims to determine the correlation between area-based socio-economic deprivation and access to bicycling infrastructure in nine Canadian cities.

Health, Environmental, and Social Benefits to Active Travel

Active travel refers to transportation methods that are "human powered" and require "non-trivial physical efforts to move across space, such as walking and bicycling" (Public Health Agency of Canada, 2014). Studies have found that active travel is associated with health, environmental, social, and economic benefits.

First, active travel helps adults achieve the daily physical activity level recommended by the Centers for Disease Control and Prevention (CDC) and the Public Health Agency of

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Canada (PHAC). They recommend that each adult (18- 64 years old) gets at least 150 minutes

of moderate-intensity physical activity per week to prevent the risk or progression of chronic

diseases (e.g., diabetes, obesity) (CDC, 2015; Canadian Society for Exercise Physiology,

2011). However, more than 20% of the adults worldwide do not meet this recommendation and

are at 20% to 30% higher risk of mortality than adults who reach recommended levels of

physical activity ("Prevalence of insufficient physical activity"). Evidence from meta-analyses

suggests that increasing adults' physical activity can be achieved through adopting active travel

(Woodcock et al., 2009; Teschke, Reynolds, Ries, Gouge, & Winters, 2012). A daily 7.5 km of

bicycling (approx. 30 minutes) can meet the minimum recommendations for daily physical

activity level for five days and has much greater health benefits (10:1 benefit to cost ratio) in

all-cause mortality rates than the potential adverse effects of air pollution exposure and traffic

accidents (Jeroen Johan de Hartog, Boogaard, Nijland, & Hoek, 2010; Mueller et al., 2015). In

addition, daily active travel, including bicycling, can be achieved for most people at a low cost

(Woodcock et al. 2009; Teschke et al., 2012).

Second, compared with traditional motorized travel, active travel is "greener" and a

more sustainable travel method. It minimizes air pollution by virtue of no emission of air

pollutants and greenhouse gases (British Medical Association, 2012), along with the added

benefit of protecting people from traffic associated diseases such as cardiopulmonary disease

and respiratory infection (Cohen et al., 2005). In addition, switching to active travel methods

can mitigate road congestions produced by motorized travel methods.

Lastly, active travel promotes social benefits by facilitating community interactions and

improving people's mental well-being (Humphreys et al., 2013). Previous research suggests

that when people are walking, jogging, or cycling in neighbourhoods, their chances of

interacting with other individuals in the community significantly increase, reducing the

tendency of community isolation associated with personal vehicle ownership and other forms

of mental illness (Humphreys et al., 2013; Martin, Goryakin, & Suhrcke, 2014).

Environmental Determinants of Bicycling

Studies on transportation and city planning show that environmental features such as

street infrastructure and safety are independent factors that impact physical activity levels

(Kelly et al., 2015). A cross-sectional study has found that by controlling the other explanatory

variables such as city size, ownership, climate, income, and education, the degree of bicycling

increases with the improvement in the supply of bike paths and lanes (Pucher, Buehler, &

Seinen, 2011). Cyclists prefer cycling in areas with separated bike lanes rather than areas

which have mixed traffic (Pucher et al., 2011). In addition, the mode share of commuting to

work by bicycling increases linearly with improvements in bike paths (Dill & Carr, 2003), and

that bicycling preferences double when there are "track" of bike paths and lanes in people's

neighbourhoods (Titze, Strongger, Janschitz, & Oja., 2008). Moreover, studies have found that

perceived neighbourhood safety affected residents' frequency of participating in physical

activity (Pucher et al., 2011). An improvement in the bicycling safety is one of the main factors

that lead to the growth in bicycling level in North America (Pucher et al., 2011).

Effect of Income Inequality and Relative Deprivation on Health Inequity

Health inequity is associated with disease, mortality, mental illness, and reduced access

to health care services. Inequities do not decline with the rise of a country's wealth and

longevity in developed countries (Coburn, 2010). Rather, a systematic review of 104 studies

demonstrates that health inequity is instead directly correlated with income inequality

(Wilkinson, 2006). The socio-economic status-based health inequity seems to accumulate with

population aging (Prus, 2007). To tackle this issue, the World Health Organization recently

intends to monitor inequality as an emerging priority goal for health post-2015 (Hosseinpoor,

Bergen, & Magar, 2015).

The presence of inequality leads to the idea of relative socio-economic deprivation,

which has been found to also lead to health inequity (Townsend, 1987; Prus, 2007). Relative

deprivation is defined as "a state of observable and demonstrable disadvantage, about the local

community or the wider society or nation to which an individual, family or group belongs"

(Townsend, 1987). Health and social researchers have shown great interest in studying the

impact of area-based socio-economic deprivation on population health and developing

standardized indices to measure deprivation (Fu, Exeter, & Anderson, 2014). According to the

literature, relative deprivation distinguishes material deprivation from social deprivation

(Salmond & Crampton, 2000). People who are materially deprived suffer from inadequate

basic necessities, resources, and living conditions (Salmond & Crampton, 2000). However,

social deprivation emphasizes the social roles of the individuals and is related to relationships,

customs, and responsibilities as a member of the society or subgroup (Salmond & Crampton,

2000). Therefore, material deprivation is more related to income and employment; however,

social deprivation is related to social cohesion (Salmond, Crampton, & Sutton, 1998; Pattussi,

Marcenes, Croucher, & Sheiham, 2001). Both have been linked with adverse health outcomes

(Salmond & Crampton, 2000; Leese et al., 2013).

Relative Deprivation and Its Impact on Environmental Support for Bicycling

Research on deprivation and active travel indicates that there is an unequal distribution

of environment and resources supporting active travel among neighbourhoods (Sallis et al.,

2011). City areas with low household income have poorer infrastructure (e.g., uneven

sidewalks), higher poverty rates, fewer amenities, and lower safety ratings that discourage

physical activity for both recreation and transportation purposes (Sallis et al., 2011; Kelly,

2015).

Meanwhile, previous research in the United States (U.S.) has found that urban planning

strategies which encourage active travel have disproportionately benefited middle-class people

in suburban areas (Day, 2006). For example, new walking and bicycling facilities are more

likely to be built in more developed areas than less developed areas in the U.S. (Lee, Sener, &

Jones, 2016). Another study exploring the association between determinants of health found an

inequity gap in access to public bike share programs in the United States; those with lower

household incomes have less access to public bike share programs (Ursaki & Aultman-Hall,

2016). These findings have identified a gap in the support for active travel between the

advantaged and less advantaged socio-economic neighbourhoods.

Furthermore, active travel could have yielded greater benefits for the less advantaged

groups because of the health burden they bear due to lack of physical exercise and the financial

difficulties of affording vehicles (Lee et al., 2016). Given the current inequitable distribution of

environmental support for bicycling, and significant potential health benefits of bicycling for

disadvantaged groups, it is important to explore factors that prevent lower socio-economic

groups from adopting methods of bicycling.

The inequity gap in the environmental support for bicycling promotes the idea of equity

planning, which refers to "promoting a wider variety of choices for individuals who have fewer

ones" (Krumholz & Forrester, 1990). More deprived populations may have fewer choices in

their daily travel, and may not be able to share the same health benefits of active travel due to

inadequate environmental support. A new term "transportation justice" has emerged to define

environmental planning methods that prevent the disproportionate impact of transportation

development on disadvantaged populations (Oswald & Mohammed, 2016). Exploring the

association between neighbourhood deprivation level and their environmental capacity for

bicycling can promote active travel methods among disadvantaged groups, which in turn

increases health benefits, an important part of transportation justice.

Necessity of Additional Studies in Canada

Most of the research and evaluation of spatial access to bicycling infrastructure has

been conducted in the U.S. and Australia. Very few studies have been done in Canada, and

study results from other countries may not be applicable to the policies and public health

practices in Canada due to different city infrastructure. It is important to fill this gap and study

how socio-economic determinants impact access and decisions to bike.

The current analysis will shed light on understanding the association between area-

based neighbourhood deprivation level in nine Canadian cities (Calgary, Toronto, Halifax,

Moncton, Montreal, Saskatoon, St. John's, Vancouver, and Victoria) and the environmental

support for bicycling in neighbourhoods in these cities. We measure neighbourhood

deprivation using the Pampalon Deprivation Index, which is a socio-economic index developed

in Canada that assesses the material and social deprivation level of neighbourhoods (Pampalon,

Hamel, Gamache, & Raymond, 2009). We use Bike Score™ as a measure of how supportive

environmental characteristics are for bicycling (Winters et al., 2016). The overall analysis

examines the association across the census tracts in the study cities, while the city-specific

analysis examines the association within each city. We also compare the descriptive statistics

of mean deprivation quintiles, Bike Score™, and 2011 journey to work cycling mode share

across the nine cities.

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Methodology

Study Area

We used census tract as unit of analysis of this study. Census tract is a standardized

geographical area with a population of 2,500 to 8,000 people. The study area included nine

cities of eight provinces in Canada (Calgary, Halifax, Moncton, Montreal, Saskatoon, St.

John's, Toronto, Vancouver, and Victoria). Pampalon Deprivation Index is only available at

the dissemination area, which is a smaller geographical area than the census tract, with a

population of 400-700 people. The deprivation quintile of dissemination area in this study was

aggregated to census tract level because the Bike Score™ data was available at the census tract

level only.

Data

Bike Score™

The data for neighbourhood environmental support for bicycling (Bike Score™) and

the 2011 journey to work cycling mode share (census) was provided by Dr. Meghan Winters

from Simon Fraser University. The Bike Score™ is a scale of 1-100 points and is weighed

equally by three components: Bike Lane Score, Hill Score, Destination and Connectivity Score

(Winters et al., 2016). The Bike Lane Score examines the bike lane infrastructure on and off

roads (Winters et al., 2016). The Hill Score measures the hilliness and steepness of the terrain

(Winters et al., 2016). The Destination and Connectivity Score measures the network distance

between amenities (Winters et al., 2016). The Bike Score™ is further classified into four levels

on the Bike Score™ website, ranging from "Somewhat Bikeable" to "Biker's Paradise" (Table

1).

At the census tract level, the 2011 cycling mode share data describes the percentage of

employed population of age 15 or older who choose cycling as the most common method of

commute (Winters et al., 2016). It only captures the cycling trips for work purposes but not for

other purposes (e.g., recreation), and the information is linked to residential location (Winters

et al., 2016). In this study 1,306 census tracts with average Bike Score ™ and 2011 cycling

mode share in the nine Canadian cities were used for analysis.

Table 1.
Bike Score™ Cut-off

Bike Score™	Description
90-100	Biker's Paradise
	Daily errands can be accomplished on a bike
70-89	Very Bikeable
	Bicycling is convenient for most trips
50-69	Bikeable
	Some bike infrastructure
0-49	Somewhat Bikeable
	Minimal bike infrastructure.

Note. From WalkScore website: https://www.walkscore.com/bike-score-methodology.shtml

Neighbourhood Deprivation

In this study, neighbourhood deprivation is measured by the 2011 Pampalon

Deprivation Index, which was derived at the dissemination area level. The Pampalon

Deprivation Index was designed in the 1990s and was intended to monitor social inequalities in

population health (Pampalon et al., 2012). The index has a material component and a social

component, each comprised of three census variables (Table 2) (Pampalon et al., 2009). The

deprivation factor scores are most typically categorized into deprivation quintiles, with quintile

five indicating the most deprived group and quintile one being the least deprived group

(Pampalon et al., 2009). We acquired the 2011 Pampalon Deprivation Index from the Institute

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National de Santé Publique du Québec (INSPQ) website for this study

(https://www.inspq.qc.ca/en/institute/about-us). The 2011 Pampalon Deprivation Index dataset

used in this study included dissemination area identifier (DAuid), 2011 population of

dissemination area, material deprivation quintile, and social deprivation quintile.

Table 2.
Components of Pampalon Deprivation Index

Component	Indicator
Material Component	The proportion of people aged 15 years and older with no high school/diploma
	The employment/population ratio of people aged 15 years and older
	The average income of people aged 15 years and older
Social Component	The proportion of individuals aged 15 years and older living alone
	The proportion of individuals aged 15 years and older who are separated, divorced, or widowed
	The proportion of single-parent families

Note. From Pampalon, R., Hamel, D., Gamache, P., Philibert, M. D., Raymond, G., &
Simpson, A. (2012). An area-based material and social deprivation index for public health in
Québec and Canada. Canadian Journal of Public Health / Revue Canadienne De Sante'e
Publique, 103(8 Suppl 2), S17-S22.

Data Linkage

We created data linkages between the DAuid and CTuid in order to merge the 2011

Pampalon Deprivation Index dataset with the Bike Score™ dataset. The June 2013 postal

codes conversion file (PCCF) for the 2011 Canadian census was obtained from the database

tool Abacus Dataverse Network. The PCCF provides the linkage between census tract and

dissemination area for all the provinces in Canada (Figure 1, Appendix B) (Statistics Canada,

2013).

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Then, the 2013 PCCF file, 2011 Pampalon Deprivation Index, and the dataset of Bike

Score™ data and census tract unique identifier (CTuid) were first input into SAS (version 9.4)

(Figure 2). In the PCCF dataset, we selected the Statistical Area Classification code (SAC) for

census metropolitan area (CMA)/ census agglomeration, census tract name (CTname), and the

dissemination area unique identifier (DAuid) for analysis. The Bike Score™ dataset was

organized by CTuid, which was a unique census tract identifier where the three-digit SAC

preceded the CTname. Therefore, we first combined the SAC and CTname in the PCCF file to

generate CTuid. Since the study area in this analysis was nine CMAs, we removed data that

was not in CMAs or census agglomerations (SAC = "000", "996", "997", "998", "999") (See

Appendix B). We then sorted the PCCF dataset and merged it with the Pampalon Deprivation

Index dataset into a new dataset by DAuid. The material and social deprivation quintile were

linked to the PCCF file by DAuid. Dissemination areas with missing Pampalon deprivation

quintiles were removed from the analysis. Afterwards, the new dataset was sorted by CTuid,

and the census tract population (CT population) was calculated by aggregating the 2011

dissemination area population (2011 DA population) in each census tract. Then the weighted

deprivation quintile by CTuid have been computed using the calculation methods listed below.

