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# Deserts, Swamps, or Tundras? A Comprehensive Investigation of Neighborhood Food Environments

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## Abstract

This study uses service area-based coverage and Poisson regression methods to assess neighborhood healthy and unhealthy food environments and food access associated with different socio-economic groups in Edmonton, Canada. We identify three types of vulnerable neighborhoods according to different food environments: food deserts, food swamps and food tundras. Key results from this article indicate: (1) child population is negatively associated with both healthy and unhealthy food resources; (2) good access to public transportation is associated with good coverage of all types of food stores; and (3) neighborhoods with higher percentages of unemployed and minority population have better coverage of both healthy and unhealthy foods in general. Tailored strategies are proposed to effectively and efficiently improve food environments with limited resources.

## Introduction

Healthy food intake is essential to overall health, and is reported to reduce the risk of nutrition-related chronic diseases such as obesity and type 2 diabetes [1,2]. There is growing evidence that physical access to different types of food outlets substantially influences dietary patterns and weight status at the population level [3-5]. A report that systematically reviews 19 Canadian community food assessments found a positive relationship between geographic access to non-nutritious food sources and obesity rate, especially among children and youth [6]. Increasingly, the community food environment has become one of the most pressing public health concerns in Canada.

Vivid descriptions of different food environments come from various ecological terms [7]. For example, originating in the United Kingdom in the 1990s, the term "food desert" is now commonly used to describe poor urban communities that lack access to fresh, healthy and affordable food in North America [8]. While there is a myriad of food desert research, a few studies also came up with the concept of "food oasis" to describe neighborhoods that have superior access to healthy food outlets [9-11]. Opposite to food oasis, the term "food swamp" to describe low-income urban communities that have a plethora of fast food restaurants and convenience stores that sell less healthy or unhealthy food, is also gaining popularity [12]. "Food swamp" is considered an especially valuable concept to describe neighborhood food environments, as the excess of unhealthy food would "inundate" or "swamp out" the healthy food choices residents have [12]. As a result, it is often suggested that the "food swamps" should be assessed together with the "food deserts" or "food oases" when trying to investigate the actual food environments and the relationship between food environments and health consequences [8].

Another strand of research on food environments is the investigation of the associations between a neighborhood's food availability and its socio-demographic characteristics [13-16]. In general, the availability of food retailers has been shown to vary according to the neighborhood's socioeconomic status, depending on study areas. For example, fewer retail sources of healthy foods (e.g., supermarkets) and more sources of unhealthy foods (e.g., fast food restaurants and conveniences stores) are found to be located in neighborhoods with higher proportions of low-income and ethnic-minority residents relative to more affluent neighborhoods or those with fewer minorities in the U.S. [17]. Comparatively, in Canada, more deprived neighborhoods have greater access to both healthy and unhealthy food outlets, with some variations across study regions [18-20]. Therefore, an in-depth investigation of the association between subpopulation and their food availability is essential for government and interest groups to implement specific policies for groups in need.

The objective of this article is to comprehensively assess neighborhood food environments and investigate associations between neighborhood characteristics and different food stores availability. Combining both healthy and unhealthy food outlets in this study, we contribute to the literature by identifying three different types of food environment. In addition to the widely assessed "food desert" and "food swamp" issues, we introduce a new concept, "food tundra," to describe neighborhoods

that have easy access to unhealthy food but deficient healthy food availability. Identification of different types of food environments is valuable for policy purposes because different types of food environment require tailored strategies to mitigate the problem. In specific, finding food tundra neighborhoods can help detect communities that have been "forced" to consume less healthy food because of the abundant availability of fast food and no easy access to healthy food. These targeted areas are in extreme need of an improved physical food environment, especially for deprived groups in these communities. Furthermore, in contrast to previous studies that adopted a distance-based method to measure the food accessibility [20-22], we also make a contribution to the literature by using the "service area" approach. The service area method addresses the "edge effect" that is often ignored by the distance-based measurement [23], and can more accurately describe the neighborhood food environment. We use a service area-based Poisson regression model to investigate the unequal associations between neighborhoods' socio-demographics and various food environments. Results from this study therefore offer a more nuanced (less biased) understanding of the physical food environment than the conventional distance-based approach, and can provide better empirical support for future policy designs.

