Montréal, le 31 octobre 2019

À qui de droit,

Je m'appelle Thi Thanh Hien Pham. Je suis professeure du département d'études urbaines et touristiques, à l'Université du Québec à Montréal. Je travaille depuis 2010 sur l'équité environnementale dans l'accès aux espaces verts et arbres en particulier à Montréal. J'ai publié plusieurs articles scientifiques sur l'équité environnementale et sur les facteurs qui expliquent la distribution inégale et inéquitable de la végétation à Montréal.

Je souhaite transmettre des recommandations relatives au verdissement comme suit :

- Le verdissement devrait être renforcé dans les quartiers défavorisés afin de réduire des impacts des problèmes environnementaux (notamment les îlots de chaleur) sur la santé de la population, et de compenser pour la population économiquement démunie et bien souvent issue des communautés ethnoculturelles. Un tel verdissement sera bénéfique pour la qualité de vie de la population.
- Le verdissement devrait être réalisé de façon prudente afin de ne pas faire augmenter la valeur des logements/les loyers et éventuellement déclencher la gentrification et l'expulsion des résidents défavorisés. Plus spécifiquement, je recommande de
    - Faire le verdissement avec le plus de participation citoyenne possible afin de comprendre les besoins en termes de végétation de tout le monde (ombrage, esthétique, etc),
    - Éviter les projets de verdissement de grande envergure, qui souvent déclenchent des changements importants de l'environnement bâti et aussi de la population.
    - Verdir en travaillant avec les professionnels en matière de logement afin de maintenir les loyers et les logements abordables pour tous résidents.

Thi Thanh Hien Pham

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Spatial distribution of vegetation in Montreal: An uneven distribution or environmental inequity?

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HIGHLIGHTS

- Examination of equity in Montreal show that low-income people and visible minorities have a more limited access to vegetation.
- Low income is more negatively associated to vegetation than minority status in all models.
- There might be other factors contributing to inequities among minority groups.
- Disparities are more substantial in street vegetation than in backyard vegetation.
- Results suggest more greening efforts in low-income neighbourhoods in order to compensate the lack of public vegetation and mitigate heat island impacts.

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ABSTRACT

Growing evidence is showing that across North American cities, underprivileged populations and racial and/or visible groups have disproportionally less access to vegetation than affluent groups, raising concerns of environmental inequity. This study aims to verify whether in Montreal (Canada) there is environmental inequity resulting from variations in urban vegetation for low-income people and visible minorities. More specifically, various vegetation indicators were extracted from very-high-resolution satellite images, including the proportion of city blocks, streets, alleys and backyards covered by total vegetation and trees/shrubs. Socio-demographic variables were obtained from 2006 Canada Census and rescaled to the city block level, by using a population-based weighing method. Statistical analysis indicates that there are disparities in the distribution of vegetation in Montreal which disfavour low-income people and, to a lesser extent, visible minorities. Disparities are also more pronounced on public land (streets, alleys) than on private land (backyards). Income is a major factor but cannot fully explain inequities among visible minorities. Notwithstanding the weak extent of such disparities, those vulnerable communities might need a better access to ecological services provided by vegetation, notably such as heat island mitigation. Compensatory equity needs to be addressed and our findings call for authorities to reconsider greening budgetary allocation and practices, especially in the most deprived neighbourhoods of the city.

1. Introduction

Numerous studies have demonstrated a wide range of benefits that urban vegetation can have on quality of life, including pollution mitigation, CO_2 sequestration, shade provision (e.g. Akbari, 2002; Nowak, Crane, & Stevens, 2006; Oke, Crowther, McNaughton, Monteith, & Gardiner, 1989). Urban vegetation and green spaces in general also appear to improve mental health (Maas et al., 2009) and offer opportunities for physical exercise and social integration, and hence have positive impacts on human health (Lee & Maheswaran, 2011). In addition, the contribution of vegetation to the mitigation of heat islands is a well-documented ecological service (e.g. Jansson, Jansson, & Gustafsson, 2007) with important implications for people living in areas that experience the resulting beneficial cooling effects and reduced energy consumption (Jensen & Gatrell, 2009). Planting vegetation is therefore becoming an appealing strategy for urban temperature reduction, as cities are increasingly faced with extreme heat events and heat islands related to global warming (IPCC, 2007).

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An important body of research shows that vegetation is often unevenly distributed within cities, so that low-income, minority or other populations lack access to the benefits provided by trees and other vegetation (e.g. Boone, Cadenasso, Grove, Schwarz, & Buckley, 2010; Grove et al., 2006; Mennis, 2006). Researchers have thus raised concerns that this disproportionate distribution may be an issue of environmental inequity (e.g. Heynen, 2006; Landry & Chakraborty, 2009; Pedlowski, Silva, Adell, & Heynen, 2002; Tooke, Klinkenberg, & Coops, 2010). Given previous evidence of disparities in Montreal's heat islands (CIHI, 2011), we will attempt to investigate whether in this city there is a disproportionate distribution of vegetation that might suggest inequity with respect to the potential heat island mitigation benefits of vegetation. Drawing on evidence of the close relationship between heat islands and vegetation (Oke et al., 1989), this study does not directly examine inequities in urban heat islands but instead focuses on inequities in vegetation.

Building from literature on environmental justice (Cutter, Holm, & Clark, 1996; Downey & Hawkins, 2008; Heynen, Perkins, & Roy, 2006; Mohai & Saha, 2006; Perkins, Heynen, & Wilson, 2004), we concentrate on examining inequity for visible minorities and low-income people, who have been found to be prone to disparities. We first seek to determine if there is evidence of a disproportionate distribution of vegetation on different types of urban residential land, including public (i.e. trees in streets and alleys) and private (i.e. residential yards) land. Second, recent studies also underline that the spatial distribution of urban vegetation is influenced by a number of factors, including a neighbourhood's age and population density, and is often spatially autocorrelated (Landry & Chakraborty, 2009; Mennis, 2006; Troy, Grove, O'Neil-Dunne, Pickett, & Cadenasso, 2007). We thus want to understand whether, after integrating such factors into the analysis, there remains a negative association between vegetation cover and the presence of the two aforementioned population groups. Finally, we examine how the association between vegetation and visible minorities varies across areas having similar income levels. As such we hope to contribute to the environmental equity debate on whether poverty can fully explain a limited access to vegetation of minority communities (Downey & Hawkins, 2008; Mohai & Saha, 2006).

