

# A ride for whom: Has cycling network expansion reduced inequities in accessibility in Montreal, Canada?

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## ABSTRACT

It is widely agreed today that the existence of a network of bicycle paths fosters a feeling of safety as well as the use of the bicycle for both recreational and utilitarian purposes. Recent studies have found a link between the presence of cycling infrastructures and gentrification. Few studies have however examined the growth of the cycling networks from the perspective of environmental equity.

The main objective of this study is to determine whether the extension of the cycling network in the urban areas of Montreal and Longueuil and the city of Laval over a quarter of a century (1991 to 2016) has reduced or reinforced inequities in accessibility for low-income populations, recent immigrants, children, and older people.

Archival maps were employed to reconstruct the cycling networks in the Montreal area in a GIS for six years (1991, 1996, 2001, 2006, 2011, 2016). Census data and spatial analysis methods were then used to measure whether or not inequities in the accessibility of the cycling network increased over the period in question.

The results show that, in 25 years, the cycling network has more than doubled in size. It can however be seen that some areas are still very poorly served, and that the network lacks connectivity. Low-income individuals have generally enjoyed good accessibility over the entire period. A strong decrease in inaccessibility for recent immigrants and seniors is also observed. The most important result is clearly that there has been little or no improvement for children, who are found to be in a situation of inequity.

## 1. Introduction

In the last few years, we have seen a revival of bicycling in North America and elsewhere in the world. Some authors even speak of a “bicycle renaissance” (Pucher et al., 2011). In order to facilitate bicycle travel over the territory and to increase cyclists' safety, we have also seen the growth of cycling infrastructures in many North American cities. It is important to remember that bicycling, as a mode of active travel, has numerous benefits for people's physical (Buekers et al., 2015; Celis-Morales et al., 2017; Farrell et al., 2016; Fishman, 2015; Fuller et al., 2013; Götschi et al., 2015) and mental health (Pucher and Dijkstra, 2003; Zhao et al., 2017). Moreover, in a context of combating climate change and reducing greenhouse gas emissions, the bicycle is considered to be one of the most promising means of alternative transportation (Pucher and Buehler, 2005). In short, the bicycle is recognized in the literature as an effective means of short- and mid-range travel, as is the case for most trips in urban areas (Fishman, 2015; Pucher et al., 2010).

Recent research in the United States (Portland and Chicago) and Brazil (Rio de Janeiro and Curitiba) has however shown that cycling

infrastructures are not equitably distributed in cities, and that this leads to better access for some populations (Flanagan et al., 2016; Tucker and Manaugh, 2017). Is this observation true for the Montreal area? To answer that question, we decided to analyze the development of the cycling network from 1991 to 2016 in considering the spatial distribution of various population groups defined by age, income, and ethnicity. Have these populations had equitable access over time to the benefits associated with the existence of a cycling network?

## 2. Literature review

### 2.1. A cycling network, a sense of security, and the practice of bicycling

Studies have shown that the practice of bicycling is influenced by the presence of cycling infrastructures. Based on a sample of 43 big American cities, Dill and Carr (2003) found a positive correlation between the existence of cycling infrastructures and the level of utility cyclists. The proximity of a bicycle path is said to be a significant environmental factor that has helped to increase the practice of bicycling (Moudon et al., 2005). Cycling infrastructures are determinant not only

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in the degree of use of the bicycle, but also in cyclists' sense of security (Fishman, 2015; Reynolds et al., 2009). Pucher et al. (2011) observed that the level of cyclists rose sharply in cities that had developed a wide range of infrastructures and programs to promote use of the bicycle and to increase users' sense of security.

In the Netherlands and Denmark, where there are major cycling networks, a study showed that, from 2004 to 2008, there were 3.5 to 5 times fewer cyclists killed per 100 million kilometres travelled than in the United States (Götschi et al., 2015). Teschke et al. (2012) found, among 14 route types, that cycling paths separated by bollards or medians were those with the lowest odds of injury: a risk that was up to one ninth of the risk incurred on a major traffic artery with parked cars and without a cycling infrastructure. Local streets were also seen to involve a very low risk.