## Study Area, Data and Methods

### Study area

As a median-sized North American city in the peri-urban area, the city of Edmonton provides an interesting case study because of its unique city structure and increasing policy focus on community food environment. The City has made substantial efforts to create a favorable food environment for Edmontonians. Established in 2012, the Edmonton Food Council launched the City's Food and Agriculture Strategy Fresh. One of the five goals in the strategy is to develop neighborhoods into healthier and more food secure communities. Developed in consultation with citizens, interest groups, businesses and organizations, the ultimate goal of Fresh is to help guide Edmonton toward a resilient food and urban agriculture system [24]. Meanwhile, the city (and the province alike) has paid particular attention to the children and adolescent group partially because of the increasing childhood (including adolescent) obesity epidemic [6]. School-based health promotion programs that aim to improve healthy living habits of students and to sustain capacity for healthy environments in school communities have been established and kept expanding across the city. For example, the Alberta Project Promoting active Living and healthy Eating in Schools (APPLE Schools) is a school-wide intervention that was launched in 2008. Fung, et al. and Vander Ploeg, et al. [25,26] reported that APPLE Schools have increased students' vegetable and fruit intake by 10% and students are 40% less likely to be overweight. In addition to educational campaigns and various nutrition programs, such as cooking clubs, the actual availability of fresh foods and unhealthy food in the neighborhood is a key factor influencing household food consumption.

### Data

There are four sets of food stores in this article that can be divided into two streams, healthy and unhealthy food outlets. Healthy food outlets include supermarkets and local grocery stores, and unhealthy food outlets include convenience stores and fast food restaurants. All the geographic sites of these food stores are obtained from DMTI Spatial Inc., which is a commercial company offering location-based data in Canada. Supermarkets are assumed to provide a full range of food products (e.g., fruit, vegetables, meat and dairy products). These full-service supermarkets are mainly the outlets of chain stores such as Sobeys, Safeway, Superstore and Walmart. Local grocery stores or specialty shops also sell fresh fruits and vegetable, meat, or fish and other seafood. Store information was further confirmed by verifying stores' official websites. Non-relevant shops, such as drug markets and liquor stores, were excluded from these two categories. Fast food restaurants are defined as quick-serving food outlets that offer relatively limited menus and food preparation options (e.g., burgers, sandwiches and pizzas), where patrons pay before receiving meals. In this study, they are primarily the outlets of franchised stores such as A&W, KFC, McDonald's, Subway and Wendy's. Stores that do not provide food services on a regular basis or non-food restaurants, such as bars and inns, were excluded from the analysis. Convenience stores are considered outlets that sell a limited selection of daily living items and offer less healthy, sugar and energy-intense food commodities. Based on the classification in the DMTI database, these stores are mainly some chain stores such as 7-Eleven and Mac's and gas station food stores. In the final dataset, we have 82 supermarkets, 40 local grocery stores, 783 fast food restaurants and 199 convenience stores in the City of Edmonton (see Figure 1 for geographic distribution of these stores). Note that restaurants providing healthy food were not included in the analysis due to the difficulty of a uniform definition.

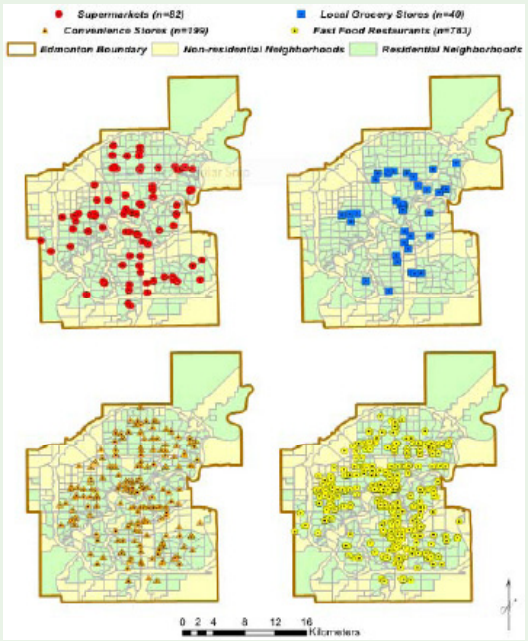


**Figure 1:** Distribution of Food Outlets in Edmonton.

We extracted the neighborhood socio-demographics from Statistics Canada, National Household Survey (2011). There are 392 defined neighborhoods in Edmonton. However, 145 are non-residential neighborhoods (mainly industrial areas) that have no data of population. We thus excluded these non-residential neighborhoods and only used 247 residential neighborhoods for analysis. Road network data and the neighborhood shape file for Edmonton were

obtained from CanMap Route Logistics (v2012.3), which is managed by the University of British Columbia. Figure 2 displays the structure of data.