This paper also focuses attention on the potential benefits of vegetation in low-income and minority neighbourhoods, especially the potential for heat island mitigation. Recent heat waves have resulted in negative public health impacts in northern cities such as Montreal (Smargiassi et al., 2009), and low-income households are among the most vulnerable populations (Health Canada, 2008). We discuss the public policy implications for public vegetation that is found to be disproportionately distributed with respect to those populations. By doing so, we add the issue of compensatory equity or need-based equity (Talen, 1998) to the ongoing debates about distributional (Landry & Chakraborty, 2009; Tooke et al., 2010) and procedural equity (Heynen et al., 2006) related to urban trees and vegetation.

2. Literature review

2.1. Uneven distribution of urban vegetation and social inequities observed

Scholars are beginning to understand the myriad of scale-dependent social and ecological factors that influence the distribution of urban landscapes, including vegetation (Chowdhury et al., 2011). First of all, the distribution of vegetation has been associated with the characteristics of the built environment that determine the space available for planting, such as urban form, land-use types and age of development (natural growth of trees and urban planning styles) (Conway & Hackworth, 2007; Mennis, 2006). Second, vegetation is also conditioned directly by household-level landscape decisions, or indirectly through support for public or private management efforts (Talarchek, 1990; Troy et al., 2007). Third, differences in residential landscaping preferences have been associated with the cultural origin of residents (Fraser & Kenney, 2000) or with a desire to display a particular group identity (Robbins, Polderman, & Birkenholtz, 2001; Zmyslony & Gagnon, 1998), a factor that at times combines with ethno-cultural exclusion and residential segregation (Buckley & Boone, 2011; Merse, Buckley, & Boone, 2009). Finally, local policies, neighbourhood associations and public agencies also influence greening and hence vegetation cover (Conway, Shakeel, & Atallah, 2011). These factors interact across space and time to shape an uneven distribution of vegetation within cities.

Numerous studies provide evidence of inequitable distribution of vegetation that tends to disfavour low-income households and certain minority groups. Limited access to the benefits provided by vegetation for low-income households has been shown in the Brazilian city of Campos dos Goytacazes (Pedlowski et al., 2002), in American cities like Tampa (Landry & Chakraborty, 2009) and Milwaukee (Heynen et al., 2006), and in Canadian cities such as Montreal, Toronto and Vancouver (Tooke et al., 2010). On the other hand, evidence of an inequitable distribution in vegetation among racial or visible minorities is less consistent. Inequity has been associated with African Americans and Hispanics in Tampa (Landry & Chakraborty, 2009) and immigrants in Toronto (Tooke et al., 2010), but not with African-Americans in Milwaukee (Heynen et al., 2006) or Baltimore (Troy et al., 2007).

2.2. Inequities related to vegetation

Studies on equity in access to urban vegetation can be framed within the larger literature on environmental justice. This literature investigates the disparities in exposure to various types of environmental burdens and benefits, and their underlying causes (e.g. Boone, Buckley, Grove, & Sister, 2009; Mohai & Saha, 2006; Pulido, 1996). A first approach, "distributional" (or "outcome") equity, measures the disparities themselves, while a second approach, termed "procedural equity" is more concerned with the processes that lead to the inequity (Cutter et al., 1996). The label "compensatory equity" was also introduced to emphasize that the need for specific benefits may be greater for some population groups than for others (Apparicio & Seguin, 2006; Boone et al., 2009; Talen, 1998). For instance, vulnerable groups who cannot afford private vegetation might have a greater need for public greening programs.

A few mechanisms contributing to income disparities in access to urban vegetation have been invoked. The poorest households tend to inhabit the neighbourhoods with the least vegetation since green neighbourhoods often have higher rents and property values (Donovan & Butry, 2010; Donovan & Butry, 2011). Neighbourhood disinvestments and privatization of city amenities in such vegetation-deprived areas contribute to increase disparities (Heynen et al., 2006). In contrast, in gentrified and more mobilized neighbourhoods, residents often demand greening interventions from city authorities as a way of maintaining or increasing property value (Conway et al., 2011; Merse et al., 2009). Furthermore, programs to improve vegetation cover have to face a number of obstacles associated with residents' income and housing tenure (Heynen et al., 2006; Perkins et al., 2004). Low-income households are less likely to invest in trees due to limited budget or means to plant trees. Renters tend to have fewer incentives to upkeep or maintain neighbourhood landscapes in general, and trees in particular. They may be reluctant to invest in a property since such improvements may cause an increase in rent (Perkins et al., 2004).

Drivers of disparities among certain minority communities are more complex, explaining partially why evidence of disproportion in vegetation varies across communities and cities. On the one hand, these communities tend to suffer from poverty, which, as we've just seen, is associated with less vegetated neighbourhoods (for example, in Montreal there is a significant correlation between low-income households and visible minority status, with a Pearson coefficient of 0.456). On the other hand, depending on the history and social dynamics of each city, other factors may play a role in shaping inequities, including a lack of political mobilization, language barriers and discrimination in access to housing (Buckley & Boone, 2011; Perkins et al., 2004; Pulido, 1996). Recent studies of environmental equity question whether income alone can fully explain why visible minorities are disproportionately exposed to environmental risks/amenities (Downey & Hawkins, 2008; Pulido, 1996). Hence the interaction of economic power and minority status merits further investigation.

2.3. Measuring vegetation equity: methodological issues

When measuring the existence of inequities in urban vegetation, a few methodological decisions need to be made. A first issue is the scale of analysis. Studies of vegetation equity in the United States and Canada typically use block group or census tract aggregation as units of analysis (grouping an average of 600 and 5000 inhabitants, respectively) (Heynen et al., 2006; Landry & Chakraborty, 2009; Tooke et al., 2010). However, even when the socioeconomic characteristics of inhabitants living in a census tract or block group are relatively homogenous, the heterogeneity of the physical environment, especially vegetation and the built environment, can be lost in such coarse-scale aggregation (Maantay, Maroko, & Herrmann, 2007). Consequently, a few authors such as Landry and Pu (2010) and Troy et al. (2007) recommend using finer scales such as the block or the parcel, especially when vegetation indicators are derived from very high resolution images (e.g., submeter spatial resolution). Yet, Canadian socio-demographic data are not available at the block or parcel levels for reasons of confidentiality. This limitation may be overcome by disaggregating the socio-demographic data from the smallest available unit to an even finer scale using interpolation techniques in which different types of ancillary data can be incorporated (Boone et al., 2009; Maantay et al., 2007). Although other scales or a combination of different scales might be interesting (Cutter et al., 1996; Mohai & Saha, 2006), here we will adopt a fine scale and focus on the local benefits of vegetation, notably heat island mitigation.