In their respective reviews of the literature, Reynolds et al. (2009) and Fishman (2015) found that a better street layout helped to increase potential cyclists' sense of security and practicing of bicycling. A Vancouver study suggests that the majority of cyclists prefer off-road paths intended for bicycling only (Winters and Teschke, 2010). In general, they don't like main streets with parked cars. Moreover, although the presence of a cycling network reduces cyclists' stress, experience plays a greater role in lowering the risks of road injury and the sense of insecurity on the road (Fernández-Heredia et al., 2014; Moudon et al., 2005). As with many sports, cycling skills improve with time and experience. In this vein, in Charlotte, North Carolina, Boyer (2017) found that experience acquired through recreational cycling helps individuals to gain enough skills to practice utility cycling.

## 2.2. Cycling and health

Macmillan et al. (2014) emphasize that every dollar invested in cycling infrastructures results in a ten times greater savings in public health services, especially in reducing mortality associated with the lack of physical activity. The greatest health benefits are seen for people who were previously inactive (Fishman, 2015). Indeed, the bicycle has been recognized in the Netherlands as an important means of preventing health problems linked to a sedentary lifestyle (Fishman et al., 2015). As well, according to de Hartog et al. (2010), the benefits of changing one's mode of travel from the car to the bicycle outweigh the risks incurred. They also maintain that the benefits of physical activity over the lifetime are nine times greater than the risks connected with exposure to air pollutants. Although the air pollution risks in extreme air pollution concentrations may outweigh the benefits of physical activity, this applies to fewer than 1% of cities across the globe (Tainio et al., 2016). In a recent study, Celis-Morales et al. (2017) found that the practice of utility cycling was associated with low risks of having a stroke, cancer, or a series of other causes of mortality. It is worth noting that these health benefits may vary by sex and age. For example, Woodcock et al. (2014) found that the positive health impacts of the London cycle hire scheme are greater for men than for women and for older than for younger users.

## 2.3. Cycling and environmental equity

Studies in the United States (Flanagan et al., 2016; Lee et al., 2016; Lusk et al., 2017; Stein, 2011; Steinbach et al., 2011) and Brazil (Tucker and Manaugh, 2017) have shown that the distribution of cycling networks is not uniform within cities, which raises issues of environmental equity (Walker, 2009). In other words, we can hypothesize that some population groups defined by socioeconomic status, ethnocultural origin, or age do not have equitable access to the benefits of a cycling network.

Recently, Flanagan et al. (2016) found that there were more cycling infrastructures in the “white” and gentrified neighbourhoods of Chicago and Portland. In New York, Stein (2011) observed that the planning of the cycling network reflected citywide transportation injustices. Some

research shows that use of the bicycle and the presence of cycling infrastructures are sometimes employed as a lever for gentrification (Hoffmann and Lugo, 2014; Stehlin, 2015). Pucher et al. (2011) found that the growth in use of the bicycle in North America had generally occurred in central cities and specifically in gentrified neighbourhoods near business districts and universities.

From a social justice perspective, Pucher and Buehler (2009) recognize that exposure to risks must be limited for all cyclists, and especially for children and seniors, who are more vulnerable. Fernández-Heredia et al. (2014) identified certain individual factors influencing bicycle travel. Some of the recurring and important individual characteristics that they found were age, income, gender, ethnic origin, possession and use of a motor vehicle, and possession of a bicycle. In their systematic review, Aldred et al. (2017) reported that sex and age also have an impact on preference for separated infrastructure. Moreover, factors related to norms and to infrastructural and cultural barriers appear fundamental (Aldred et al., 2016) and were said to have had a dissuasive effect on potential cyclists in the past (Aldred, 2012).