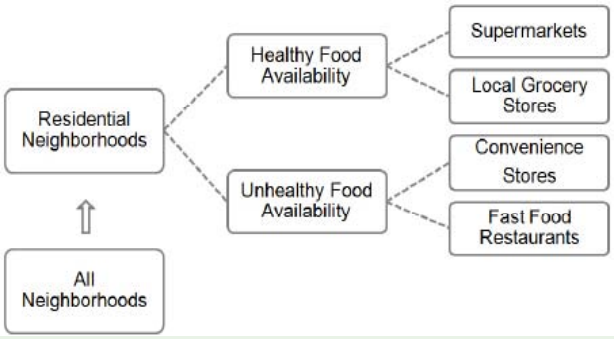


**Figure 2:** Data Structure.

## Measuring accessibility/availability using GIS approach

Distance-based measurement is the most commonly used method in food access research in the sense that distances between study areas and food outlets were calculated [22,27]. However, using the centroid of a neighborhood to calculate the distance to represent the entire neighborhood's food accessibility fails to capture the heterogeneity within a neighborhood (i.e., the different accesses in different sub-areas). An additional methodological drawback of using the distance-based measurement is the constraint of distance to the closest food outlet. This may underestimate the food availability when there are stores clustering in certain areas, which is particularly obvious in the case when a large number of fast food restaurants and convenience stores often exist in a single neighborhood.

As a result, researchers have proposed other methods to alternatively capture neighborhood food availability. For example, [22,28] Lu and Qiu and Wang, et al. adopted the coverage method to measure neighborhoods' food availability by drawing buffers based on the center of study areas and thus counting the number of total food stores within a threshold distance (e.g., 1-km). However, these studies also chose the centroid or population-weighted centroid of a neighborhood to represent the whole neighborhood or community. Additionally, food stores outside the neighborhood boundary can be easily neglected when evaluating store availability for a specific neighborhood, which leads to the "edge effect" [23,29]. Sadler, et al. reported that including the edge effect or incorporating food stores outside the targeted neighborhoods can account for approximately 37% higher in accuracy of food access estimation.

A service area, as the name suggests, defines an area around a food outlet that could be served by the store given certain access criteria (e.g., within 30 minutes walking distance or within a certain threshold road distance like 1-km). This concept has been widely used in literature of the assessment of public services such as health agencies, transit stations, and sewerage services [30-32]. However, there exists limited research in the field of food access. Quantitative analysis of service areas study is even scarcer. Larsen and Gilliland created a "service area" of 1-km based on each supermarket to assess the level of supermarket access in the case of London, Ontario, but their results were primarily at the descriptive level using mapping techniques. In this study, we first calculated the "service area" for each store, based on a threshold road network distance. Following Larsen and Gilliland [33], we chose 1-km as the threshold to conduct the service area analysis. Figure 3 shows the distribution of service areas in four different cases when different food outlets are selected.

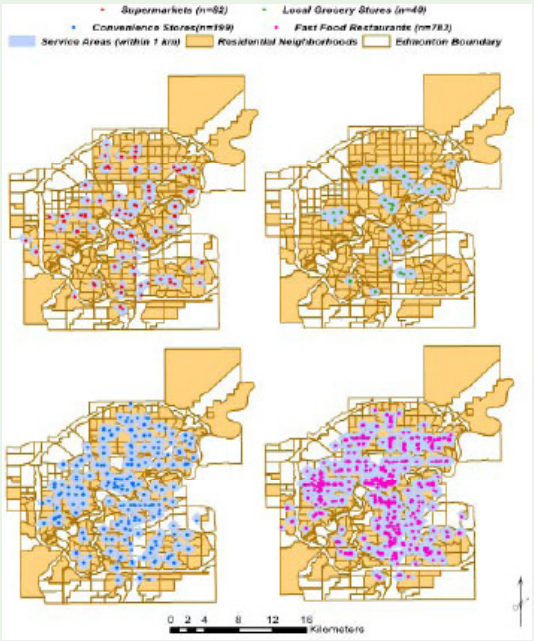


**Figure 3:** Service Areas of Food Outlets in Edmonton.

## Model and data analysis

The classic linear regression model using the Ordinary Least Squares (OLS) technique is a common practice in literature that examines the relationship between food accessibility and neighborhood socio-demographics [22,27,34]. Others have used Poisson regression models to investigate the number of stores in association with neighborhood characteristics [35-38]. This technique can mitigate the problem of clustering food stores in the study area, as a better representation of food accessibility than the distance-based method. However, most prior studies directly used the store counts within a neighborhood, which ignores the case when residents commute to neighboring communities to purchase food (the so-called "edge effect" issue). To address this problem; we adopted the "service area" method and included those stores in nearby neighborhoods as long as their service areas cover, at least partially, for each neighborhood. The specification of Poisson regression model is as follows,