After that, the dataset with weighted deprivation quintiles were merged with Bike Score™

dataset by CTuid. Census tracts with missing Bike Score™ or Bike Score™ with missing

CTuid were removed from the analysis.

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Figure 1. *Example of Linkage between Postal Code, Dissemination Area, and Census Tract*

Before linkage:
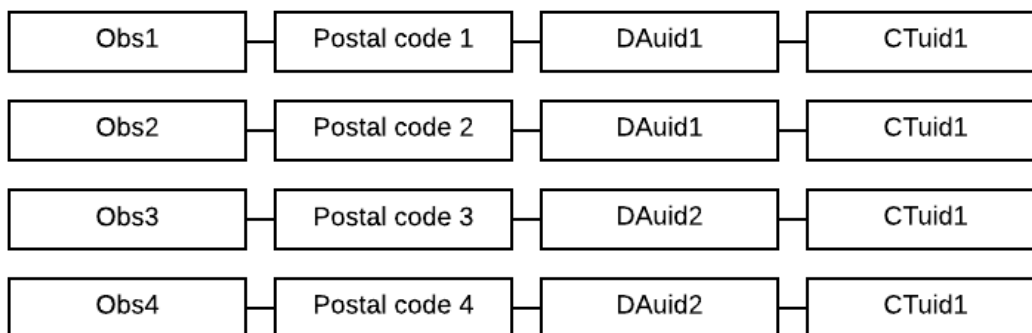
After Linkage:
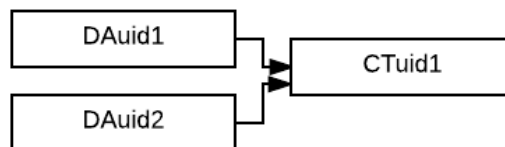
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Figure 2. *Flow Chart of Data Linkage*
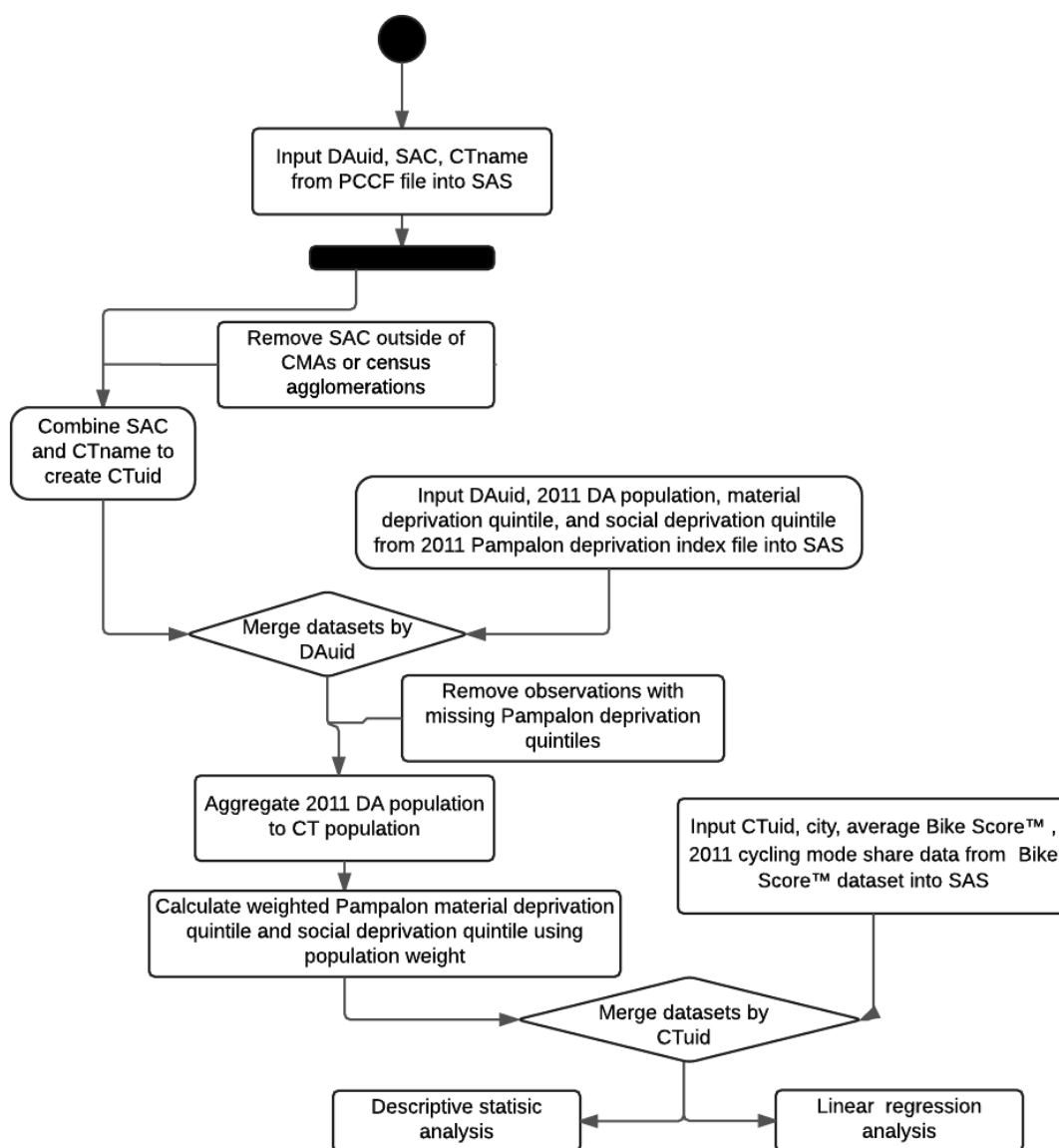
Calculation of Weighted Deprivation Quintile at Census Tract Level

The Pampalon Deprivation Index is only available at the dissemination area level;

however, the data of Bike Score™ is at census tract level, which is a larger geographical area

than the dissemination area. Therefore, a weighted Pampalon deprivation quintile was created

to assess the association between neighbourhood deprivation and Bike Score™ at census tract

level. The weighted deprivation quintile was developed through multiplying the original

deprivation quintile at each dissemination area by the proportion of the population in each

dissemination area in the census tract to which the dissemination area belonged. After this, the

weighted deprivation quintile at each dissemination area was aggregated by CTuid. In the end,

each census tract had a weighted material deprivation quintile (Quint_M_w), and a weighted

social deprivation quintile (Quint_S_w). The weighted Pampalon deprivation quintile was

further linked with the Bike Score™ dataset by CTuid. The calculation of weighted

deprivation quintile was conducted using SAS (version 9.4). The development of the weighted

deprivation quintile was to serve the purpose of this analysis at census tract level; however, it

was not the intention of the quintile data.

Statistical analysis

All statistical analysis was conducted in SAS (version 9.4). In the overall analysis, we

performed linear regression analyses to explore the association between weighted material and

social deprivation quintile and Bike Score™ at census tract level across the nine cities. In the

city-specific model, we examined the city-specific linear relationship between Bike Score™

and neighbourhood weighted material and social quintile. We also generated ArcGIS maps to

visualize the patterns of material and social deprivation of each city and calculated descriptive

statistics to make comparisons across census tracts of the nine cities.

We modeled the outcome of neighbourhood Bike Score™ with weighted material and

social deprivation quintile of the nine cities as independent variables using the linear regression

models. The first linear regression model assessed the association between neighbourhood

Bike Score™ and weighted material deprivation quintile, and the second model assessed the

association between neighbourhood Bike Score™ and weighted social deprivation quintile.

Similarly, in the city-specific model, we conducted the linear regression analyses to

examine the association between weighted material and social deprivation quintile and Bike

Score™ within each city. The outcome variable was the neighbourhood Bike Score™, and the

independent variables were weighted material deprivation quintile and weighted social

deprivation quintile. The unit of analysis was the census tract inside each city. The material and

social deprivation quintile maps of each city were generated using ArcMap10.3.

Results

Overall Descriptive Characteristics of the Analysis

We analyzed 1,300 census tracts in nine cities for this study. The average Bike Score™

of census tracts ranges from 15.7 to 100, with the mean being 71.9. The mean weighted

material deprivation quintile is 2.9, and the mean weighted social deprivation quintile is 3.6.

The weighted deprivation quintile has decimals because it is created by multiplying the

population weight to the original Pampalon deprivation quintile score at each dissemination

area, and then aggregated to the census tract level. Both weighted material deprivation quintile

and social deprivation quintile range from 1 to 5, which is the same as the original Pampalon

deprivation quintile. The cycling mode share (%) at census tract level ranges from 0 to 11.5%,

with a mean of 2.9%.

City-Specific Descriptive Characteristics of the Analysis

Among the nine cities, the mean number of census tracts per city is 144, ranging from

15 (Moncton) to 536 (Toronto) (Table 3). The city with the lowest mean of average Bike

Score™ is St. John's (46.3) while the city with the highest mean of average Bike Score™ is

Saskatoon (79.4). No city has a mean average Bike Score™ that can be characterized as

"Biker's Paradise" (90-100). Five out of the nine cities have means that fall into the range of

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"Very Bikeable" (70-89). Three out of the nine cities have mean Bike Score™ that fall in the

range of "Bikeable" (50-69). Two cities fall in the category "Somewhat Bikeable" (0-49).

Further, there is an inequality in average cycling mode share between cities (Table 3; Appendix

C). For example, Victoria has a relatively high percentage of mean cycling mode share

(11.5%), while St. John's has 0% average cycling mode share (Table 3). There are variations in

variable means and substantial standard deviations both within and between cities.

Table 3. *Descriptive Statistics of Bike Score™ and Weighted Pampalon Deprivation Quintiles for Nine Canadian Cities*

Study Area	Total Number of Census Tracts in CMA	Number of Census Tracts with Bike Score™	Number of Census Tracts with Bike Score™ and Pampalon Deprivation Score	Average Bike Score™ (mean, (SD))	Weighted Material Deprivation Quintile (mean, (SD))	Weighted Social Deprivation Quintile (mean, (SD))	Cycling Mode Share (%) (mean, (SD))
Calgary	253	221	220	74.5(12.9)	2.1(1.1)	3 (1.2)	1.2 (1.8)
Halifax	98	23	23	67.1(14.8)	2.1 (1.1)	4.3 (0.9)	3.9 (3.9)
Moncton	30	15	15	49.3(15.3)	2.9 (0.7)	3.9 (0.8)	0.4 (0.8)
Montreal	970	310	308	78.9(17.7)	3.2 (1.2)	4.4 (0.7)	4.8 (4.6)
Saskatoon	59	43	43	79.4(10.6)	2.2 (1)	3.3 (1)	2.2 (2.4)
St. John's	47	24	24	46.3(16.0)	2.8 (1)	3.7 (0.8)	0.0 (0.0)
Toronto	1151	538	536	66.9(16.4)	3.2 (1.4)	3.3 (1)	2.0 (3.8)
Vancouver	478	115	114	78.2(14.6)	2.7 (1.4)	3.4 (1.2)	4.1 (3.7)
Victoria	78	17	17	74.3(17.1)	1.8 (0.5)	4.7 (0.4)	11.5(4.3
Total	**5623**	**1306**	**1300**	**71.9(17.2)**	**2.9 (1.4)**	**3.6 (1.1)**	**2.8 (4.1)**

Note. SD= Standard Deviation. Average Bike Score™ at census tract level ranges from 15.7 to 100. Weighted Material Deprivation Quintile ranges from 1 to 5. Weighted Social Deprivation Quintile ranges from 1 to 5. Cycling Mode Share at census tract level ranges from 0 to 33.9.

Scatter Plots of Bike Score™ and Overall Weighted Material and Social Deprivation

Figure 3 and Figure 4 show the fitted regression lines and scatter plots of Bike Score™

and weighted deprivation quintiles across the census tracts. It highlights the nature of the

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association between Bike Score™ and material and social deprivation. The regression lines are

in different directions for weighted material and social deprivation. There is a downward trend

of data on the Bike Score™ and weighted material deprivation quintile (negative slope),

indicating a negative association; and, an upward trend of data on the Bike Score™ and

weighted social deprivation quintile (positive slope), showing a positive association.

There is a similar amount of dispersion in the data across quintiles in the scatter plot of

Bike Score™ and the weighted material deprivation quintile. However, on the scatter plot of

Bike Score™ and weighted social deprivation quintile, there is a significantly greater amount

of dispersion in the higher quintiles.