## 2.4. Population groups studied

According to a number of studies, children (Emond and Handy, 2012; Kaplan et al., 2016; McDonald et al., 2016; Pucher and Buehler, 2009), older people (Aldred et al., 2016; Ekman et al., 2001), low-income populations (Bergeron, 2014; Fernández-Heredia et al., 2014; Horton, 2006), and immigrants (Fernández-Heredia et al., 2014; Smart, 2010) would profit from having better access to the cycling network because of the various associated benefits. The question of accessibility is especially important for children and older people due to their physiological vulnerability or more limited abilities to manoeuvre a bicycle (Armstrong 2013, cited in Aldred et al., 2016; Bulsink et al., 2016; Kaplan et al., 2016; Pucher and Buehler, 2009; Sakurai et al., 2016). In addition, because of their social vulnerability, in the United States and Spain (Madrid), low-income populations and immigrants often do not have a car and travel more by bicycle (Fernández-Heredia et al., 2014; Smart, 2010) in central neighbourhoods, where they are exposed to denser traffic.

In this study, we will therefore concentrate on these population groups, which have moreover been selected in a number of studies on environmental equity: that is, children, older persons, people in low-income households, and recent immigrants (Day, 2010; Lee et al., 2016; Lusk et al., 2017; Mulholland, 2008; Séguin and Apparicio, 2013; Steinbach et al., 2011; Talen and Anselin, 1998).

## 2.5. Research objectives

This research has two objectives. We will first calculate various indicators in order to describe the development of the Montreal's cycling network over a 25-year period (1991 to 2016) from the point of view of its expansion, densification and connectivity, in considering the type of bike paths for the first dimension. Our second objective is to determine whether the development of the network has led to a reduction or reinforcement of inequities in accessibility for the four population groups studied. One of the main contributions of the paper is thus to propose an analysis of the cycling network and its accessibility from a longitudinal perspective, which has until now rarely been done, according to Fishman (2015) and Buehler and Dill (2015).

## 3. Data and methods

### 3.1. Study area

The study area comprises three parts of the Montreal census metropolitan area: the urban areas of Montreal and Longueuil, and the city of Laval (Fig. 1). The bicycle path network was first developed in these