$$Y(N_i)|\lambda(N_i) \sim Poisson\{\lambda(N_i)\}$$

$$\ln\{\lambda(N_i)\} = X_i\hat{a} + \varepsilon(N_i)$$

where $Y(N_i)$ is the count of service areas in neighborhood $N_i$, and $\lambda(N_i)$ is the expected count of service areas at the same location. As a common assumption, the logarithm of the expected count is a linear function of covariates and an error term that represents the unobserved elements [14,37]. $X_i$ is a vector of neighborhood-level

covariates (including an intercept term) of neighborhood $N_i$, and â is a vector of coefficients to be estimated. $\varepsilon(S_i)$ is an i.i.d. unobserved error term.

The neighborhood-level independent variables include: the percentage of children population aged under 19 (Children); the percentage of the senior population aged 65 and over (Senior); the percentage of residents who have a higher education such as postsecondary certificate, diploma or degree (High Education); the percentage of unemployed residents (Unemployment); the percentage of minority group (Minority), which refers to immigrants who are mainly South Asian, Chinese, Black, Filipino, Latin America etc.; the median income at the neighborhood level (Median Income); the percentage of private car access (Private Car), which refers to individuals who have access to a car, truck, or van as primary commuting transportation, including both passengers and drivers; and the percentage of residents using public transport who take buses and trains as the primary travel option (Public Transit). Note that both Private Car and Public Transit are based on residents who are over 15 and employed.

## Results

### The neighborhood socio-demographics in Edmonton

Statistics from Table 1 indicate that residential neighborhoods in Edmonton have an average of 2.31 service areas based on healthy food outlets. Overall, the availability of supermarket is almost doubled compared to local grocery stores. However, in some neighborhoods, the number of service areas of local grocery stores is higher than that of supermarkets. However, in some neighborhoods, the number of service areas of local grocery stores is higher than that of supermarkets. For the unhealthy food sources, the average number of service areas is about 15, with 80% coming from fast food restaurants. Additionally, heterogeneity is evident among neighborhoods with respect to the spatial pattern of service areas based on different food sources. Figure 3 demonstrates that neighborhoods in the downtown area (located in the center part of the city) are almost covered by any type of food providers. However, neighborhoods in the southwest region of the city, named "River bend" that were discussed in details by Wang, et al.[22], have quite limited access to both healthy food outlets, but there are several unhealthy food sources in that region. Another interesting finding is that the neighborhoods in the northeast part of the city have very limited healthy food stores but a rich clustering of convenience stores and a few fast food restaurants. Several supermarkets but almost no local grocery stores exist in the southeast region of the city. At the same time, quite a few fast food restaurants and convenience stores gather in that region, this may crowd out the healthy food options.

In terms of the neighborhood socio-demographics, Table 1 further shows that slightly more than 40% of residents in the city rely on private cars for daily commuting, and about 8% of them choose public transport as their primary transit option. Almost half of residents earned higher education and the maximum is as high as 75%. The average median income among neighborhoods across the city is around $CAD 38,000. However, the gap between the rich and poor is rather huge with the maximum being more than 20 times than the minimum. The rate of unemployed residents is relatively low with an average of 2.24% across the city, with residents in some neighborhoods fully employed. There are neighborhoods with dominantly white residents, and some neighborhoods have more than half minority groups and immigrants. In some neighborhoods, the percentage of children and seniors can be as high as 35% and 43%, respectively, and the minimum percentage is less than 5%.