The impact of the built environment and spatial dependence on vegetation must be taken into account, even if these factors alone cannot account for the fact that a given group has less access to amenities than other groups. The built environment is important because residing in densely populated areas may be an individual choice, especially for residents who favour proximity to services and walkability (Steiner, 2008), even if this means less space for vegetation. It is also important to control for spatial autocorrelation of vegetation because of the potential bias it can introduce in regression models. In addition, spatial autocorrelation can be the result of socio-historical and ecological factors, and may suggest some other causal mechanisms not accounted for in the model. In the absence of a full understanding of the ecological, historical and social underpinnings of such autocorrelation, techniques such as spatial regression can be used to control for spatial dependence and make statistical estimates more robust (Anselin, 2005; Lloyd, 2007). Those models allow us to some extent to include the effects of missing historical or ecological factors that shape clusters of both similar and dissimilar neighbouring blocks (such as a green park adjacent to a 'grey' block). Inclusion of the built environment and spatial dependence in quantitative studies is useful in uncovering explanations for vegetation cover, and can often help formulate solutions.

When investigating the causes of urban vegetation disparities and designing greening policies, it is also essential to analyze public and private vegetation separately (Heynen et al., 2006). This is because vegetation management differs depending on types of land ownership. Limited access to private vegetation may be compensated by a better access to publicly managed vegetation.

3. Study area and data

This study is conducted on the former city of Montreal (before the municipal mergers of 2002), covering 149 km^2 and inhabited by 1 million people in 2006 (Fig. 1). Founded in 1642, Montreal was the hub for trade in natural resources. From the early 1800s, large infrastructure projects were undertaken to consolidate its role. During the next 100 years, industrialization was amplified and Montreal's territory began to explode. But this was also the period when the city witnessed intense income inequality and ethnic separation, giving rise to highly segregated neighbourhoods (Gilliland & Olson, 2010). Its population tripled from 1900 to 1930, reaching 820,000 people, and continued to increase during two waves of suburbanization. Since the 1970s, the city has undergone a deindustrialization process and a shift toward the knowledge economy (Castonguay & Dagenais, 2011). Fig. 1 illustrates the geography of housing construction year, and low-income and visible minority populations in Montreal.

Three types of data were integrated in this study: (1) QuickBird satellite data; (2) low-income population and visible minorities variables from the 2006 Canada Census at the dissemination area (DA; Canadian equivalent of the US block group) and census tract levels; (3) GIS data from the City of Montreal used to locate different elements of the built environment (buildings, construction date of buildings, streets, alleys, yards of residential parcels – Fig. 2). Note that a residential *yard* equals the total surface of a residential parcel minus the surface occupied by buildings. The surface could be either in front or behind the building, although in Montreal this area is usually behind the building.

4. Methodology

We rely on a two-step methodology (Fig. 3). The first step involves the processing and the structuring of GIS and satellite data in order to compute vegetation indicators and variables, while the second step covers the evaluation of environmental equity. We favoured a fine-grained analysis scale, the city block, which corresponds to the area bounded by intersecting streets. This choice is based on the fact that a city block is relatively homogenous in terms of built environment and land use, especially compared to census tracts and block groups. All told there are 6511 blocks in the study area.

4.1. Data processing

4.1.1. Vegetation indicators

Three QuickBird images acquired on September 18th and 23rd 2007 (at a 60 cm resolution) were used to identify two forms of vegetation: trees/shrubs and lawn. Relying on previous studies using very high resolution images to classify urban vegetation, we chose an object-oriented approach implemented in eCognition 8.1 (Delm & Gulinck, 2009; Mathieu, Aryal, & Chong, 2007). The detailed methodology used to develop the land cover classification used in our analysis is described in Pham et al. (2011). We validated the classification by comparing it to 50 randomly selected 200 m × 200 m plots (1% of total study area) that were manually digitized from the three QuickBird images while referencing Google Earth aerial photography and Bing oblique images.

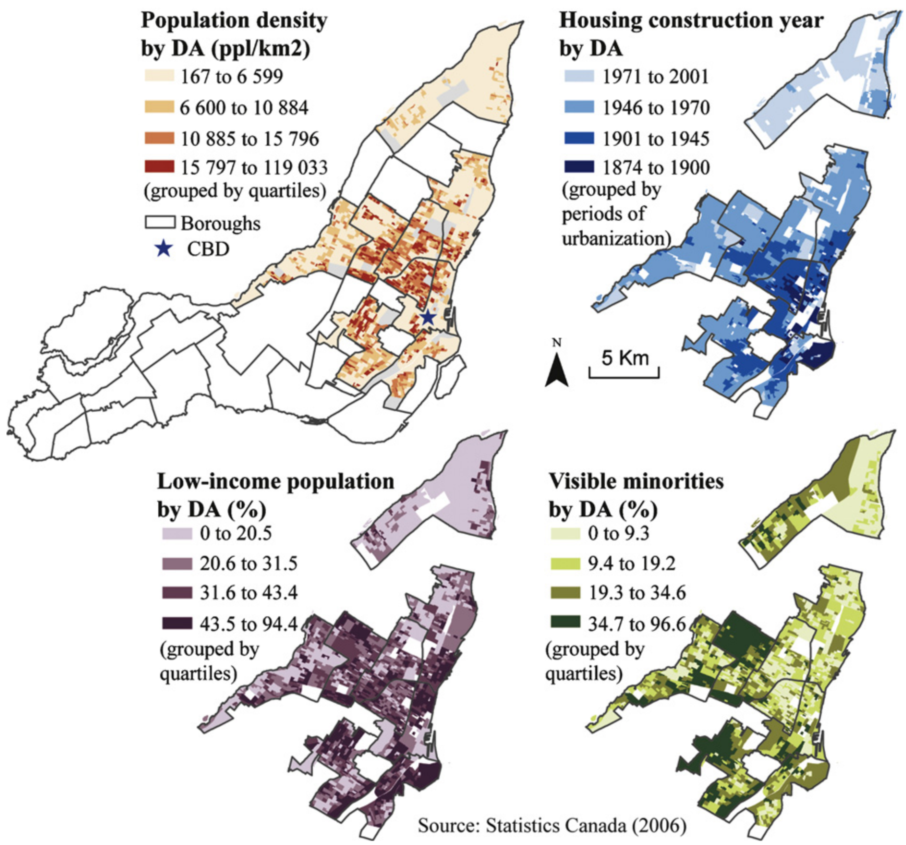

Fig. 1. Example of GIS data from the City of Montreal.

The overall accuracy was 75%, which is similar to other studies using the object-oriented approach (e.g. Delm & Gulinck, 2009; Mathieu et al., 2007).

Using GIS data from the city of Montreal, the classified image was separated into 60-cm raster maps representing public lands of the street and alleys, and private land of the residential yard. Two vegetation maps were created separately depicting the percentage of total vegetation and the percentage of trees/shrubs for city blocks. Six other maps were also created to depict the percentage of public streets, public alleys, and private yards within city blocks that are covered by total vegetation and trees/shrubs.