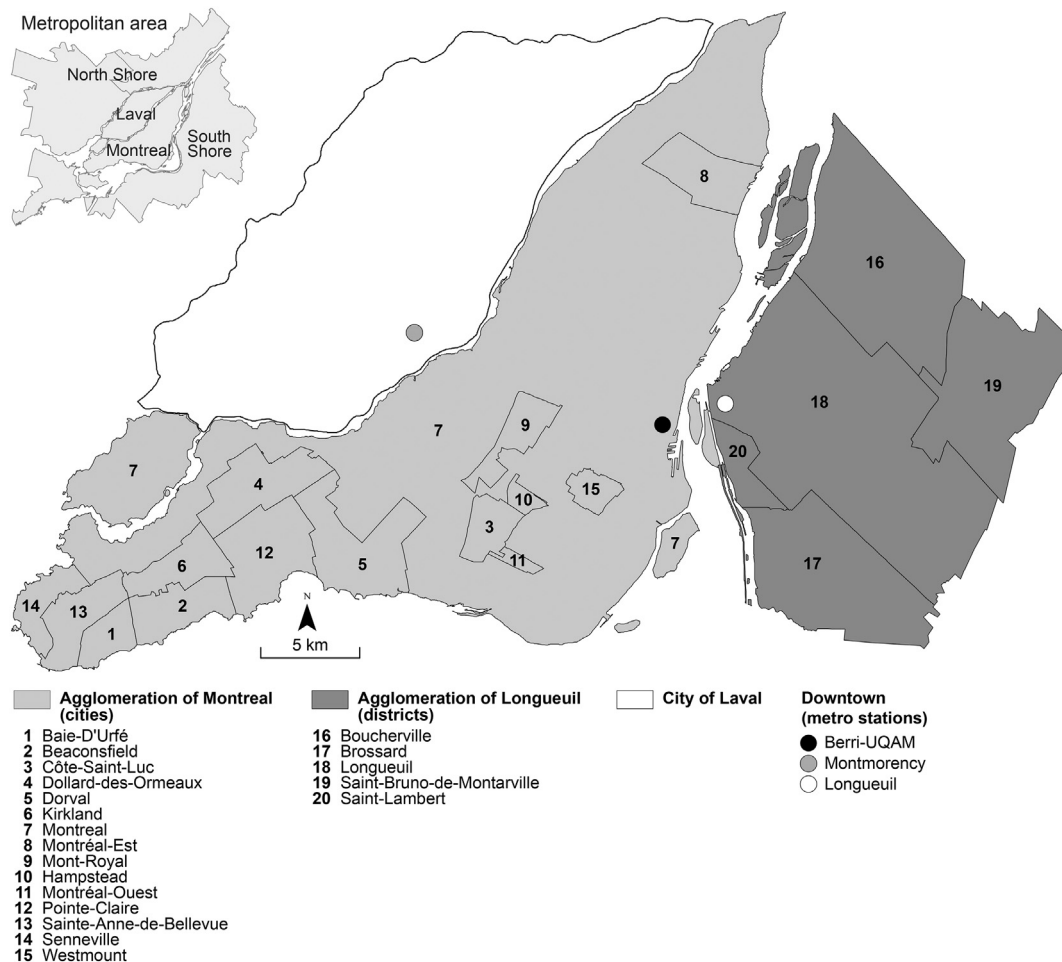


Fig. 1. Study area.

three areas, and complete data for the entire study period were available. In 2016, the study area had a surface area of 1030 km<sup>2</sup> and included 2.8 million inhabitants, representing 68% of the population of the census metropolitan area. This study area is especially interesting for examining bicycling, as it presents a range of different characteristics: a very developed cycling network, a bike-sharing system (BIXI), the practice of winter bicycling, etc. According to [Pucher and Buehler \(2005\)](#) study, at the start of the 2000s, Montreal was the Canadian city with the highest level of bike use for commuting to work, despite its winter being more severe than in other Canadian metropolitan areas. Most of the Montreal studies looked at the impacts of the practice of bicycling on health and/or safety ([Apparicio et al., 2016](#); [Fuller et al., 2013](#); [Grenier et al., 2013](#); [Hatzopoulou et al., 2013](#); [Strauss et al., 2013](#)). However, these studies did not analyze the distribution of the cycling network from an environmental equity perspective and from a longitudinal point of view.

### 3.2. Data collection

#### 3.2.1. Population data

The socioeconomic and socio-demographic data for the period studied come from the Statistics Canada population censuses of 1991, 1996, 2001 and 2006, and from the 2011 National Household Survey. The files of the geographic boundaries of the census tracts also come from Statistics Canada. The data extracted from each of the population censuses and from the National Household Survey are the total population, the population aged 5 to 14, the population aged 65 and over, the population of immigrants who had arrived within < 5 years, and the low-income (after income tax) population.

#### 3.2.2. The cycling and road networks

The cycling network was constructed in ArcGIS using archival maps and open data from the different cities studied. The basic network used is the result of a merger of the various cycling networks in 2016, which are available in digital form for each of the areas: that is, the urban areas of Montreal and Longueuil, and the city of Laval. Next, according to their availability, archival maps from various sources—municipal services and Vélo Québec<sup>1</sup> bike path guidebooks—had to be employed in order to reconstruct the cycling network for each of the six years (1991, 1996, 2001, 2006, 2011 and 2016) corresponding to the Statistics Canada census years. Whenever possible, two cartographical sources were used to validate the data on the cycling networks. For these five years, we listed seven types of infrastructures ([Fig. 2](#)). For analytical purposes, these infrastructures were grouped into three categories: cyclist-only bike paths, on-street bike lanes, and multi-use off-street paths (e.g. walking, roller-blading, and skateboarding). For example, in 2016, cyclist-only bike paths represented 63% of the network studied, on-street bike lanes, 26%, and multi-use off-street paths, 11%. In order to take into account the continuity of the cycling network beyond street intersections and to reduce calculation errors in measuring connectivity, the ends of the sections of bike path were extended by 12 m, which corresponds to the average width of Montreal-area intersections ([Morency et al., 2013](#)), as done by [Schoner and Levinson \(2014\)](#). The road network used in the GIS is that of Adresses Québec (AQ Directions) ([Gouvernement du Québec, 2015](#)).

<sup>1</sup> Vélo Québec is a key non-profit organization and the main Quebec cyclists' pressure group working to promote bicycling.