**Table 1:** Summary of Service Area and Neighborhood Characteristics (N=247).

| Variable[a] | Median | Mean | Minimum | Maximum |
|---|---|---|---|---|
| Service Area (No.) | | | | |
| Healthy Food Outlets | 2 | 2.31 | 0 | 13 |
| Supermarkets | 1 | 1.52 | 0 | 6 |
| Local Grocery Stores | 0 | 0.79 | 0 | 8 |
| Unhealthy Food Outlets | 12 | 14.97 | 0 | 109 |
| Fast Food Restaurants | 9 | 12.08 | 0 | 99 |
| Convenience Stores | 3 | 2.89 | 0 | 10 |
| Population Density (1,000 per km$^2$) | 2.8 | 3.27 | 0.01 | 99.7 |
| Children (%) | 23.43 | 22.8 | 4.88 | 35.05 |
| Senior (%) | 10.91 | 12.36 | 1.1 | 43.27 |
| High Education (%) | 44.98 | 46.27 | 13.82 | 75.86 |
| Unemployment (%) | 2.13 | 2.24 | 0 | 7.37 |
| Minority (%) | 23.52 | 23.88 | 0 | 56.6 |
| Median Income (1,000 $CAD) | 35.91 | 37.6 | 3.23 | 65.22 |
| Private Car (%) | 42 | 41.71 | 9.32 | 68.86 |
| Public Transport (%) | 6.82 | 7.25 | 0 | 19.04 |

[a]We investigated the potential multicollinearity problem and found coefficients of correlation matrix are all relatively small.

### Identification of different types of food environments

Following the common practice, we chose the combination of low healthy food availability, low income, and high population density to define "food deserts" [8]. Neighborhoods with the number of service areas fewer than two (below the city median), which constitute about 45% of all residential neighborhoods in the city, were defined to have low availability. We then selected the bottom quartile (25%) of median income and top quartile (25%) of population density as the other two criteria. As a result, this leads to seven neighborhoods that might be considered food deserts. A "food swamp" usually refers to as a low-income urban community that has a plethora of unhealthy food outlets such as fast food restaurants and convenience stores [12]. We thus chose the number of service areas more than 20 (approximately 25% of all residential neighborhoods) as the high availability of unhealthy food. Combined with other two criteria namely bottom quartile of median income and top quartile of population density, we identified 13 food swamp neighborhoods for the city. As policy makers and other interest groups are particularly interested in identifying the most vulnerable neighborhoods, we introduce the concept of "food tundra" by overlapping the "food desert" with "food swamp" neighborhoods to characterize those neighborhoods with poor access to healthy food but have excessive coverage of unhealthy food outlets. In particular, we found three food tundra neighborhoods across the city. Figure 4 shows the three types of neighborhood with different food environments, and Tables 2 and 3 summarize these neighborhood characteristics.

**Table 2:** Definitions of Food Desert, Food Swamp, and Food Tundra Neighborhoods.

| | Healthy Food Availability | Unhealthy Food Availability | Median Income | Population Density |
|---|---|---|---|---|
| Food Desert (N=7)[a] | number of service area ≤ 1 | - | bottom quartile (25%) | top quartile (25%) |
| Food Swamp (N=13)[a] | - | number of service area ≥ 20 | bottom quartile (25%) | top quartile (25%) |
| Food Tundra (N=3)[a] | number of service area ≤ 1 | number of service area ≥ 20 | bottom quartile (25%) | top quartile (25%) |

[a]The seven food desert neighborhoods are: Aldergrove, Belmead, Bisset, Blue Quill, Cromdale, Casselman, and Thorncliff; the 13 food swamp neighborhoods are: Alberta Avenue, Aldergrove, Belmead, Boyle Street, Central McDougall, Eastwood, Garneau, Kameyosek, La Perle, Queen Alexandra, Queen Mary Park, Thorncliff, and Weinlos; the three food tundra neighborhoods are: Aldergrove, Belmead, and Thorncliff.

**Table 3:** Summary of Neighborhoods with Different Food Environments.

| Variable | Mean Value | | | |
|---|---|---|---|---|
| | Food Desert | Food Swamp | Food Tundra | City |
| | (N=7) | (N=13) | (N=3) | (N=247) |
| Service Area (No.) | | | | |
| Healthy Food Outlets | 1 | 4.85 | 1 | 2.31 |
| Unhealthy Food Outlets | 14.57 | 40 | 27 | 14.97 |
| Population Density (1,000 per km$^2$) | 4.15 | 4.72 | 3.73 | 3.27 |
| Children (%) | 24.1 | 19.77 | 25.42 | 22.8 |
| Senior (%) | 8.76 | 10.34 | 9.3 | 12.36 |
| High Education (%) | 44.27 | 44.68 | 43.99 | 46.27 |
| Unemployment (%) | 3.79 | 3.47 | 2.79 | 2.24 |
| Minority (%) | 24.06 | 26.67 | 28.89 | 23.88 |
| Median Income (1,000 $CAD) | 29.96 | 27.52 | 30.09 | 37.6 |
| Private Car (%) | 39.69 | 34.92 | 40.98 | 41.71 |
| Public Transport (%) | 10.54 | 10.64 | 10.02 | 7.25 |