Figure 3. *Scatter Plot for the Average Bike Score™ and Weighted Material Deprivation Quintile*
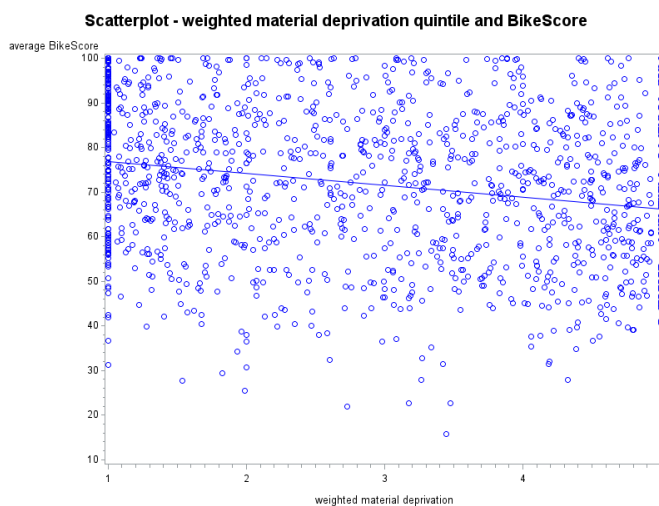
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Figure 4. S*catter Plot for the Average Bike Score™ and Weighted Social Deprivation Quintile*

Scatterplot - weighted social deprivation quintile and BikeScore
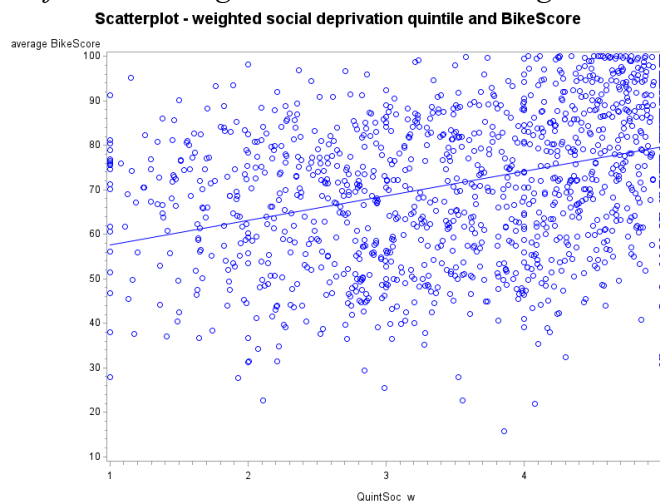
Spatial Patterns of the Weighted Deprivation in Nine Cities

The maps show that the patterns of deprivation vary across the nine cities (Appendix A). In some cities, neighbourhoods with a high level of material deprivation are clustered together in some regions of the city. For example, in Vancouver, there is an increasing level of material deprivation from the west side to the east side. In Calgary, the most materially deprived neighbourhoods cluster on the northeastern corner of the city. However, in other cities, the most materially deprived neighbourhoods are distributed across the city (e.g., Montreal). Further, the patterns of material deprivation do not mirror social deprivation in cities. Census tracts with a high level of material deprivation do not necessarily have a high level of social deprivation (Appendix A; Figure 5).

Overall Regression Analysis

The overall regression analysis suggests that an additional quintile increase in weighted material deprivation is associated with a 2.7-unit decrease in Bike Score™ (β= -2.7, 95% CI:

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-3.3 to 2.0) (Table 4). The relationship is negative and statistically significant (p<0.0001),

suggesting that the more materially deprived neighbourhoods tend to have worse

environmental supports for bicycling. Approximately 4% of the variation in the relationship is

accounted for by weighted material deprivation.

The second regression analysis suggests there is a positive association between the

average Bike Score™ and weighted social deprivation quintile. An additional quintile increase

in weighted social deprivation is associated with a 5.5-unit increase in Bike Score™ (β= 5.5,

95% CI: 4.7 to 6.3) with weighted social deprivation explaining 13% of the variation in the

relationship. The positive association suggests that the more socially deprived neighbourhoods

tend to have better environmental supports for bicycling. Also, the weighted social deprivation

has a greater parameter estimate (β= 5.5, 95% CI: 4.7 to 6.3) compared with the average Bike

Score™ than the weighted material deprivation (β= -2.7, 95% CI: -3.3 to 2.0), indicating a

slightly stronger association.

Table 4. *Results of Linear Regression Models of Estimating Association between Bike Score™*
and Weighted Material and Social Deprivation Quintile

Variables	Model 1 Weighted material deprivation β (95% CI)	Model 2 Weighted social deprivation β (95% CI)
Constant	79.6 (77.4 to 81.2)	52.2 (49.2 to 55.1)
Weighted material deprivation quintile	**-2.7 (-3.3 to -2.0)******	----
Weighted social deprivation quintile	----	**5.5 (4.7 to 6.3)******
R^2	0.04	0.13
N obs	1300	1300

Note. CI=Confidence Interval. N obs= Number of Observations ns p>0.05   * p<=0.05
**p<=0.01   ***p<=0.001   ****p<=0.0001

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City-Specific Regression Analysis

In the city-specific regression analysis, cities such as Halifax, Montreal, Toronto, and

Vancouver show an inverse relationship between the neighbourhood Bike Score™ and

weighted material deprivation quintile (β= -2.6, β= -5.7, β= -2.3, β= -4.3, respectively) (Table

5), with more materially deprived neighbourhoods tend to have worse environmental supports

for bicycling. The negative association is significant for three out of the four cities (Montreal,

Toronto, and Vancouver) ($p<0.001$).

The data shows that there is a positive association between neighbourhood Bike

Score™ and weighted social deprivation quintile for all nine cities. The positive association

between Bike Score™ and weighted social deprivation quintile is significant for seven out of

nine cities (Calgary, Moncton, Montreal, Saskatoon, St. John's, Toronto, Vancouver) (Table

5), suggesting that the more socially deprived neighbourhoods tend to have better

environmental supports for bicycling than the less socially deprived areas.

Table 5.

*Results of Linear Regression Models of Estimating Association between Neighbourhood Bike
Score™ and Weighted Material and Social Deprivation Quintile*

Model 1: Linear Regression model of neighbourhood Bike Score™ and weighted material deprivation within each city

	Calgary	Halifax	Moncton	Montreal	Saskatoon	St. John's	Toronto	Vancouver	Victoria
				β (95% CI)					
Intercept	72.2 (68.2 to 75.7)	72.7 (58.0 to 87.4)	20.2 (-17.5 to 57.8)	97.1 (91.9 to 102.3)	74.1 (66.4 to 81.9)	39.1 (18.2 to 60.1)	74.2 (7.8 to 77.6)	89.7 (84.4 to 95.0)	49.6 (20.9 to 78.4)
Weighted Material Deprivation Quintile	1.1 (-0.4 to 2.6)	-2.6 (-8.8 to 3.5)	9.9 (-2.5 to 22.4)	**-5.7**** (-7.2 to -4.2)**	2.4 (-0.8 to 5.7)	2.5 (-4.5 to 9.6)	**-2.3**** (-3.3 to -1.3)**	**-4.3*** **(-6.0 to -2.5)**	14 (-1.7 to 29.6)
R^2	0.009	0.04	0.18	0.15	0.04	0.02	0.04	0.18	0.2
N obs	220	23	15	308	43	24	536	114	17

Model 2: Linear Regression model of neighbourhood Bike Score™ and weighted social deprivation within each city (standard error from the mean)

Intercept	62.7 (58.5 to 66.9)	51.7 (18 to 85.4)	10.8 (-27.1 to 48.7)	10.9 (0.1 to 21.7)	64.1 (53.8 to 74.5)	11.9 (-17 to 40.9)	52.9 (48.1 to 57.7)	56.4 (49.5 to 63.4)	-22.5 (-135.5 to 90.5)
Weighted Social Deprivation Quintile	4.0**** (2.7 to 5.3)	3.6 (-4.1 to 11.3)	9.8* (0.3 to 19.3)	15.4**** (12.9 to 17.8)	4.6** (1.6 to 7.6)	9.3* (1.6 to 17)	4.2**** (2.8 to 5.6)	6.4**** (4.5 to 8.4)	20.6 (-3.4 to 44.5)
R^2	0.14	0.04	0.28	0.34	0.19	0.22	0.06	0.28	0.18
N obs	220	23	15	308	43	24	536	114	17

Note. ns $p>0.05$ * $p<=0.05$ **$p<=0.01$ ***$p<=0.001$ ****$p<=0.0001$

There are also inter-city variations for the association between neighbourhood Bike Score™ and weighted deprivation. First, the nature and directions of the association between material and social deprivation and Bike Score™ vary among the cities. For certain cities, the associations between Bike Score™ and weighted material deprivation and weighted social deprivation have different directionality (one positive and one negative) (e.g., Halifax, Montreal, Toronto, Vancouver); however, the rest show same directions (all positive or all negative) (Figure 5). Second, the strengths of the associations differ across cities. For some cities, the regression model has larger parameter estimates than the other cities, which indicates stronger relationships among Bike Score™ and weighted deprivation quintiles as compared to cities with smaller parameter estimates. For example, the parameter estimates for weighted material and social deprivation quintile for Montreal are much greater than those from the other cities, which indicates stronger associations between neighbourhood Bike Score™ and weighted material and social deprivation than other cities (Table 5; Figure 5).

Figure 5.

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*City-Specific Scatter Plots for the Average Bike Score™ and Weighted Material and Social
Deprivation Quintile*
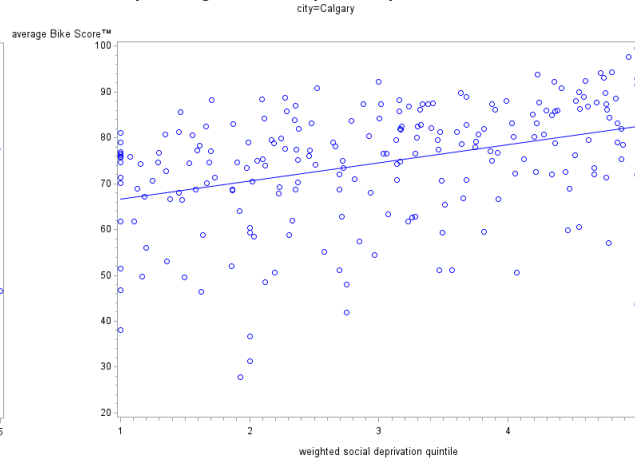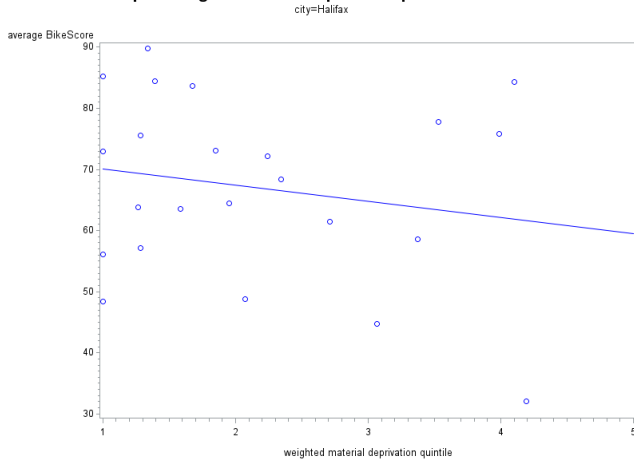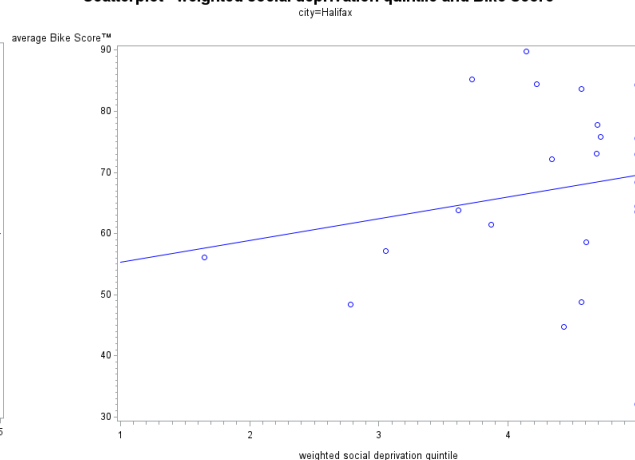
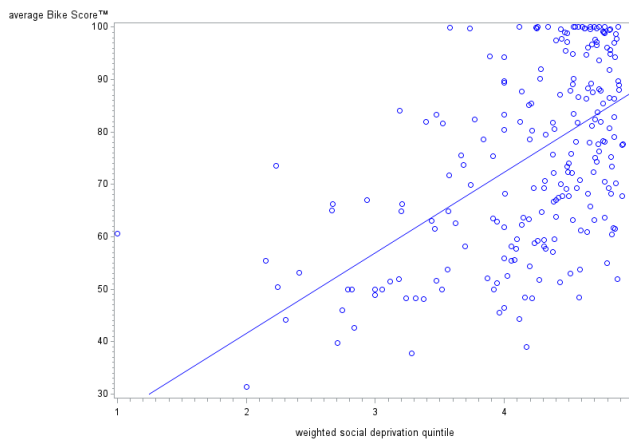# AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL SUPPORT FOR BICYCLING IN CANADA