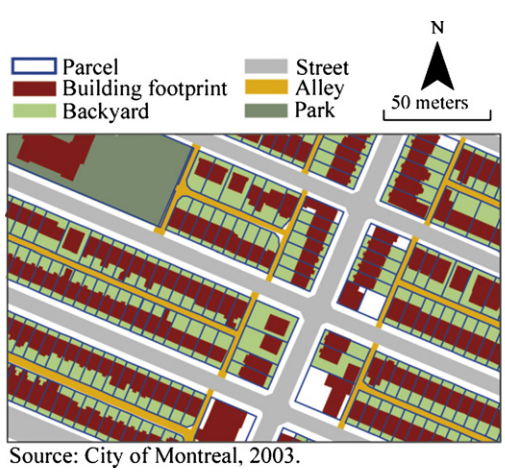

Fig. 2. Study area: the former City of Montreal (on the island of Montreal).

4.1.2. Socio-demographic variables

Our analysis of environmental inequity focuses on low-income households and visible minorities. *Low-income population before tax* is a census variable referred to as "income levels at which families or persons not in economic families spend 20% more than average of their before tax income on food, shelter and clothing" (Statistics Canada, 2006, p. 143). *Visible minorities* encompass: "Chinese, South Asian, black, Filipino, Latin American, Southeast Asian, Arabic, West Asian, Japanese, Korean, and other groups of visible minorities like Pacific Islanders" (Statistics Canada, 2006: 116). We are aware ethnocultural groups may differ greatly in their preferences for vegetation, and some may prefer less or no vegetation (Fraser & Kenney, 2000; Talarchek, 1990). Combining all the groups into one category may mask those variations in preferences. However, the low percentage of each group in the total population would prevent a statistically robust analysis if we were to test the hypothesis of environmental inequity separately on each group. We can also justify the use of this variable for purposes of consistency, because it is used by Statistics Canada as an official indicator of employment equity (Statistics Canada, 2006, p. 116).

In order to disaggregate socio-demographic data from DA to city blocks, we used a population-based weighting technique with the dissemination-block population as ancillary data. Dissemination blocks are the basic geographic area used by Statistics Canada, equivalent to city blocks (Statistics Canada, 2006, p. 224). Although this method assumes a homogeneous distribution of the two demographic groups within each DA, lack of a priori knowledge regarding potential heterogeneity of these groups prevented the use of a potentially more accurate method.

The rescaling formula consists of multiplying the low-income and visible minority population of the DA in which the block is

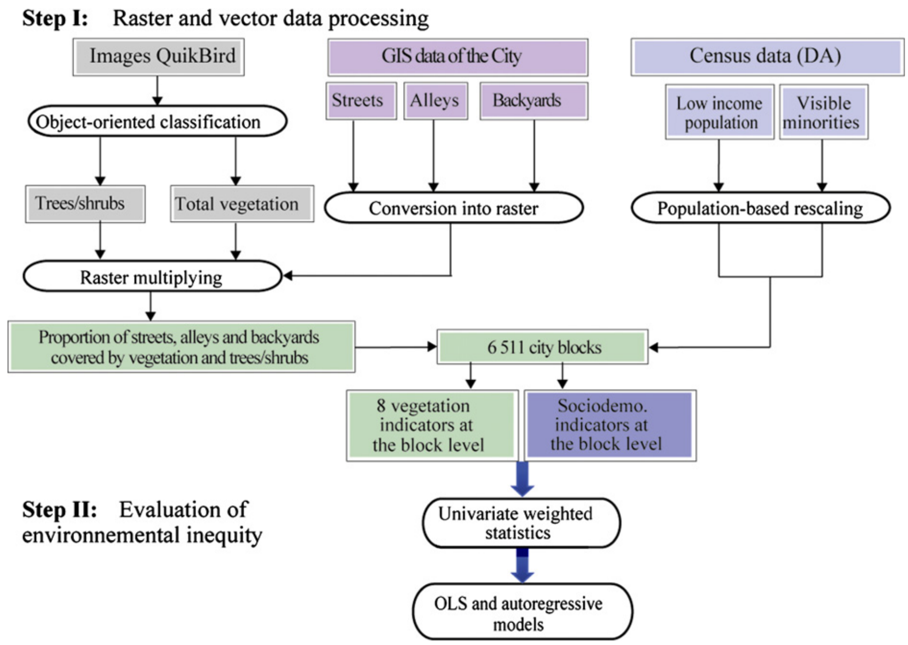

Fig. 3. Methodology steps.

located by the ratio of the total population of the block to the population of the DA (equation 1).

$$PopLowInc_{block} = PopLowInc_{DA} \frac{PopTotal_{block}}{PopTotal_{DA}} \quad (1)$$

To validate the robustness of the interpolation, we did the same exercise but with data interpolated from the census tract level to the block level and then aggregated from the block level data to the DA level (suggested by Maantay et al., 2007). The correlation between the interpolated values and those provided by Statistics Canada for the total population, low-income people and visible minorities are respectively 0.93, 0.85 and 0.88, which is comparable to the results of Maantay et al. (2007). Note that the total population of the DA may not equal the summed population of all blocks due to rounding in the Statistics Canada data.

4.2. Measuring environmental inequity

To investigate the existence and extent of inequity, we first calculated univariate statistics weighted by the total population, low income population and visible minorities, for all the vegetation indicators. This allowed us to examine if these indicators appeared lower for the two target groups than for the total population.

Multivariate regression, using ordinary least squares models (OLS) were developed to take into account the built environment and evaluate the association between vegetation and socio-demographic variables. Two variables representing the built environment were introduced: population density and neighbourhood age. Neighbourhood age and its square term were both introduced as control variables to capture the non-linear effect on the presence of vegetation (Grove et al., 2006; Landry & Chakraborty, 2009; Mennis, 2006). Three types of models were conducted to evaluate the relationships of vegetation with visible minorities (M models), low-income people (L models), and the two variables and their interaction term (ML models) in order to to capture the interaction between low income and visible minorities (Table 1).

To control for spatial dependence of vegetation, we resorted to spatial regression models. We executed two spatial autoregressive models in GEODA (Anselin, 2005): one in which the dependent variable is spatially lagged (spatial lag model, Eq. (2)) or one with spatially autocorrelated errors (spatial error model, Eq. (3)).

$$y = \rho W y + X\beta + \varepsilon \quad (2)$$

$$y = X\beta + \lambda W(y - X\beta) + \varepsilon \quad (3)$$

where y is the vegetation indicator, X is variable representing the built environment or socio-demographics, β is the vector of slopes associated with X, ε is a vector of error terms, W is the spatial lag term, ρ is the spatial lag coefficient, and λ is the spatial error coefficient.