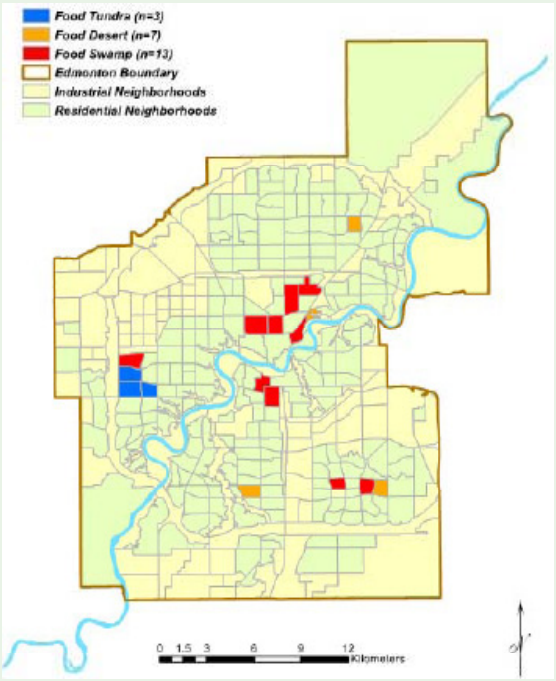


**Figure 4:** Identification of Neighborhoods with Different Food Environments.

For the three "food tundras," (i.e., Aldergove, Belmead and Thorncliff) on average, there is only one supermarket service area for each neighborhood, however, each neighborhood has 27 unhealthy food retailers that can serve the residents. Tundra neighborhoods are all located in the western part of the city and have relatively high population with disadvantaged socio-economic status (i.e., higher unemployment rate, less high educated population, lower median income and less access to private cars). The three neighborhoods also have higher percentage of children and minority population.

## Food availability and neighborhood socio-demographics

With regard to the socio-demographic inequity, many U.S. studies have found that deprived population, such as seniors, immigrants and unemployed residents, have comparatively poor access to fresh foods [11,33]. However, our results (Table 4) show these disadvantaged groups actually have better healthy food coverage in Edmonton. In particular, unemployment rate is significantly positively correlated with an increase in the number of service areas, and minority groups are also found to be living in neighborhoods that are well served by healthy food outlets overall. The results are consistent with other Canadian studies. For example, a study in Montreal, Quebec showed a positive relationship between social deprivation index (which includes unemployment rate and recent immigrants) and the number of supermarkets within 1-km [39]. Similar results were also found in another city of the same province, Gatineau, that deprivation is overall positively correlated with better accessibility to fresh fruits and vegetables [40]. Black, et al. [18] also indicated a positive association between visible minority resident's rate and the number of large supermarkets and fresh food stores within 1-km of residential addresses in British Columbia. However, one noteworthy outcome is the significantly negative association between neighborhood's children percentage and the number of service areas given both types of fresh food sources. Similar results in Saskatoon showed that neighborhoods with higher rate of children aged 5-14 have poorer access to the nearest healthy food stores [34]. Considering the increasing obesity rate among children and youth in the province [6], this finding should raise local authorities' awareness of the food environment, especially for adolescents. The unfavorable access to healthy food could potentially contribute to children's unhealthy dietary habit.

Although we find that overall, disadvantaged groups have relatively adequate access to health food stores, we also reveal that for these swamp, desert, and tundra neighborhoods, the percentages of deprived populations are higher than the city average. However, the inversed situations in those 20 neighborhoods are not significant enough to influence the regression results, which represent the average

situation (of the 247 neighborhoods). Our seemingly contradictory results from the food environment assessment for specific vulnerable neighborhoods and a general association analysis are both important and essential to better understand the issue and design appropriate policies and programs to improve the food environment in the city. Meanwhile, overly exaggerating the food environment issue and the unfavorable inequality between different socio-economic groups should be avoided.