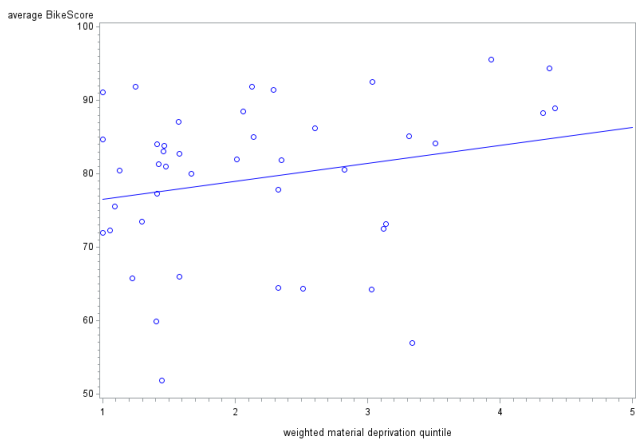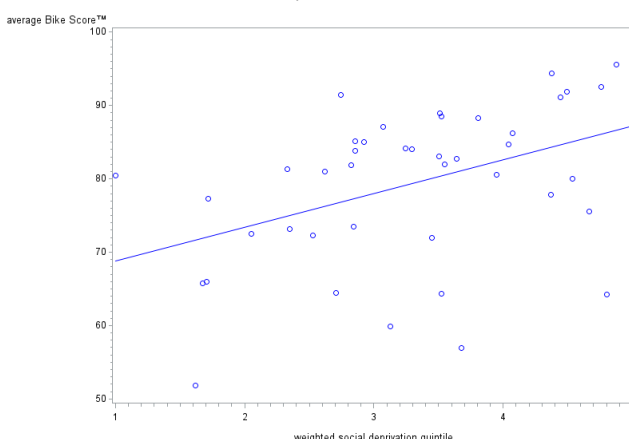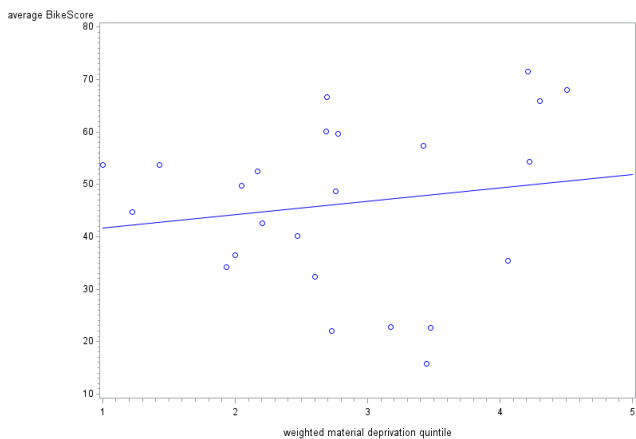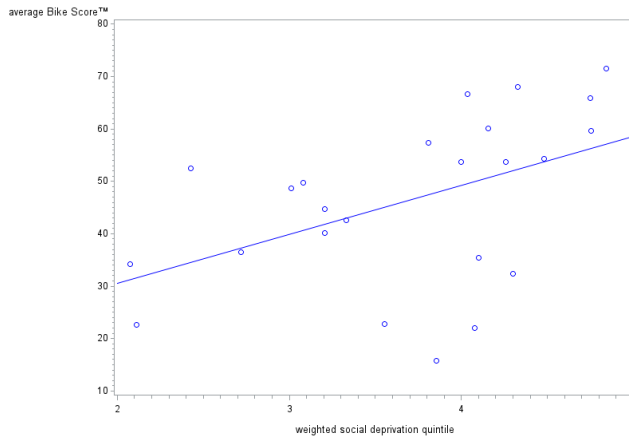**Scatterplot - weighted material deprivation quintile and BikeScore**
city=Toronto

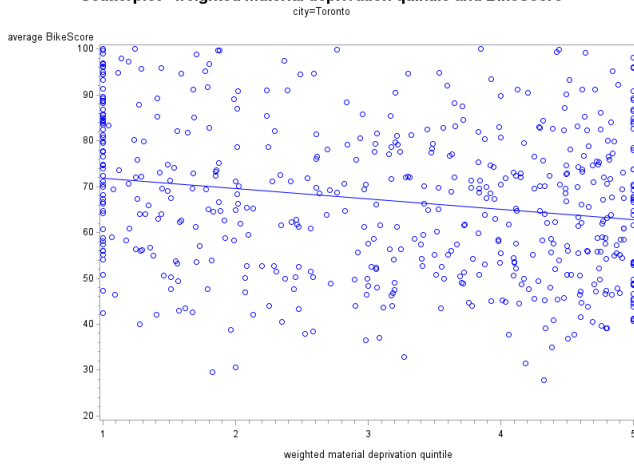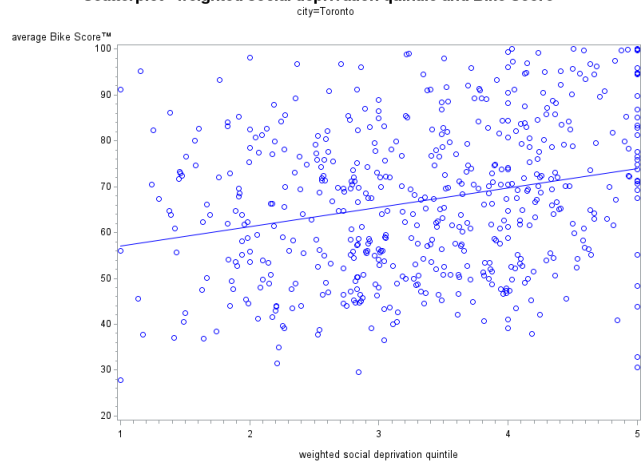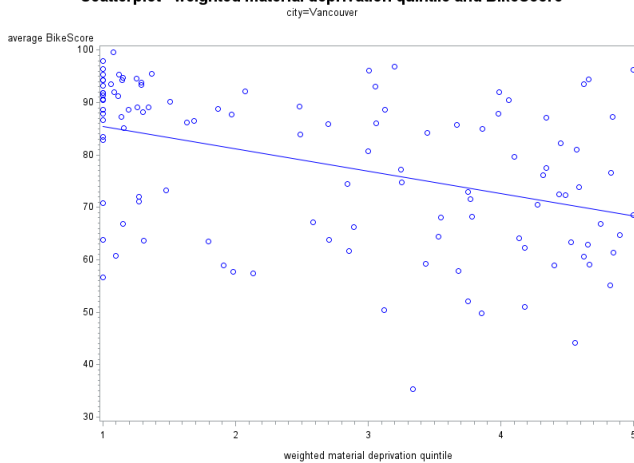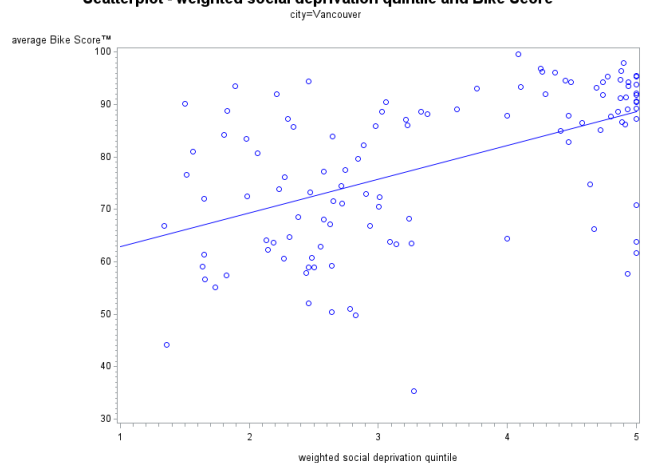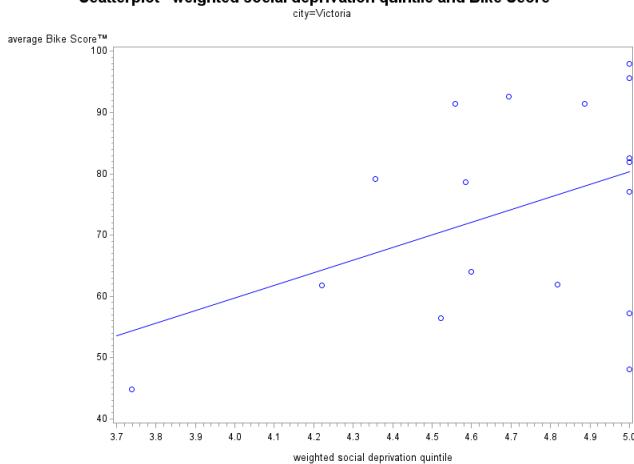**Scatterplot - weighted social deprivation quintile and Bike Score™**
city=Toronto

**Scatterplot - weighted material deprivation quintile and BikeScore**
city=Vancouver

Scatterplot - weighted social deprivation quintile and Bike Score™
city=Vancouver

Scatterplot - weighted social deprivation quintile and Bike Score™
city=Victoria

Scatterplot - weighted material deprivation quintile and BikeScore
city=Victoria

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SUPPORT FOR BICYCLING IN CANADA
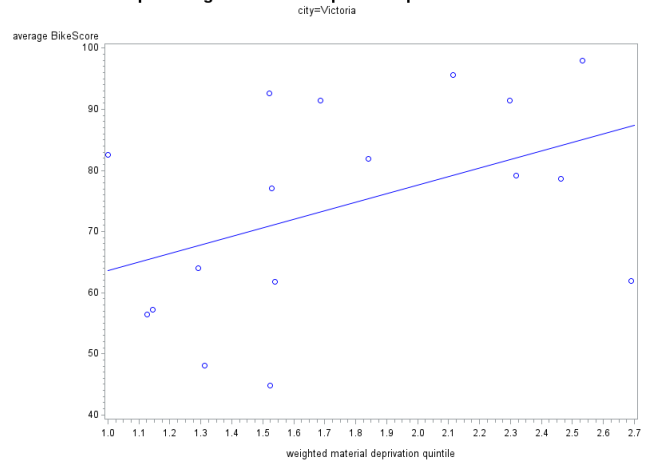
Discussion

This study examined the association between Bike Score™ and neighbourhood

deprivation both between and within nine Canadian cities. As one type of active transportation,

bicycling has been found to yield significant health benefits through increasing physical

activity level with minimal social cost (Kelly et al., 2014; Woodcock et al., 2009; Teschke et

al., 2012). The international health organizations and many countries have invested

considerably in promoting bicycling in local communities through bike share programs and

infrastructure development (Pucher et al., 2011). The previous ecological studies on health

equity suggest that neighbourhood deprivation is associated with negative health outcomes

(Salmond & Crampton, 2000). Areas with lower household income have poorer infrastructure

and people have less access to facilities and health services (Kelly et al., 2015). This study

assesses both material and social deprivation at the neighbourhood level, and the findings of

this study can help urban planners and policy makers in city planning in providing more

equitable development strategies to encourage bicycling.

Results of this study supported the "income inequality" theory that was used to explain

health inequity in the literature (Braubach &Fairburn, 2010). The overall analysis of 1,300

census tracts has found that material deprivation has a negative association with

neighbourhood Bike Score™, which suggests that in neighbourhoods with higher annual

income, education, and employment status, the environmental features are more "bicycle-

friendly" than those in lower socio-economic neighbourhoods. This result supports our

hypothesis and is in alignment with previous research on income inequality and adverse health

outcomes (Braubach &Fairburn, 2010). Moreover, in the city-specific models, significant

inverse relationships were found in cities with large number of census tracts (Toronto,

Montréal, and Vancouver). Thus, it is recommended for urban planners, health professionals,

and policy makers to change transportation policies and allocate more resources and funds to

the development of bicycling facilities (e.g., bike lanes), especially in neighbourhoods with

lower income and employment rates.

However, contrary to our hypothesis, we conclude that there might be a positive

association between area-based social deprivation and neighbourhood Bike Score™. In the

overall analysis, we have found that for each additional quintile increase in weighted social

deprivation, the neighbourhood Bike Score™ increases by on average of 5.5 (β= 5.5, 95% CI:

4.7 to 6.3). The difference in the direction of the material deprivation and social deprivation

regression model suggests that materially deprived neighbourhoods may not necessarily

correlate with "social exclusion" (Testi & Ivaldi, 2008). This phenomenon is shown in the city-

specific maps where the patterns of material deprivation quintile and social deprivation quintile

do not match well (See Appendix A). One possible explanation is that the elderly people tend

to have more resources than the younger people and are more likely to be widowed, live alone,

and reside in affluent neighbourhood.

Another explanation for the positive association between social deprivation and

neighbourhood Bike Score™ is that the Pampalon Deprivation Index did not provide a

complete framework for studying social inequalities in health because the factors determining

social deprivation selected from the census survey were mostly about family size and marital

status, which were traditional measures of evaluating social status (Pampalon et al., 2012).

They did not capture other social issues such as immigrants, aboriginal population, and

changes in values of families and relationship statuses. For example, the people who choose to

immigrate to Canada tend to have high education and be more materially well-off (Picot et al.,

2012). However, they may be living alone or do not have a large family due to their recent

immigration status. As such, immigrants may be classified as "socially deprived" according to

the Pampalon Deprivation Index, even if they are located in relatively well-off, bicycle friendly

areas. Also, the Pampalon Deprivation Index does not reflect evolving family dynamics and

rise in the affluent urban population who choose to be unmarried and childless. Longitudinal

data suggested that the percentage of Canadians who were unmarried (i.e., never married,

divorced or separated, widowed) increased from 39.1% in 1981 to 53.6% in 2011 (Milan,

2011). Meanwhile, the share of lone-parents increased from 8.4% to 16.3% in Canada from

1961 to 2011 (Milan & Bohnert, 2011). Family size has become smaller, with on average of

2.9 people per family in 2011 compared to 3.9 people in 1961 (Milan & Bohnert, 2011). From

2001 to 2011, the percentage of households comprised of couples with children dropped from

30.5% to 26.5% while the percentage of households comprised of couples without children

rose from 28% to 29.5% (Milan & Bohnert, 2011). In 2011, the percentage of one-person

households surpassed the percentage of couple households with children for the first time

(Milan & Bohnert, 2011). The family dynamics in Canada have undergone significant changes

due to social and economic changes (Milan & Bohnert, 2011). Conjointly, living alone is now

a new marker of "modern economic independence" instead of a result of divorce or

widowhood, which was more commonly associated in the past (Bielski, 2013). These young

and mid-life professionals with relatively high income and good connections, take up more

than 45% of the condo residents in downtown neighbourhoods in Vancouver, Calgary, and

Toronto, where housing prices are high (Bielski, 2013).