We used queen distance weights matrices (i.e. included immediately adjacent blocks) because city blocks in Montreal are mostly regular and have similar size and shape. For each model (i.e., total block, street, alley and yard), the choice of either spatial lag or error was based on the Lagrange Multiplier and Robust Lagrange Multiplier tests which indicate whether the spatial dependence occurs at the error term or the dependent variable (Anselin, 2005). This is also consistent with other studies (Donovan & Butry, 2010; Landry & Chakraborty, 2009).

5. Results

5.1. Vegetation indicators

The maps in Fig. 4 show that vegetation indicators vary across the city in different ways. The total vegetation within blocks varies along a gradient from the centre to the periphery: densely populated blocks in central boroughs have less vegetation than blocks in peripheral boroughs (Fig. 4a). Street vegetation is relatively high in certain central boroughs, such as the Plateau-Mont-Royal (labeled as 1 in Fig. 4b), whereas it is lower in downtown (Ville-Marie, 2) as well as in peripheral boroughs (like Rivière-des-Prairies, 3). Alley vegetation does not appear to exhibit clear spatial variation (Fig. 4c), suggesting alleys do not seem to be greener in any one borough than elsewhere. Backyard vegetation appears to be more abundant in peripheral boroughs than central ones (Fig. 4d), which probably accounts for the variation in the total vegetation along the core-periphery axis.

Table 1
Socio-demographic and control variables at the city block level (only blocks with population).

	Abbr.	N[a]	Mean	S.D.	P5	Q1	Q2	Q3	P95
Density (inhabitants/ha)	Inhab/ha	5036	109	78	19	55	97	146	235
Median age of residential buildings	AgeBuild	5036	59	27	19	43	54	78	106
Low-income population (%)	LowInc	5036	29.55	15.66	6.06	17.86	28.18	39.55	58.00
Visible minorities (%)	VisMin	5036	22.05	17.89	2.15	8.77	17.28	30.16	60.00

S.D.: Standard deviation; P5: 5th percentile; Q1: 1st quartile; Q2: median; Q3: 3rd quartile; P95: 95th percentile.
[a] Although we have calculated the indicators for 6511 blocks comprised in the study area, we conducted statistical analysis for 5036 blocks that contain population.

5.2. Evaluation of environmental inequity

For lack of space, we only present the univariate statistics of four vegetation indicators (Table 2). The alley indicators were excluded because their variations appear to be weak across the boroughs (Fig. 4c). Street vegetation and backyard vegetation were also excluded because they show the same trend as street trees/shrubs and backyard trees/shrubs. The four retained indicators were weighted by the total population, visible minorities and low-income people.

Mean and median values indicate that low-income people and visible minorities inhabit blocks with less vegetation than the total population (mean values respectively of 23.5% and 24.1% against 25.8%; median values of 21.5% and 22.5% against 23.8%). Weak differences are also observed with the three other vegetation indicators. Note however that the differences between the three types of population increase in the greenest blocks, especially the differences between low-income people and the total population (P90 values in Table 2).

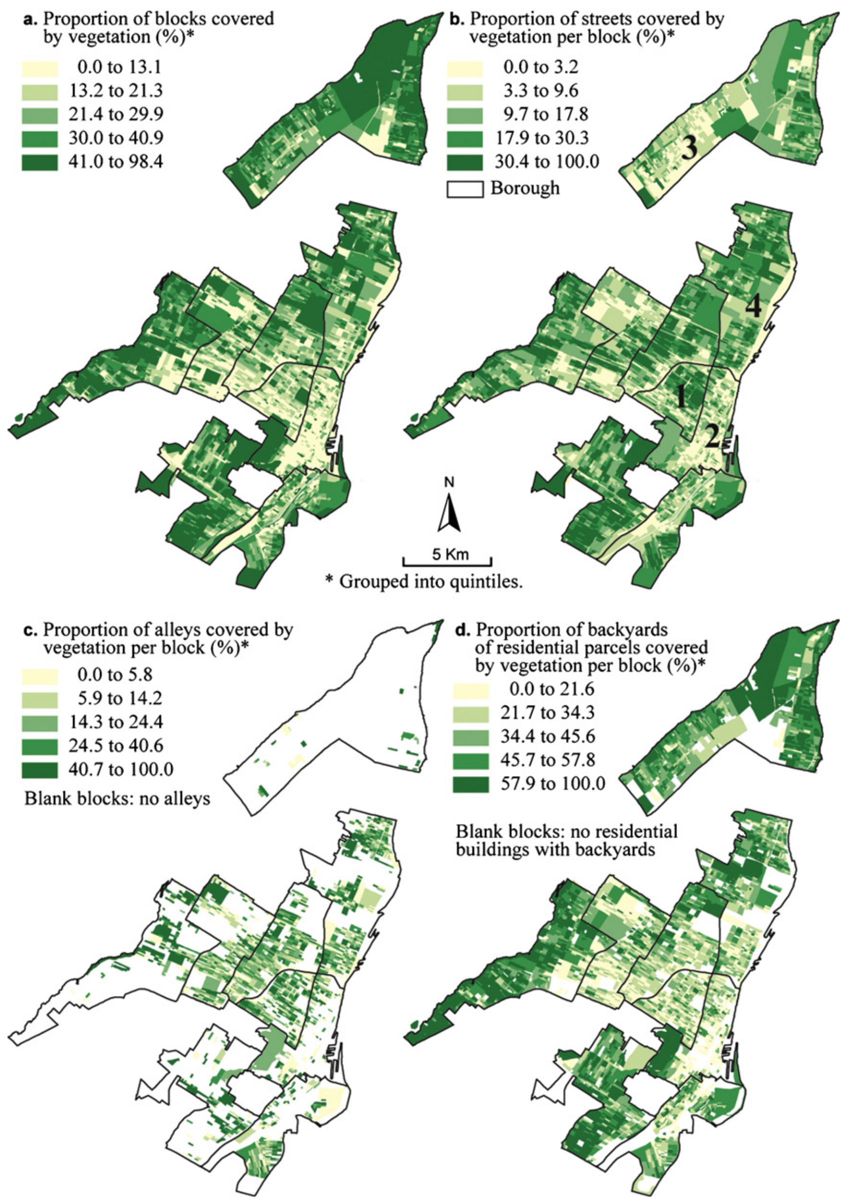

Fig. 4. Four vegetation indicators mapped at the city block level.

Table 2
Univariate statistics of the vegetation indicators weighted by total population and the two target groups.