## I. Cyclist-only bike paths

Off-street bicycle path



On-street bicycle path (with protection)



On-street bicycle path (without protection)



## II. On-street bike lanes

Bike lane



Shared bike lane



## III. Multi-use off-street paths

Park path



Multi-use trail and path



Photo credit: First author

Fig. 2. Types of bicycle paths and bike lanes.

### 3.3. Qualifying the network and its accessibility

#### 3.3.1. Measuring expansion and density

In order to characterize the development of the cycling network –our first research objective–, its expansion was calculated for each area (Montreal, Laval, and Longueuil) and for each study year. This expansion was calculated based on the linear extension of the cycling network measured in kilometres. As had been done by several other authors (Dill, 2004; Flanagan et al., 2016; Tressider, 2005), two density indices were calculated: the length of the cycling network per km<sup>2</sup> of surface area for the three areas studied; and the length of the cycling network divided by the length of the road network, expressed as a percentage, excluding roads where bicycling is forbidden (highways, highway access roads, restricted-access bridges).

#### 3.3.2. Measuring connectivity

The connectivity of the cycling network was measured for each

area. Connectivity is an important measurement: a highly connected network allows users to reduce their travel distances and gives them several choices of routes, depending on their preferences (Dill, 2004; Lowry and Loh, 2017; Marqués et al., 2015; Schoner and Levinson, 2014; Titze et al., 2008). Trips are more effective when a network has a high level of connectivity, as it allows a vast range of different routes to connect the various destinations in the same territory. Several widely-used connectivity measures (Chen et al., 2014; Chin et al., 2008; Dill, 2004; Lowry et al., 2016; Lowry and Loh, 2017; Tressider, 2005) were calculated: the beta index, the gamma index, the connected nodes ratio, and the intersection density.

The beta index ( $\beta$ ) is used to characterize the complexity of the network (Derrible and Kennedy, 2010) and represents the relationship between the number of links ( $e$ ) and the number of nodes ( $v$ ):

$$\beta = e/v$$

where a perfect grid would have a theoretical value of 2.5 (Bejleri et al.,



2010; Tressider, 2005). This measure is moreover frequently used in studies on active transportation; some authors also call it the “link node ratio” (Chin et al., 2008; Dill, 2004; Tal and Handy, 2012; Tressider, 2005).

The gamma index ( $\gamma$ ) is used to measure the degree of connectivity, that is, the number of links existing in the network in relation to the theoretical number of maximum possible links (Chen et al., 2014; Derrible and Kennedy, 2010; Tressider, 2005):

$$\gamma = e / (v - 2)$$

with values ranging from 0 to 1, that is, from a low to a high degree of connectivity.

The connected nodes ratio (CNR) is the number of intersections ( $i$ ) divided by the total number of nodes ( $v$ ) in the network:

$$\text{CNR} = i/v$$

where a perfect grid would obtain a result of 1 (Dill, 2004; Tressider, 2005).

Finally, the intersection density ( $D_j$ ) is the number of intersections per km<sup>2</sup> for each study area ( $A_j$ ):

$$D_j = i/A_j$$

where the higher the value is, the greater is the connectivity (Dill, 2004).

### 3.3.3. Evaluating the quality of the network in relation to the typology

One can also evaluate the quality of the cycling network in considering its typology (Winters and Teschke, 2010). For example, the growth in the number of kilometres of infrastructures can be calculated for the three previously mentioned categories of infrastructures.

### 3.3.4. Measuring the accessibility of the cycling network

In order to measure the accessibility of the cycling network, in connection with our second research objective, the proximity of bike paths was used to measure the accessibility of the cycling network. The measures of accessibility were calculated using the Network Analyst extension in ArcMap 10.5. Urban cycling networks are permeable. Unlike highway networks or subway networks (Chen et al., 2014; Derrible and Kennedy, 2010), they do not have well-defined access points. Access points were therefore created at each street intersection crossing the cycling network. Two measures of accessibility were used: network distance to the nearest section of the cycling network, and the distance to the nearest cyclist-only bike path from the centroid of the different census tracts (Apparicio et al., 2008; Apparicio et al., 2007; Handy and Niemeier, 1997; Talen and Anselin, 1998).