Also, the results of the regression analyses captured the direction and nature of the

relationship between weighted neighbourhood deprivation and environmental support for

bicycling. Since Bike Score™ is a weighted sum of three components: Bike Lane Score (50%),

Hill Score (25%), and Destination Connectivity Score (25%) (Winters et al., 2016), it is

unlikely that the relationship can be explained by any of the components alone, for example,

hilliness.

In addition, we have found nuances in the city-specific analysis of the association

between Bike Score™ and neighbourhood deprivation. First, the direction and magnitude of

the associations between Bike Score™ and material and social deprivation vary both within

and between cities. The degree of overlap between the weighted material and social

deprivation also varies by city. In a city, the patterns of weighed material deprivation and

social deprivation are distinctive. Second, the average percentage of cycling mode share across

the nine cities varies from 0% to 11.5 %, which reflects the difference in people's usage of

bicycling to work between cities. Last, even though most of the cities have average Bike

Score™ that falls into "bikeable" to "very bikeable," there are still cities that have average

Bike Score™ that is only evaluated as "somewhat bikeable". Therefore, this suggests that the

association between neighbourhood deprivation and Bike Score™ may need to be further

examined within the context of a particular city, as each city may have different urban

planning, geography, culture, and policies on bicycling. The association could then be further

discussed after accounting for these multiple factors.

Strengths and Limitations

The strength of this study is that it is the first exploratory analysis that adopts a health

equity approach in linking neighbourhood Bike Score™ with Pampalon deprivation quintiles

to assess the correlation between neighbourhood environmental support for bicycling and

material and social deprivation. This study includes nine cities across Canada, in eight out of

ten Canadian provinces, and the analysis is both Canada-wide and city-specific.

However, this study also has several limitations. First, this study used the weighted

deprivation quintile, which was based on the proportion of the population living in each census

tract. The development of the weighted deprivation quintile serves the purpose of this study,

but is not the intention of the quintile data provided by INSPQ. Second, the 2011 Pampalon

Deprivation Index may not reflect the recent change in population and national census data,

some indicators have evolved and can indicate different aspects of living condition (e.g., living

alone and social deprivation) (INSPQ, 2011). Third, this study does not account for spatial

autocorrelation, which a phenomenon when proximate objects are more likely to be correlated

with each other than distant objects in the ecological analysis (Lichstein, Simons, Shriner, &

Franzreb, 2002). Census tracts that are clustered together are very likely to be similar in Bike

Score™, deprivation level, and cycling mode share. The existence of spatial autocorrelation

may influence the parameter estimates of the regression analyses (Lichstein, Simons, Shriner,

& Franzreb, 2002). Therefore, the overall analysis (census tract level analysis) can be

improved by incorporating city variable into the analysis and adopting a fixed effects model to

adjust the regression analyses by the city, which accounts for the clustered nature of census

tracts in cities. The city-specific model can be improved by calculating the global Moran's I,

which is a measure of the spatial autocorrelation of the location and associated feature values

(Darmofal, 2015). It helps evaluates whether the patterns of associated attributes are random or

not (Darmofal, 2015). If the Moran's I statistic is significant, it means that spatial

autocorrelation does exist in the association and a spatial autoregressive analysis can be

performed to further explore the association (De Smith, Goodchild, & Longley, 2009). Lastly,

the findings of this observational study can only be used to explain the association between

neighbourhood deprivation and environmental support for bicycling. It may not be used to

predict individual bicycling behavior in certain areas directly because it has been found that

bicycling behavior has multiple determinants, for example, gender and "bike culture" in the

local area (Pucher et al., 2011).

Recommendations

In the future, we recommend that public health professionals conduct more research on

environmental support for bicycling and material and social deprivation, for example in-depth

interviews on a small subset of the population, to understand residents' beliefs and perceptions

on economic and social factors that influence a neighbourhood's environmental support for

bicycling. This study has found that neighbourhood Bike Score™ is significantly negatively

associated with material deprivation level. Thus, urban planners and policy makers who wish

to promote higher bicycling rates should allocate adequate funds and resources to

neighbourhoods with low income for their infrastructure development (e.g., bike lanes).

Additionally, when policy makers and decision makers are investing in promoting bicycling in

a city, they should adopt city-specific strategies and consider multiple factors such as as

population density, distance to cycling to work versus other purposes, and size and scope of

diverse cities when designing equitable policies and programs that target deprivation issues

within the context of the city.

Reflections

As a public health student, this study further enriches my knowledge of the dynamics

between socio-economic factors, built environment, and population health, which I have

learned from the class. It also deepens my understanding of the existence of inequity in the

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society and its impact on population health. Moreover, in this study, I used Pampalon

Deprivation Index, which was the same index as I used for my immunization rate project in

practicum. This capstone project connects my previous knowledge of socio-economic

determinants of health and experience in conducting statistical analyses. It also broadens my

idea of the applications of the socio-economic index in different public health fields such as

bicycling. Moreover, I understand from the analytical results that there are variations in the

same health problem across different cities. For example, the associations between Bike

Score™ and weighted material and social deprivation vary both within and between cities.

Therefore, health policies need to be designed and implemented within the context of the local

area. In the future, as a public health practitioner, I will keep the importance of socio-economic

determinants of health in mind and continue developing strategies and programs that meet the

specific needs of the city.

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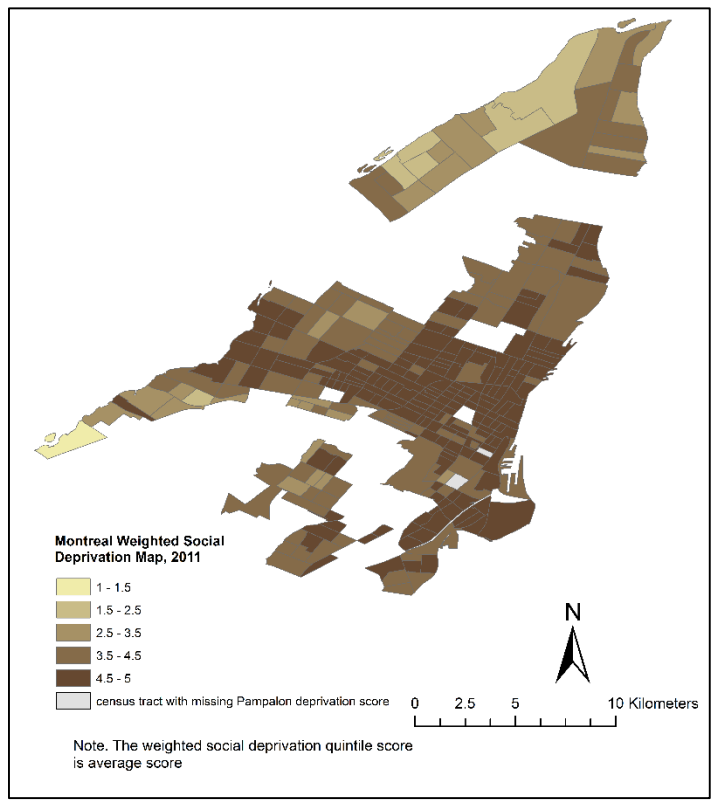greenhouse-gas emissions: Urban land transport. *The Lancet, 374*(9705), 1930.

AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL
SUPPORT FOR BICYCLING IN CANADA

Appendix A

The 2011 Weighted Material and Social Deprivation Maps of Nine Cities
***Calgary***
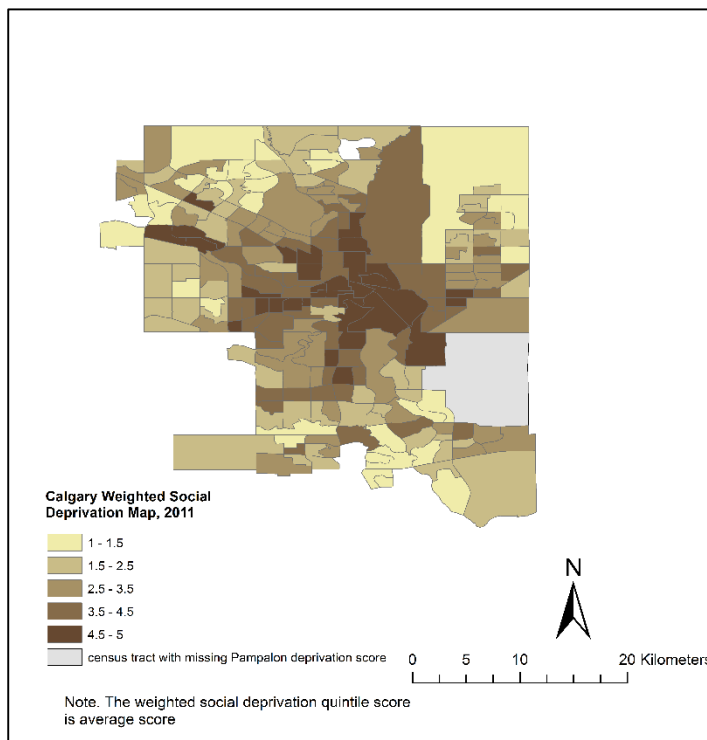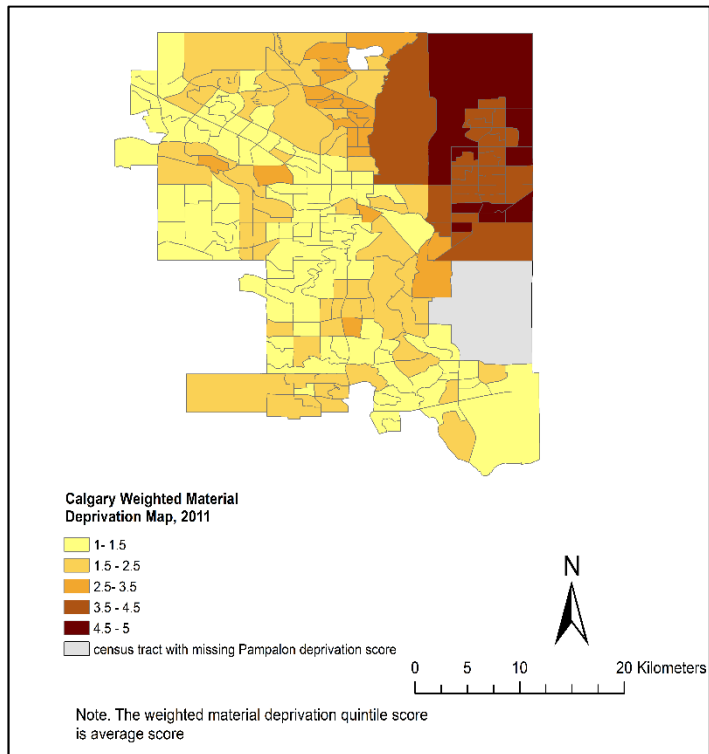
Calgary Weighted Material Deprivation Map, 2011
- 1- 1.5
- 1.5 - 2.5
- 2.5 - 3.5
- 3.5 - 4.5
- 4.5 - 5
- census tract with missing Pampalon deprivation score

Note. The weighted material deprivation quintile score is average score

Calgary Weighted Social Deprivation Map, 2011
- 1 - 1.5
- 1.5 - 2.5
- 2.5 - 3.5
- 3.5 - 4.5
- 4.5 - 5
- census tract with missing Pampalon deprivation score

Note. The weighted social deprivation quintile score is average score

AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL
SUPPORT FOR BICYCLING IN CANADA

Halifax
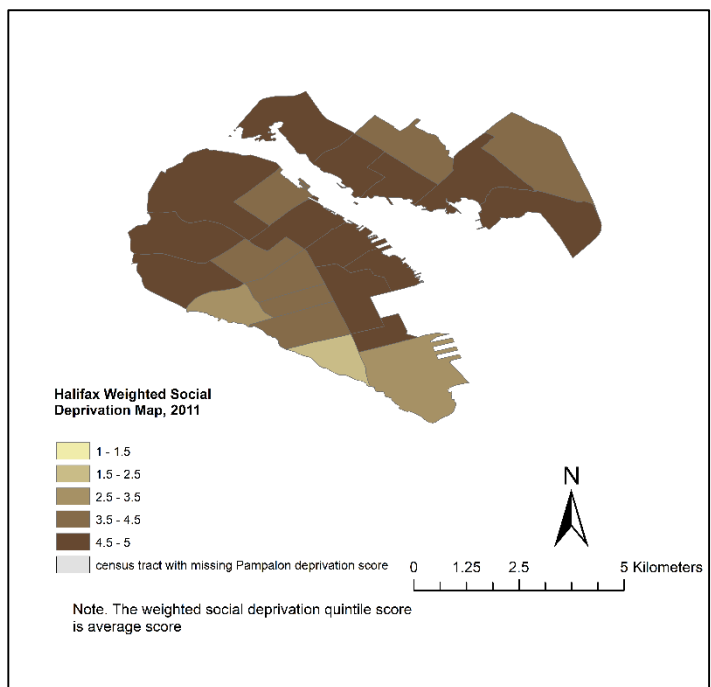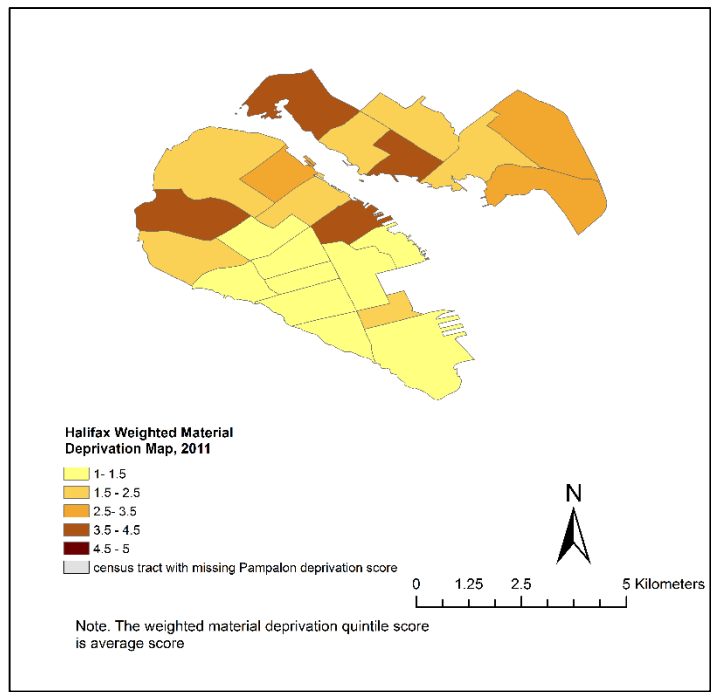
AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL
SUPPORT FOR BICYCLING IN CANADA