Indicator	Weighting	Mean	P10	Q1	Q2	Q3	P90
Blocks	Total pop.	25.8	8.7	15.4	23.8	34.6	45.1
Total vegetation	VisMin	24.1	7.2	13.7	22.5	32.4	43.2
	LowInc	23.5	7.6	13.7	21.5	31.0	41.1
Blocks	Total pop.	10.8	2.6	5.2	9.0	14.5	21.5
Trees/shrubs	VisMin	10.3	2.0	4.6	8.8	14.2	20.9
	LowInc	9.8	2.2	4.7	8.3	13.3	19.6
Streets	Total pop.	7.7	0.5	1.8	4.9	11.3	19.2
Trees/shrubs	VisMin	6.5	0.3	1.3	4.0	9.1	16.8
	LowInc	7.0	0.5	1.7	4.6	10.0	17.5
Backyards	Total pop.	16.7	4.6	8.8	14.8	22.7	32.3
Trees/shrubs	VisMin	16.6	3.9	8.2	14.7	23.2	32.7
	LowInc	15.8	4.1	8.0	14.0	21.7	30.7

P10: 10th percentile; Q1: 1st quartile; Q2: median; Q3: 3rd quartile; P90: 90th percentile.

Table 3
SAR models computed for the block vegetation indicators.

	SAR_{lag} – total vegetation			SAR_{lag} – trees/shrubs	
Model	L1	M1	ML1	L2	M2
W*y*	0.593***	0.591***	0.589***	0.715***	0.722***
	(48.19)	(48.24)	(47.50)	(68.70)	(70.14)
Constant	18.267***	8.481***	19.795***	2.797***	2.759***
	(21.61)	(21.76)	(21.29)	(7.47)	(7.31)
AgeBuild	0.246***	0.241***	0.244***	0.160***	0.150***
	(11.59)	(11.36)	(11.49)	(14.32)	(13.50)
$AgeBuild^2$	−0.002***	−.002***	−0.002***	−0.001***	−0.001***
	(−13.60)	(−3.72)	(−13.33)	(−14.24)	(−13.86)
Inhab/ha	−1.146***	−1.252***	−1.161***	−0.311***	−0.361***
[sqrt.]	(−24.12)	(−6.77)	(−24.31)	(−13.27)	(−15.83)
VisMin	–	−0.018**	−0.059**	–	−0.010**
	–	(−2.16)	(−3.10)	–	(−2.21)
LowInc	−0.057***	–	−0.104***	−0.039***	–
	(−5.54)	–	(−6.34)	(−7.30)	–
Interaction			0.002***		
VisMin-LowInc			(3.69)		
Pseudo R^2	0.604	0.597	0.602	0.625	0.622
AIC	36373	36486	36449	30816	30797
Moran's *I*	−0.039	−0.033	0.404	−0.049	−0.053

Z-values in parentheses.
Moran's *I* was calculated with the residuals from the SAR_{lag} models. M = models for visible minorities. L = models for low-income people. ML = models for both visible minorities and low-income people.
* Significant at $p < 0.1$.
** Significant at $p < 0.05$.
*** Significant at $p < 0.001$.

Table 4
SAR models computed for the street vegetation indicators.

	SAR_{lag} – total vegetation			SAR_{lag} – trees/shrubs	
Model	L3	M3	ML3	L4	M4
W*y*	0.642***	0.641***	0.628***	0.636***	0.640***
	(52.12)	(51.65)	(49.94)	(50.76)	(51.09)
Constant	−1.685*	−0.763	−0.065	−1.843***	−1.477***
	(−2.25)	(−1.00)	−0.078	(−4.56)	(−3.61)
AgeBuild	0.383***	0.348***	0.386***	0.202***	0.186***
	(16.14)	(14.77)	(16.29)	(15.82)	(14.69)
$AgeBuild^2$	−0.003***	−0.003***	−0.003***	−0.001***	−0.001***
	(−14.89)	(−4.57)	(−15.36)	(−14.53)	(−14.21)
Inhab/ha	0.057	−0.033	0.073	0.013	−0.043
[sqrt.]	(1.18)	(−0.72)	(1.53)	(0.52)	(−1.74)
VisMin	–	−0.094	−0.105***	–	−0.038***
	–	(−0.27)	(−5.21)	–	(−7.73)
LowInc	−0.132***		−0.134***	−0.061***	
	(−11.95)		(−7.69)	(−10.29)	
Interaction			0.001***		
VisMin-LowInc			(2.75)		
Pseudo R^2	0.491	0.485	0.490	0.475	0.470
AIC	38210	38256	38116	32021	32081
Moran's I	−0.037	−0.031	0.380	−0.042	−0.037

* Significant at $p < 0.1$.
*** Significant at $p < 0.001$.

Table 5
SAR models computed for the alley vegetation indicators.

	SAR_{err} – total vegetation			SAR_{err} – trees/shrubs	
Model	L5	M5	ML5	L6	M6
Lambda	0.367***	0.389***	0.3711***	0.328***	0.389***
	(15.24)	(16.51)	(15.46)	(13.26)	(16.51)
Constant	49.055***	48.071***	54.018***	16.526***	48.071***
	(10.47)	(10.49)	(11.35)	(6.93)	(10.49)
AgeBuild	−0.276*	−0.339**	−0.345***	−0.019	−0.339**
	(−2.20)	(−2.76)	(−2.83)	(−0.30)	(−2.76)
AgeBuild^2	0.002*	0.002*	0.002**	0.000	0.002*
	(1.97)	(2.19)	(2.53)	(0.53)	(2.19)
Inhab/ha	−0.560***	−0.591***	−0.487**	−0.186*	−0.591***
[sqrt.]	(−3.76)	(−3.96)	(−3.28)	(−2.30)	(−3.96)
VisMin	–	−0.191***	−0.236**	–	−0.191***
	–	(−5.89)	(−3.13)	–	(−5.89)
LowInc	−0.261***	–	−0.290***	−0.135***	–
	(−7.57)	–	(−5.31)	(−7.19)	–
Interaction			0.003		
VisMin-LowInc			(1.86)		
Pseudo R^2	0.198	0.204	0.214	0.150	0.204
AIC	18103	18115	18077	15680	18115
Moran I	−0.025	−0.026	0.262	−0.027	−0.023

* Significant at $p < 0.1$.
** Significant at $p < 0.05$.
*** Significant at $p < 0.001$.

Significant Moran's I values calculated with the OLS residuals (e.g. varying from 0.20 to 0.54) tested by Monte Carlo simulations in GEODA indicate that there was a problem of spatial dependence for all OLS models. Because spatial dependence indicates a violation of the assumption of independence of residuals in OLS models, we only present the results of the autoregressive models in the next sections because they permit us to control for spatial dependence and thus are more robust (e.g. note the statistically insignificant Moran's I values and significant Z-values of Wy and λ in Tables 3–6). Chosen based on Lagrange Multiplier tests (Anselin, 2005), spatial lag models (identified as SAR_{lag}) were used when the dependent variable was block, street, and yard vegetation, while the spatial error model (SAR_{err}) was adopted for alley vegetation.