## 3.4. Classical and logistic regression

Once the two measures of accessibility had been calculated on the level of census tracts, several regression models were conducted for the six years (1991, 1996, 2001, 2006, 2011 and 2016). They allow one to determine whether, because of its extension, the accessibility of the cycling network has improved or deteriorated over time for the population groups studied. It should be noted that there were not the same number of census tracts every year. It was consequently not possible to apply panel regression.

Two types of regression were conducted: a classical regression (OLS) and a logistic regression. For the classical regression, the dependent variables were the network distance to the nearest section of the cycling network and the distance to the nearest cyclist-only bicycle path from the centroid of the census tract. For the logistic regression, the dependent variables were the access to the cycling network within a 500-metre radius and the access to a cyclist-only bike path within a 500-metre radius from the centroid of the census tract. It is true that access may vary by group and a lower threshold could have been appropriate. However, with an average speed of 15 km/h (Jensen et al., 2010;

Thompson et al., 1997), an urban cyclist takes around 2 min to ride 500 m. For pedestrian, accessibility is often measure with a 400 m radius (Achuthan et al., 2010; Iacono et al., 2008; Vale et al., 2015). In that respect, 500 m was considered as a minimal distance for bicycle commuting.

Based on the literature in the fields of environmental equity (Carrier et al., 2016; Day, 2010; Mulholland, 2008; Pham et al., 2012; Rigolon, 2017; Talen and Anselin, 1998; Yuan et al., 2017) and transportation (Ekman et al., 2001; Fernández-Heredia et al., 2014; Pucher and Buehler, 2009; Smart, 2010), the following independent variables were introduced into the models: the percentages of children aged 5 to 14, of seniors aged 65 and over, of people in low-income households, and of recent immigrants.

In the models, several control variables were used: dummy variables for the areas (with Montreal as the reference category) and Euclidean distance between the census tracts and respective downtown of each study area, since, according to the literature, there is a strong correlation between the distance to the downtown and the presence of cycling paths (Flanagan et al., 2016; Pucher et al., 2011). The intermodal metro stations Berri-UQAM, Longueuil and Montmorency were used as downtowns for each of the areas studied, that is, Montreal, Longueuil and Laval, respectively.

## 4. Results

### 4.1. Major expansion of the cycling network from 1991 to 2011

Fig. 3 illustrates the expansion of the cycling network from 1991 to 2016 over the entire territory. A growth rate of 162% is seen for the period studied. In the three areas under study, the density of the cycling network also showed a constant increase (Table 1). Nevertheless, in 2016, the cycling network only represented 13.3% of all potentially cyclable streets in the study area. This proportion, like the density of the kilometres of cycling network per km<sup>2</sup>, did however double during the period. The area studied with the most marked expansion is the city of Laval, which has almost seen a four-fold increase of its network (3.91) in 25 years. In Montreal, Laval and Longueuil, the length of the cycling network increased from 270 km to 732 km, from 50 km to 196 km, and from 174 km to 368 km respectively during the period studied.

### 4.2. Little increase in connectivity

The results of the various measures of connectivity, which is an important aspect of the quality of a cycling network (Dill, 2004; Lowry and Loh, 2017; Marqués et al., 2015; Oswald Beiler et al., 2017; Schoner and Levinson, 2014; Titze et al., 2008), show very little improvement in the network (Table 2). The connected nodes ratio for all of the study area only rose from 0.47 to 0.60 for the entire period. As for the beta index used to measure the complexity of the network, it only increased from 0.99 to 1.21 out of a maximum of 2.5, which indicates a poor improvement. Montreal and Laval nonetheless saw their respective networks become more complex than Longueuil did. The gamma index used to measure the degree of connectivity also grew very little, from 0.33 to 0.40 (out of 1) for the entire study area, as was the case in each urban area. It should however be noted that the intersection density rose from 0.37 of an intersection per km<sup>2</sup> in 1991 to 1.41 intersections per km<sup>2</sup> in 2016 which indicates a major gain. A portion of these results may perhaps be due to the efforts made by the cities of Montreal, Laval and Longueuil, which have been working for the past few years to improve network connectivity in order to link the various centres of activity, and to increase the possibilities of trips between the different destinations as well as the fluidity of the network.