Moncton
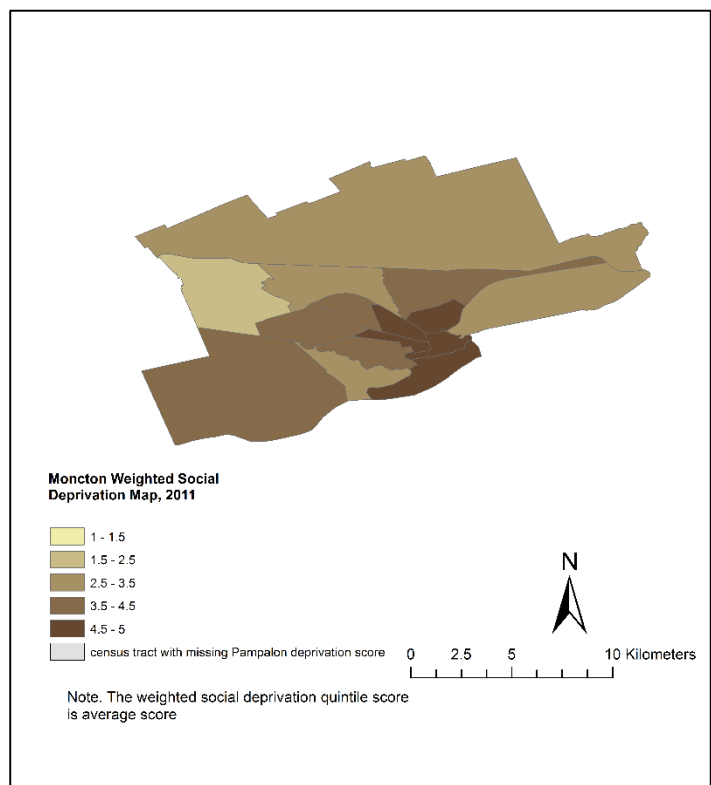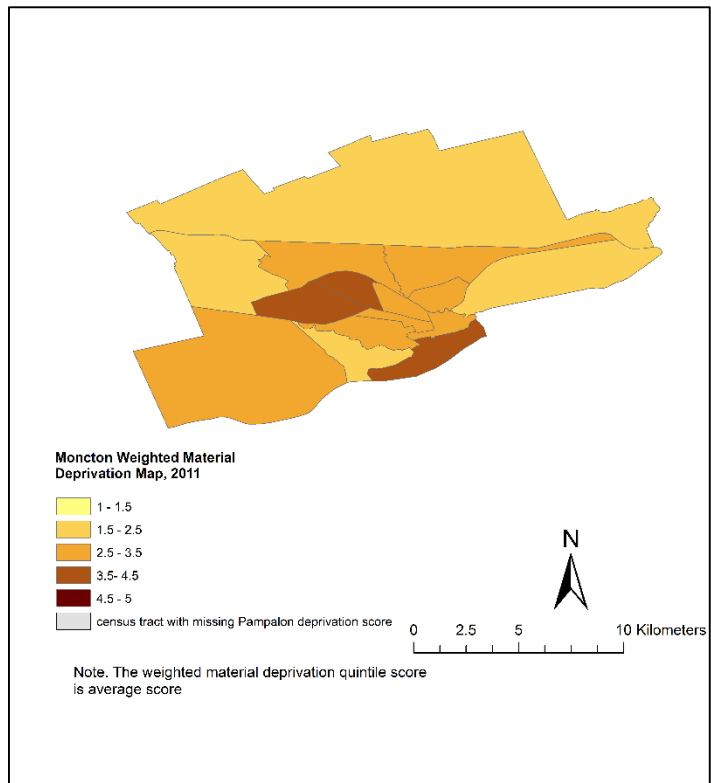
AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL
SUPPORT FOR BICYCLING IN CANADA

Montreal
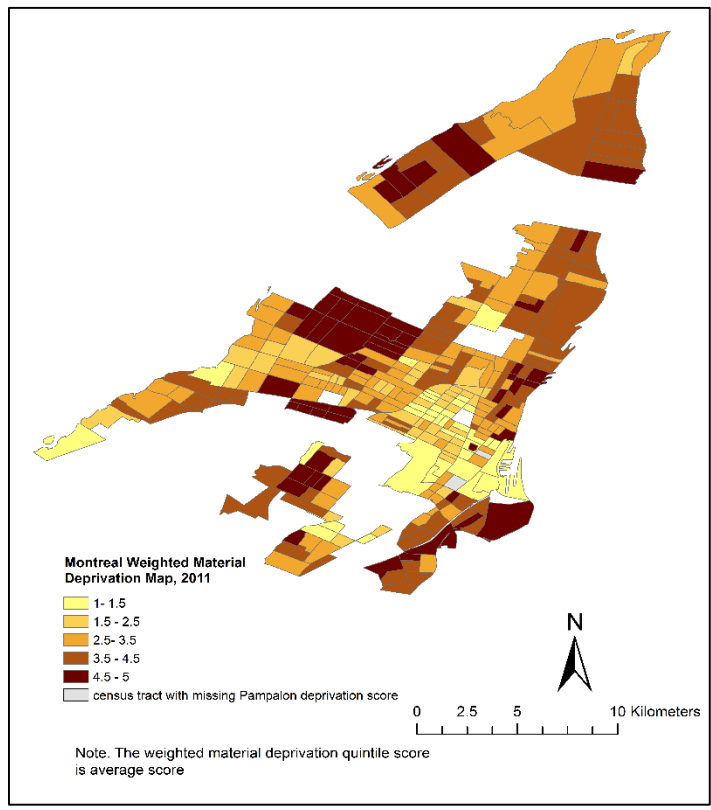
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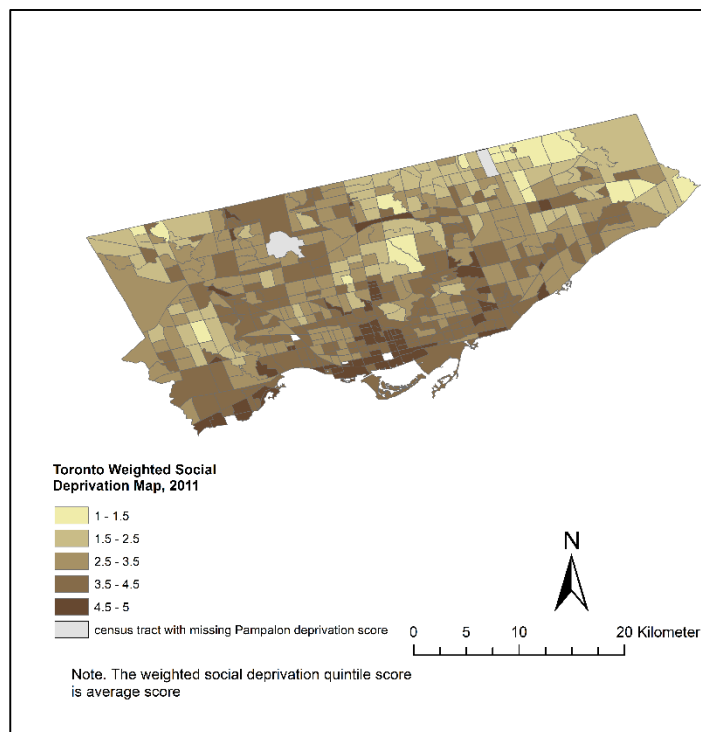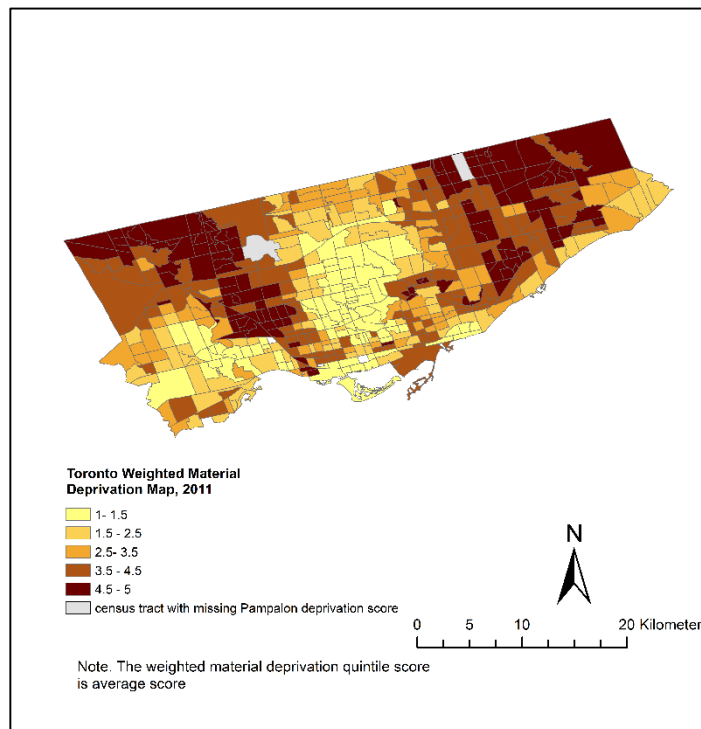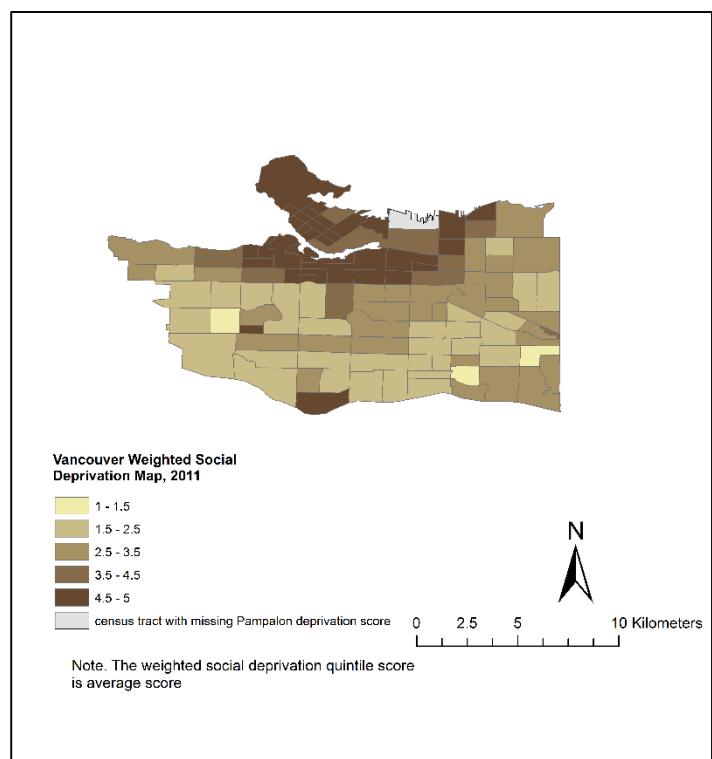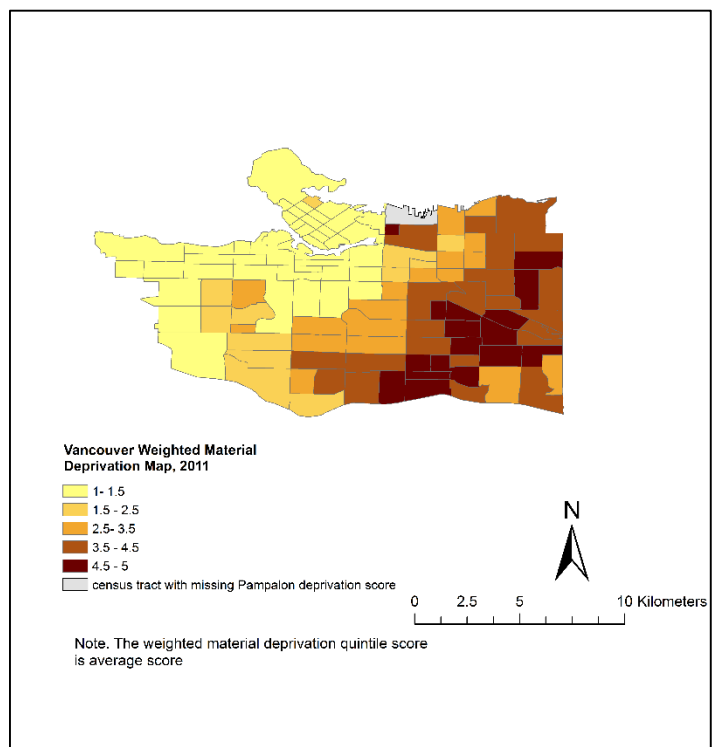SUPPORT FOR BICYCLING IN CANADA