When it comes to the unhealthy food availability, many studies in United States have found that unemployed and immigrant groups are more vulnerable and have easier access to less favorable food outlets such as fast food restaurants and convenience stores [41-43]. Our results, as shown in Table 5, are generally consistent with their findings. For instance, neighborhoods with higher rates of unemployment and minority groups have more service areas of unhealthy food sources. For the adolescent and senior groups, however, they are less likely to get access to these unhealthy foods compared to other age groups. Similar results can be found in another Canadian prairie city (Saskatoon)in which neighborhoods with a higher rate of children aged 5-14 have longer distances to the nearest unhealthy food stores [34]. Wealthy residents tend to live where there are fewer services of unhealthy food outlets, although the effect is relatively small. But such results do not exist when it comes to healthy food availability. Residents with high education tend to have more healthy food services, but the association turns out to be statistically insignificant for the unhealthy food availability.

**Table 4:** Poisson Regression Results for Healthy Food Outlets (N=247).

| Variables | Service Area (No.) | | |
|---|---|---|---|
| | Supermarkets | Local Grocery Stores | Healthy Food Outlets |
| Constant | 1.979*** | 2.007*** | 2.680*** |
| | -0.597 | -0.761 | -0.469 |
| Children | -3.884*** | -7.399*** | -5.292*** |
| | -1.341 | -1.66 | -1.035 |
| Senior | 0.691 | 0.482 | 0.41 |
| | -0.863 | -1.113 | -0.68 |
| High Education | -1.099 | -2.672*** | -1.663*** |
| | -0.742 | -0.973 | -0.588 |
| Unemployment | -2.518 | 21.662*** | 6.989* |
| | -5.233 | -6.432 | -4.048 |
| Minority | 1.701*** | 0.127 | 1.350*** |
| | -0.631 | -0.9 | -0.515 |
| Median Income | -0.015 | 0.014 | -0.003 |
| | -0.01 | -0.014 | -0.008 |
| Private Car | -1.198 | -3.060** | -1.925*** |
| | -0.913 | -1.256 | -0.735 |
| Public Transport | 4.902** | 6.629** | 5.054*** |
| | -1.988 | -2.711 | -1.599 |
| Log-likelihood | -362.9 | -272.15 | -449.8 |
| Pseudo $R^2$ | 0.103 | 0.218 | 0.183 |

***Indicate the coefficient is significant at 1%.
**Indicate the coefficient is significant at 5%
*Indicate the coefficient is significant at 10% level, respectively. Standard errors are in parentheses.

**Table 5:** Poisson Regression Results for Unhealthy Food Outlets (N=247).

| Variables | Service Area (No.) | | |
|---|---|---|---|
| | Fast Food Restaurants | Convenience Stores | Unhealthy Food Outlets |
| Constant | 5.236*** | 1.902*** | 5.212*** |
| | -0.183 | -0.488 | -0.169 |
| Children | -9.141*** | -3.030*** | -8.209*** |
| | -0.452 | -1.039 | -0.412 |
| Senior | -1.336*** | 0.474 | -1.161*** |
| | -0.291 | -0.688 | -0.266 |
| High Education | 0.026 | -0.692 | -0.12 |
| | -0.252 | -0.557 | -0.229 |
| Unemployment | 4.756*** | -1.46 | 3.429** |
| | -1.751 | -3.912 | -1.589 |
| Minority | 2.015*** | 1.059** | 1.876*** |
| | -0.223 | -0.457 | -0.199 |
| Median Income | -0.016*** | -0.027*** | -0.018*** |
| | -0.003 | -0.008 | -0.003 |
| Private Car | -1.995*** | 1.243* | -1.474*** |
| | -0.309 | -0.675 | -0.279 |
| Public Transport | 1.397** | 4.202*** | 1.775*** |
| | -0.673 | -1.455 | -0.609 |
| Log-likelihood | -1249.3 | -464.29 | -1300.33 |
| Pseudo $R^2$ | 0.386 | 0.096 | 0.375 |

***Indicate the coefficient is significant at 1%.
**Indicate the coefficient is significant at 5%
*Indicate the coefficient is significant at 10% level, respectively. Standard errors are in parentheses

## Discussion

Similar to the results in previous studies in Edmonton [16,21,22], the food desert neighborhoods are scattered across the city. Besides the relatively low availability of healthy food service areas, they have lower private car access and higher percentage of children and unemployed residents in comparison to the city average. As for the policy recommendations, the establishment of community gardens and farmers' markets may potentially help increase the fresh food availability and thus improve the food environment in these desert neighborhoods [22,44]. For the food swamp neighborhoods, there is a clear pattern of three clusters in the city, including the city core, university area and the western part of the city (Figure 4). In comparison to the city average, these neighborhoods have higher rates of unemployment and minority groups, have much lower private car access, and rely more on the public transportations. Additionally, the percentages of children and senior residents are lower in these communities.