For all spatial models except street models, population density was significantly and negatively associated with vegetation cover, while the age of residential buildings was significant in all but two of the alley models. These results are consistent with other studies (Boone et al., 2010; Grove et al., 2006; Mennis, 2006) suggesting potential mechanisms of (in)equities in vegetation.

In models investigating equity for low-income people (L models in Tables 3–6), regression coefficients show that the percentage of low-income population has a significant and negative association (at $p < 0.001$) with all the vegetation indicators (Z-values between −4.66 and −11.95). This means vegetation cover is lower in areas with a high percentage of low-income population. Model comparisons indicate that the magnitude of negative association between low-income and total vegetation is largest for public lands (L3 street model Z-values = −11.95; L5 alley Z-values = −7.57) than for private yards (L7 Z-values = −4.79). The same relative results were found between low incomes and trees/shrubs (i.e. L2, L4, L6 and L8 models). This suggests that low-income populations have less access to both total vegetation and trees/shrubs on public land (in streets and alleys) than on private land (backyards).

Distributional disparities are more nuanced for visible minorities (M models, Tables 3–6). Significant Z-values of nearly all M models have a weaker negative association and in one model have a slightly positive association with vegetation when compared to those of the low-income (i.e., L) models. Visible minorities have a significant negative association with total vegetation for the block (M1) and the alley (M5), while the relation with total vegetation is not significant for the street (M3) and backyard (M7). There is a significant negative relationship between visible minorities and trees/shrubs for all the block (M2) and public lands (i.e. street M4 and alley M6), but a weak ($p < 0.1$) positive association with trees/shrubs in the yard (M8). These suggest that visible minorities have less access to trees/shrubs in all public lands, less access to total vegetation at the block and alley, but that they have slightly greater access to trees/shrubs in private yards.

In all the income-minority interaction models (ML models, third columns in Tables 3–6), low-income people have a negative and significant association with the vegetation indicators on both public and private lands. In the block (ML1 and ML2) models, visible minorities have a significant negative association with total vegetation but less so with trees/shrubs ($p < 0.1$), while the interaction term has a positive and significant association. In the street models (ML3 and ML4), visible minorities have a negative association and the interaction has a positive association. The alley models show a significant negative association with visible minorities and total vegetation, a weaker ($p < 0.1$) negative association with trees/shrubs, and neither model has a significant interaction term. Finally, there is no significant association between minorities and private yard vegetation (ML7 and ML8), while the interaction is significantly positive. Although these interactions are significant, their coefficients are weak.

Following the method suggested by Downey and Hawkins (2008), we plotted the amount of total vegetation against the percentage of minorities by using coefficients estimated from the ML regressions (see Fig. 5). The plots were created separately for two types of blocks: low-income blocks with 39.55% low-income residents (Q3 in Table 1) and high-income blocks with 17.86% low-income residents (Q1 in Table 1). All other significant variables are held at their mean value while non-significant variables are held at 0.

In both categories of city blocks, as the proportion of visible minority residents increases, the amount of total vegetation on blocks, in streets and in alleys decreases. In contrast, as the proportion of minority resident increases, the amount of private vegetation increases. However, the relationships between visible minority and vegetation are moderated by poverty, where the association between minority and vegetation is stronger in high-income blocks as compared to low-income ones. This suggests that

Table 6
SAR models computed for the backyard vegetation indicators.

	SAR_{lag} – total vegetation			SAR_{lag} – trees/shrubs	
Model	L7	M7	ML7	L8	M8
Wy	0.612***	0.608***	0.606***	0.708***	0.707***
	(49.78)	(49.82)	(49.18)	(66.14)	(66.07)
Constant	25.862***	25.707***	26.992***	4.625***	4.745***
	(22.29)	(22.26)	(21.74)	(8.41)	(8.58)
AgeBuild	0.241***	0.243***	0.257***	0.220***	0.212***
	(8.54)	(8.71)	(9.19)	(13.50)	(13.12)
AgeBuild^2	−0.002***	−0.002	−0.002***	−0.002***	−0.002***
	(−9.94)	(−0.55)	(−10.22)	(−13.27)	(−12.96)
Inhab/ha	−1.361***	−1.509***	−1.403***	−0.482***	−0.595***
[sqrt.]	(−22.47)	(−5.34)	(−23.09)	(−13.90)	(−17.62)
VisMin	–	0.010	−0.028	–	0.014*
	–	(0.96)	(−1.18)	–	(2.21)
LowInc	−0.063***	–	−0.137***	−0.036***	–
	(−4.79)	–	(−6.61)	(−4.66)	–
Interaction			0.002***		
VisMin-LowInc			(3.33)		
Pseudo R^2	0.586	0.581	0.588	0.606	0.603
AIC	38476	38610	38521	34415	34421
Moran I	−0.049	−0.062	0.384	−0.066	−0.071

* Significant at $p < 0.1$.
*** Significant at $p < 0.001$.

low-income people, be they part of a visible minority or not, are likely to live in a more barren environment as compared to the wealthy. Comparing the largest difference between a block with 0% visible minorities and a block having more than 60% visible minorities, total block vegetation cover is reduced from 28% to 21%, street vegetation from 34% to 24%. As for backyard vegetation, on affluent blocks the trend is reversed; as the proportion of visible minorities increases, the amount of vegetation in backyards tends to increase (the largest difference being about 3%). In low-income blocks, the amount of vegetation in backyards appears to be stable.

6. Discussion

The case of Montreal investigated in this paper allows us to shed new light on environmental inequity in the spatial distribution of vegetation. Our findings suggest that in Montreal, within blocks having a similar (built) environment and level of spatial dependence, low-income people (and to a lesser degree, visible minorities) suffer from disparities in vegetation cover.

One possible explanation is that housing costs (rental or purchase) may be lower in vegetation-deprived areas and more affordable for low-income people. For example, Des Rosiers, Thériault, Kestens, & Villeneuve (2002) have demonstrated that in Quebec City (Canada), property value increases proportionally with the presence of trees around buildings. Another plausible explanation is that there are fewer local actors who campaign for tree planting in low-income areas compared to higher-income areas. For example, our own anecdotal observations suggest that local actors campaign less for tree planting in low-income, low vegetation cover areas like Hochelaga (4 in Fig. 4b) than in higher-income, gentrified neighbourhoods like the Plateau-Mont-Royal (1 in Fig. 4b) where residents made numerous efforts to re-green their alleys and streets.