Saskatoon
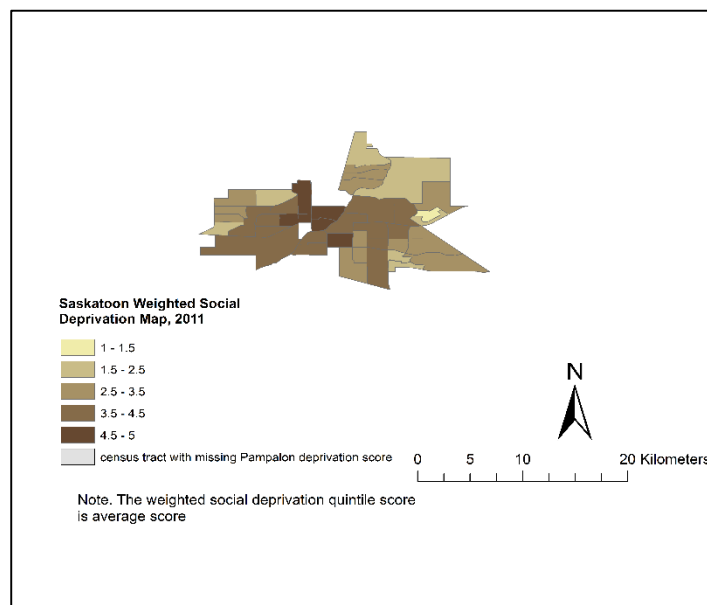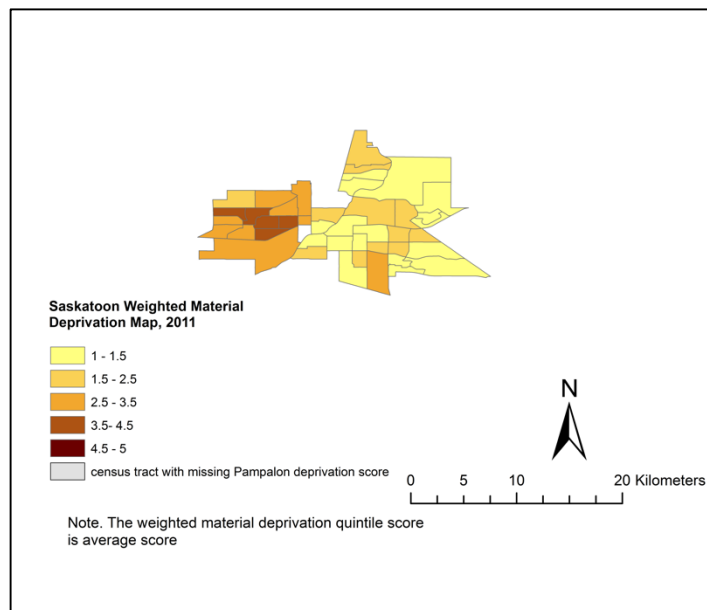
AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL
SUPPORT FOR BICYCLING IN CANADA

St. John's
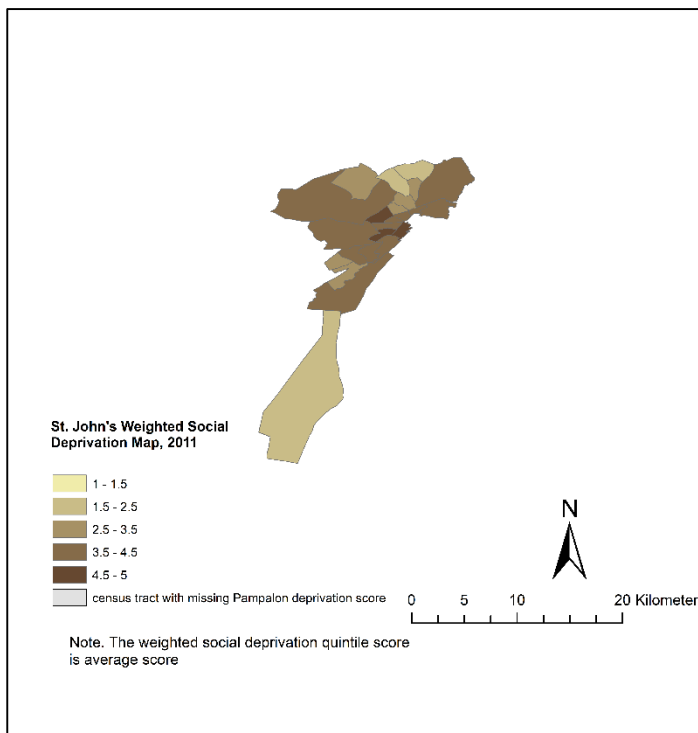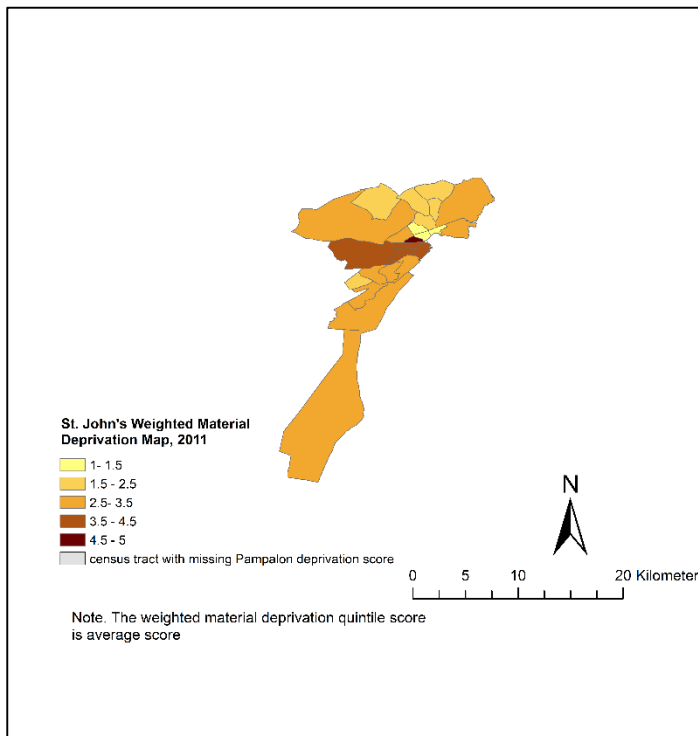
AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL
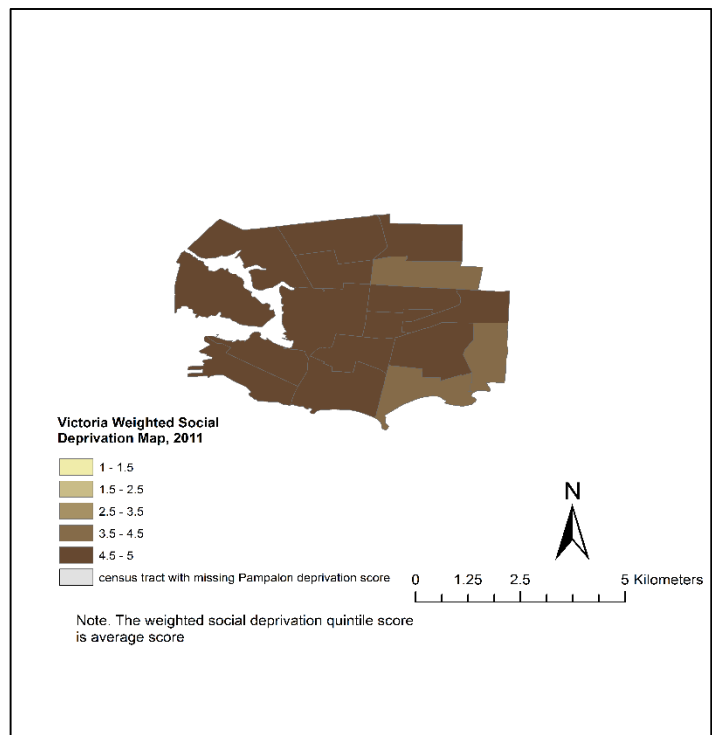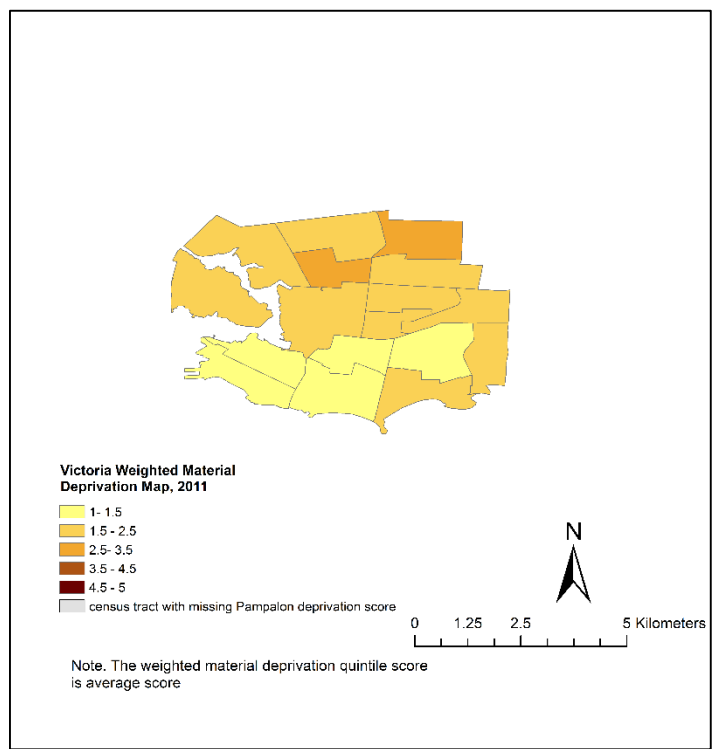SUPPORT FOR BICYCLING IN CANADA

Toronto

AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL
SUPPORT FOR BICYCLING IN CANADA

Vancouver

AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL
SUPPORT FOR BICYCLING IN CANADA

Victoria

AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL
SUPPORT FOR BICYCLING IN CANADA

Appendix B

Record Layouts and Data Descriptions of Postal Code^OM Conversion File (PCCF)

Postal Code^OM Conversion File (PCCF) and Retired 2010 (R2010.txt) record layouts

Position	Size	Tvne[1]	Field name	Description
1	6	C	Postal code^OM	Postal code^OM
7	3	C	FSA^©	Forward sortation area^©
10	2	C	PR	Province or territory code
12	4	C	CDuid	Census division unique identifier
16	7	C	CSDuid	Census subdivision unique identifier
23	70	C	CSDname	Census subdivision name
93	3	C	CSDtype	Census subdivision type
96	3	C	CCScode	Census consolidated subdivision code
99	3	C	SAC	Statistical Area Classification code (includes CMA/CA)
102	1	C	SACtype	Statistical Area Classification type (includes CMA/CA)
103	7	C	CTname	Census tract name
110	2	C	ER	Economic region code
112	4	C	DPL	Designated place code
116	5	C	FED03uid	Federal electoral district – 2003 Representation Order unique identifier
121	4	C	POP_CNTR_RA	Population centre/rural area code
125	1	C	POP_CNTR_RA_type	Population centre/rural area type
126	8	C	DAuid	Dissemination area unique identifier
134	2	C	Dissemination block	Dissemination block code
136	1	C	Rep_Pt_Type	Representative point type
137	11	N	LAT	Latitude of lowest level geographic area for postal code^OM record (as indicated in Rep_Pt_Type variable)
148	13	N	LONG	Longitude of lowest level geographic area for postal code^OM record (as indicated in Rep_Pt_Type variable)
161	1	C	SLI	Single link indicator
162	1	C	PCtype	Postal code^OM type
163	30	C	Comm_Name	Community name
193	1	C	DMT	Delivery mode type
194	1	C	H_DMT	Historic delivery mode type
195	8	C	Birth_Date	Birth date (yyyymmdd)
203	8	C	Ret_Date	Retired date (yyyymmdd)
211	1	C	PO	Delivery installation
212	3	C	QI	Quality indicator
215	1	C	Source	Source of geocoding
216	1	C	POP_CNTR_RA_SIZE_CLASS	Population centre and rural area classification

Note. The type 'N' refers to numeric values while 'C' refers to both alphabetic and numeric characters. From 2013, "Census of Canada. Postal Code Conversion File, June 2013 Postal Codes, 2011 [2013]", http://hdl.handle.net/11272/10029 Statistics Canada [Distributor] V5 [Version]

AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND ENVIRONMENTAL
SUPPORT FOR BICYCLING IN CANADA

*Statistical Area Classification code (SAC) and reference area*

| Statistical Area Classification code (SAC)	Reference area
000	Territories, outside of CA
001-995	CMA/CA unique identifier
996	Strong metropolitan influenced zone
997	Moderate metropolitan influenced zone
998	Weak metropolitan influenced zone
999	No metropolitan influenced zone

Note. From June 2013 Postal Code[OM] Conversion File (PCCF), Reference Guide

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Running head: AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND
BICYCLING IN CANADA