Results from different types of neighborhoods can help the city identify the key areas with high potential for local businesses and neighborhoods that need particular support. Improving the city's food environment requires careful consideration and tailored plans for different neighborhoods. For those food swamps with adequate access to healthy foods, policy and public efforts may focus on educational campaigns and community-supported programs to promote healthy dietary habits. For those food deserts (the food tundras excluded), because these neighborhoods are spread across the city, one big

supermarket will not solve the problem for all simultaneously. Policy interventions that encourage new supermarket businesses through tax credits and other forms of benefits may not work effectively as these big businesses usually require large amounts of input (e.g., infrastructure, labor, parking space), and the purchasing power and population are relatively low in these areas. A more realistic plan is to support other small businesses (e.g., local grocery stores and specialty stores) and alternative fresh food suppliers (e.g., food-producing community gardens and yard gardens), which is consistent with the proposed Fresh strategy. For the three food tundra neighborhoods, they are the most vulnerable communities which have no easy approximation to healthy foods but are heavily surrounded by abundant unhealthy foods. Alternatively, the relative cost of accessing to fast foods is lower than any other neighborhoods in the city. This makes the disadvantaged subpopulations such as children, low-income families, and households without access to private cars within the area most vulnerable groups that deserve more public attention and policy efforts. Strategies such as supporting for local grocery stores and alternative fresh food suppliers will also help relieve the issue. Meanwhile, because all three neighborhoods are located at the same area, a new large supermarket offering a wide variety of healthy and fresh foods might substantially improve the food environment for the entire area and is thus worth municipal and community interventions.

In combination of results from both healthy and unhealthy food outlets (Tables 4 and 5), we can see that public transit displays a significantly positive association with both healthy and unhealthy food availability. This positive relationship can be explained through the supply and demand theory. Residents largely relying on public transit tend to live near public transit centers in the city, where a fairly large number of food outlets are located. Despite quite a few available healthy food outlets, there are pervasive unhealthy food sources, which could inundate residents' healthy food options. As a result, it is not surprising that a group of food swamp neighborhoods cluster in the downtown area where there is the most convenient public transit system across the city, as shown in Figure 4. While establishing a more complete public transit network can improve healthy food access by attracting more fresh food businesses, our results further imply that advocating educational campaigns for a healthy diet, may be of higher need to ameliorate the overall food environment in these neighborhoods. Another note from the comparison is the negative relationship between the children group and the number of service areas in both healthy and unhealthy food sources. Children are beginning to make their own food and snack choices and the dietary habits formed during these years can have a long-lasting impact on their health throughout the lifespan [45], policy makers and other interest groups may want to pay special attention to the food environment of this group. Our findings can thus provide some clues for future policy designs. Although children tend to have fewer service areas of unhealthy food, the healthy food availability is also limited. Specific programs, such as the involvement in community gardens and participation in APPLE Schools, might be helpful in neighborhoods with high children rates.

## Conclusion

This study uses a service area-based method to assess neighborhood food environments and investigates the associations between food availability and neighborhood socio-economic status using Poisson regression models. The key results include that (1) communities with higher rates of unemployed and minority groups have better access to both healthy and unhealthy foods relative to those with fewer unemployed and minority population. However, for the three types of vulnerable neighborhoods (food swamps, food deserts and food tundras), they have high percentages of disadvantaged population; (2) neighborhood with high child population face poor coverage of both healthy and unhealthy food stores in nearby areas; and (3) public transport is positively associated with the availability of all types of food retailers. Implications for improving vulnerable neighborhoods food environments using different strategies and promoting local grocery stores and urban agriculture are discussed to provide useful information for future policy designs and project improvement.

From a practical perspective, the identification of food swamps, food deserts, and food tundras provides policymakers and the general public with an in-depth understanding of neighborhood food environments and contributes to the design of more effective strategies given different types of neighborhoods. Results also assist in identifying the most vulnerable communities that require immediate and substantial support and thus attribute to a better allocation of the limited municipal resources (e.g., financial and staff supports).

Finally, the service area-based method considers spatial heterogeneity within a neighborhood/community and solves the edge effect at the same time. Therefore, it might be a useful expansion of the traditional distance-, coverage-, and density-based assessments and OLS/Poisson regression methods. Broadly speaking, food environment also involves food quality and affordability. Future research may find it helpful to take the two into consideration, together with food availability, when investigating neighborhood food environment.

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