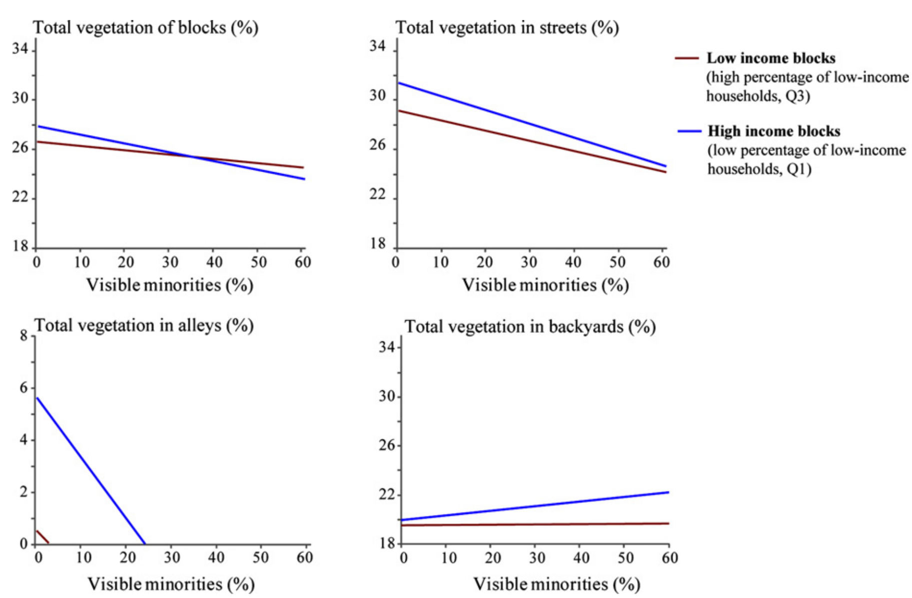

Fig. 5. Relations between visible minorities and the total vegetation in (a) blocks, (b) streets and (c) alleys, and (d) private yards (*Note*: because of its small range of variation, the vertical axe of total vegetation in alleys was set in a smaller scale than the other vertical axes).

Findings on interactions between income and visible minorities suggest there might be other factors explaining why visible minorities in Montreal are associated with blocks of low vegetation. As most of visible minorities in Montreal are recent immigrants (the Pearson correlation of these two variables being 0.78), it is possible that because of language barriers they have less access to greening and but also more urgent preoccupations than vegetation (e.g. Perkins et al., 2004). We do not deny there could also be racial discrimination towards these communities, but in-depth research is needed to confirm that.

On the other hand, despite there being less vegetation on public lands, our results reveal that in Montreal, visible minorities have slightly better access to trees/shrubs in private yards (after controlling for the built environment). There are at least two possible explanations for such good access: certain ethnocultural minorities favour planting trees in gardens according to their cultural background; or they inherit a legacy from past residents, as indeed social legacies may have important influences on present landscapes (Boone et al., 2010). For example, in a few blocks of Parc-Extension, where South and Southeast Asians are predominant, we observe row houses having fairly green yards with wild plants or vegetables. These areas were formerly inhabited by Mediterranean immigrants who preferred gardens with enough space to grow their own vegetables (Routaboule, Anselin, & Eveillard, 1995).

Overall, our results demonstrate a slightly uneven distribution of vegetation (i.e. weighted statistics of vegetation indicators). Regressions also indicate that a 10% rise in the proportion of low-income people only entails a 0.6% loss of vegetation cover in blocks and a 1.3% loss in streets (coefficients being −0.057 and −0.132 in the L1 and L3 models respectively). Notwithstanding such slight (distributional) inequity in vegetation, the lack of vegetation may affect people in different ways depending on their income. More specifically with respect to mitigation of urban heat island effects, the ability to invest in technical solutions as a mitigation strategy is less available to low-income households who may lack the income to pay for air-conditioning. Moreover, due to their limited budget they are not likely to be able to afford vacations in the countryside during summer heat waves (CIHI, 2011; Health Canada, 2008). The need for good access to the cooling benefits of public vegetation may be more important to low-income populations, and thus raises a concern regarding compensatory equity. Therefore, despite the somewhat minimal distribution inequity evidenced by our study, urban planners and policy makers should be concerned with compensatory equity in the most deprived neighbourhoods of Montreal.

More importantly, we found that disparities were more pronounced on public land, for example with street vegetation, when compared to private land vegetation. Since street vegetation is usually managed by public organizations, public investment is the major factor in planting and maintaining vegetation, and hence, should be non-discriminatory and independent of the socioeconomic status of the population. This evidence points to the need for equitable budgetary allocation for street vegetation in the city.

7. Conclusion

This study highlights nuances of environmental equity in Montreal by investigating the interaction between poverty and minority status, isolating public and private vegetation, and pointing to compensatory equity although weak disparities were observed. Several limitations of our study are worth noting. First, we did not examine the vegetation cover in the surrounding area of each block. Is there environmental inequity if one lives in a block without vegetation next to a tree-shaded park? Although the use of spatial regression to some extent incorporates factors associated with nearby blocks in the analysis, a sensitivity analysis of vegetation at different distances around the residential habitat would be helpful in assessing inequity related to other benefits of vegetation (e.g., for mental health or physical activities). Second, the present study is conducted at the city block level but as proposed by certain authors (e.g. Landry & Pu, 2010), future parcel-scale analysis within our study area may reveal additional insight as to the reasons for the disproportionate distribution. Finally, the use of population-based weighting to estimate demographic characteristics at the block unit of analysis assumes that the distribution of low-income and visible minority populations within each dissemination area is proportional to the distribution of total population. This limitation has the potential to bias our results if the demographics within the DA were extremely heterogeneous.

Our results also pose several opportunities for new research. For example, due to the broad definition of visible minorities, expanded analysis on environmental equity should be conducted for each group of visible minorities. In addition, as there have been various greening campaigns and policies conducted in Montreal over the years, it would be relevant to evaluate the effects of these measures.

The issue of compensatory equity raised in this study has important implications for urban planning and policy, especially because disparities are found to be more pronounced in access to public vegetation than to private vegetation. Specifically, low-income groups may have a disproportionate need for urban heat island mitigation strategies that rely less on expensive air-conditioning. Recent fatalities and hospitalizations of urban residents associated with summer heat waves in high latitude cities, which will be worsened because of global warming (IPCC, 2007; Smargiassi et al., 2009), suggest that this need should be taken seriously. In addition to other potential strategies (e.g. white roofs) (Pataki et al., 2011), cities can address this compensatory inequity and potentially limit the negative health impacts of summer heat waves through equitable public investment and greening programs.

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