Appendix C
The 2011 Journey to Work Cycling Mode Share Maps of Nine Cities
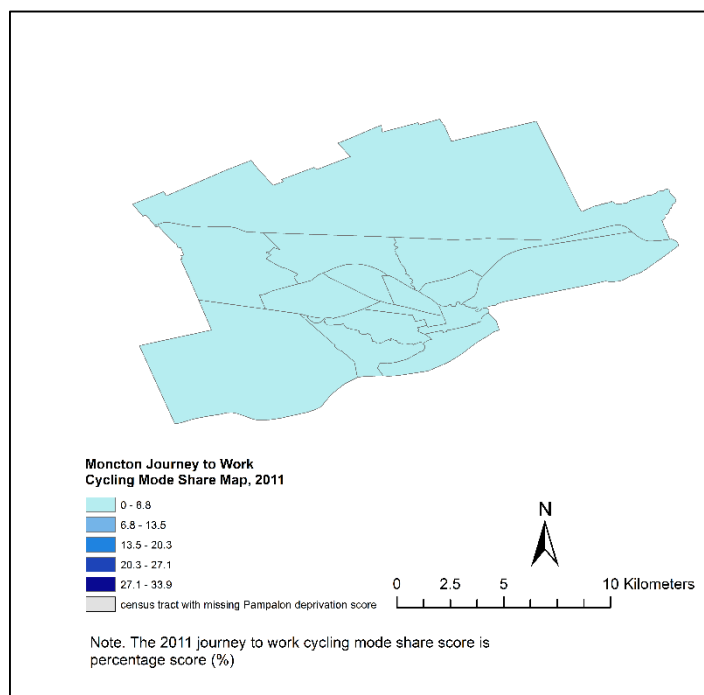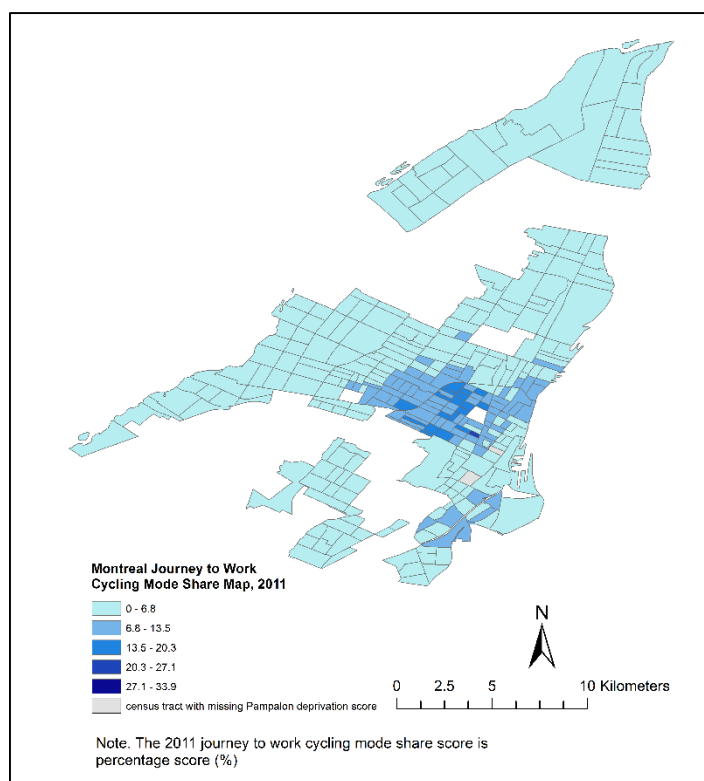**Calgary**
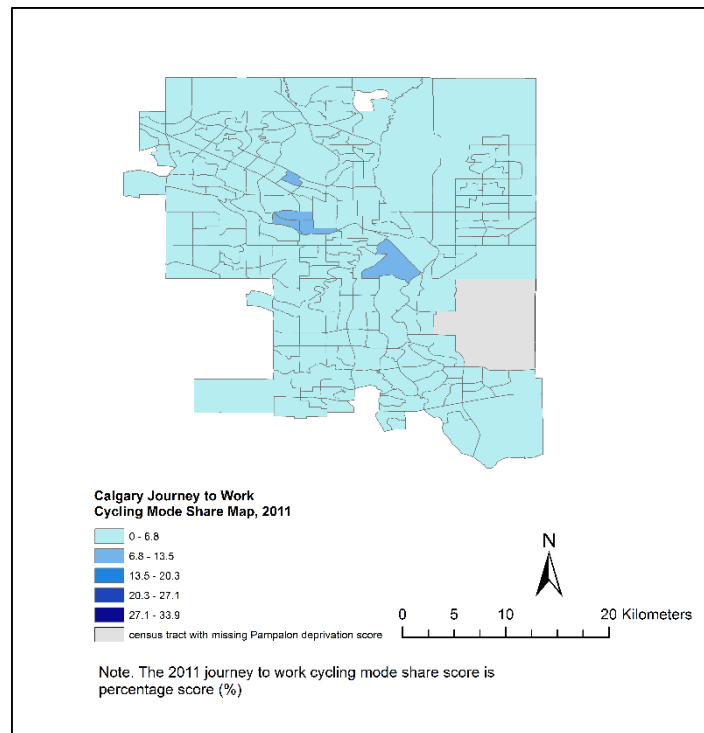
Halifax
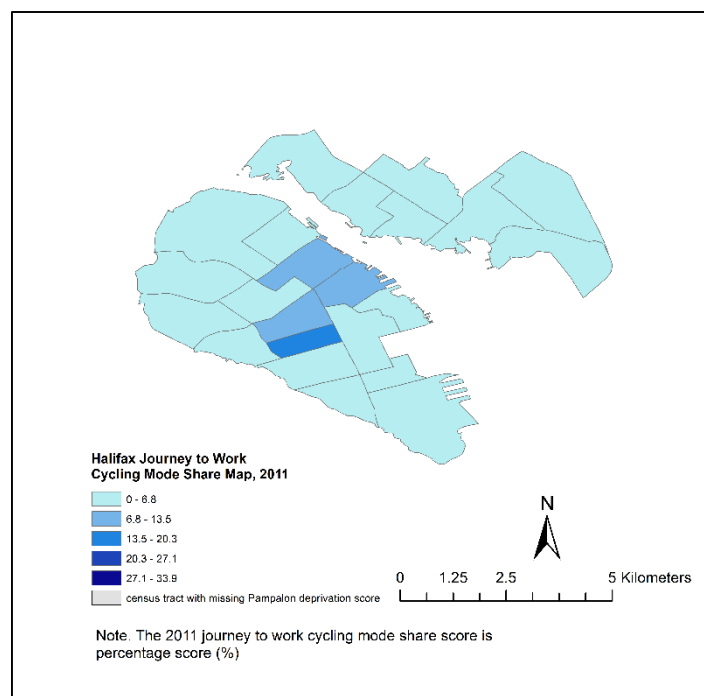
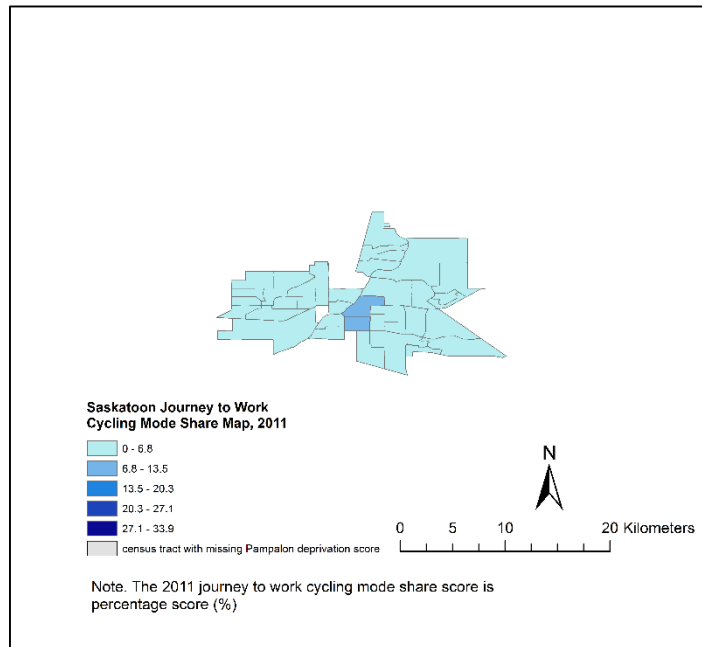AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND BICYCLING IN
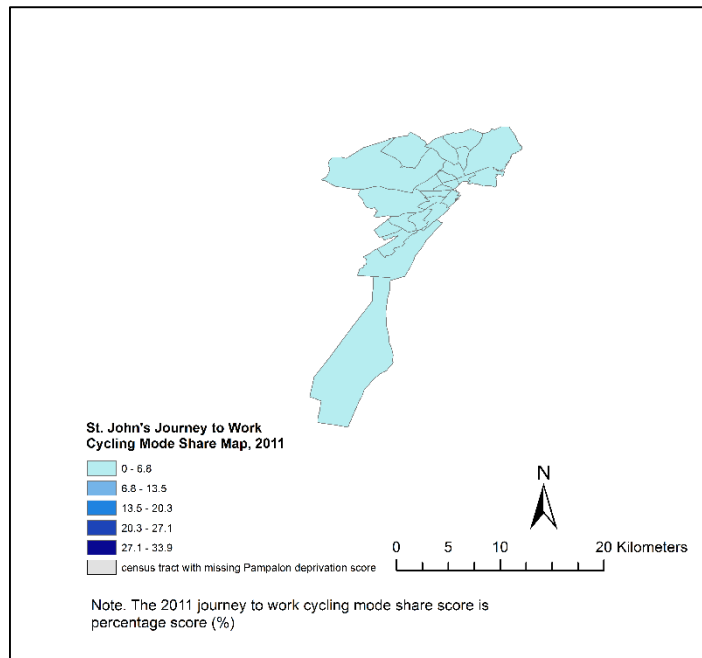CANADA

Moncton

Montreal

AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND BICYCLING IN CANADA
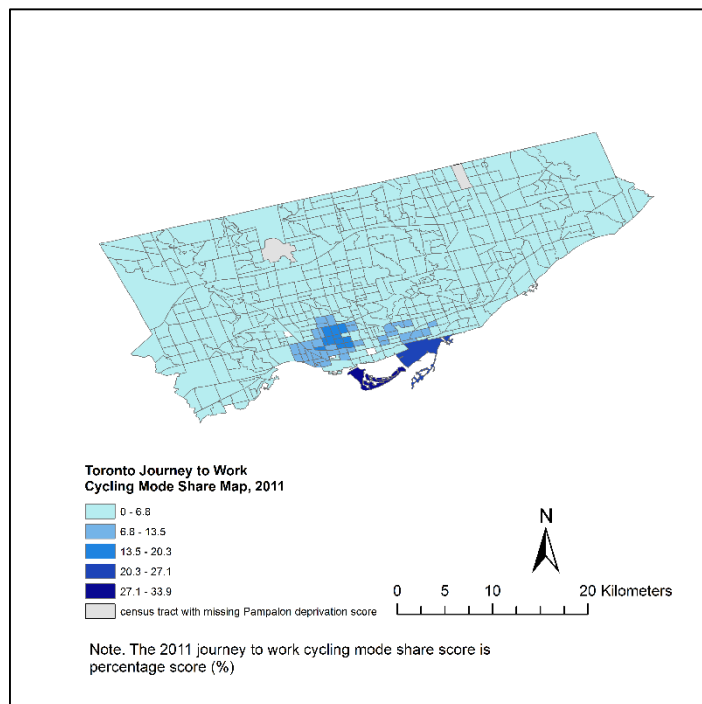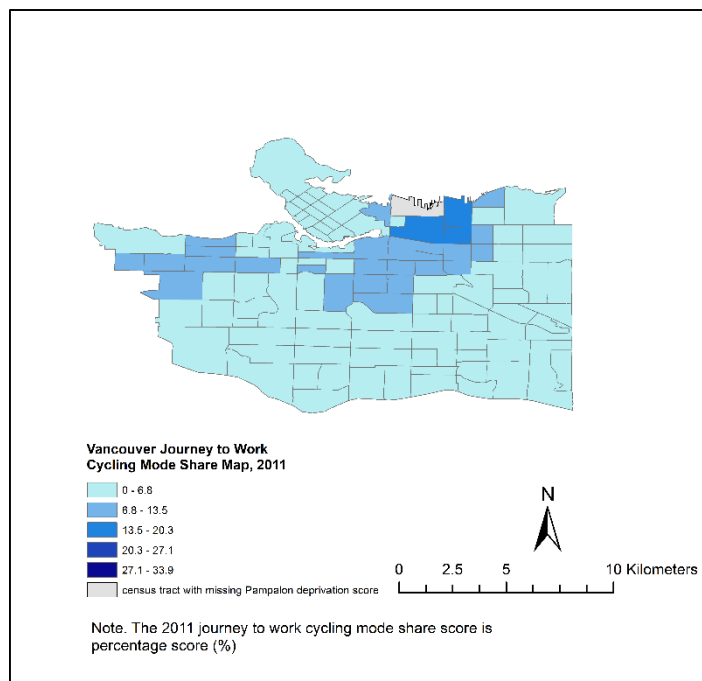
Saskatoon

St. John's

AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND BICYCLING IN
CANADA

Toronto

Vancouver

AREA-BASED SOCIO-ECONOMIC DEPRIVATION AND BICYCLING IN
CANADA
Victoria

Victoria Journey to Work
Cycling Mode Share Map, 2011

0 - 6.8
6.8 - 13.5
13.5 - 20.3
20.3 - 27.1
27.1 - 33.9
census tract with missing Pampalon deprivation score

0   1.25   2.5   5 Kilometers

Note. The 2011 journey to work cycling mode share score is
percentage score (%)