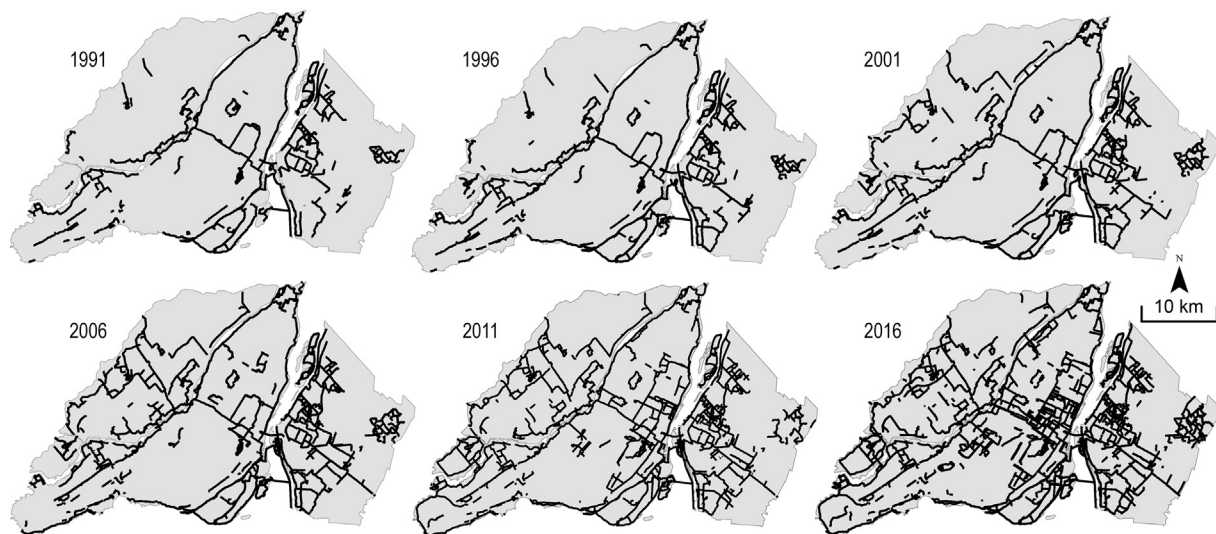


Fig. 3. Greater Montreal cycling network expansion – 1991 to 2016.

**Table 1**  
Expansion and density of the cycling network.

Year	Areas	Total length (km)	Network per km <sup>2</sup>	Percentage of cycling network out of all roads
1991	Montreal	270	0.54	4.8
	Laval	50	0.20	2.8
	Longueuil	174	0.62	7.7
	All	495	0.48	5.1
1996	Montreal	323	0.65	5.7
	Laval	55	0.22	3.1
	Longueuil	206	0.73	9.1
	All	584	0.57	6.0
2001	Montreal	348	0.70	6.2
	Laval	107	0.43	6.0
	Longueuil	251	0.88	11.1
	All	705	0.68	7.3
2006	Montreal	391	0.78	6.9
	Laval	153	0.62	8.5
	Longueuil	276	0.97	12.2
	All	819	0.80	8.4
2011	Montreal	546	1.09	9.7
	Laval	178	0.72	9.9
	Longueuil	315	1.11	13.9
	All	1039	1.01	10.7
2016	Montreal	732	1.46	13.0
	Laval	196	0.80	10.9
	Longueuil	368	1.30	16.2
	All	1296	1.26	13.3

**Table 2**  
Connectivity of the cycling network.

Year	Areas	Connected nodes ratio	Beta index	Gamma index	Intersection density
1991	Montreal	0.46	1.00	0.34	0.35
	Laval	0.31	0.83	0.28	0.09
	Longueuil	0.52	1.02	0.34	0.67
	All	0.47	0.99	0.33	0.37
1996	Montreal	0.49	1.09	0.36	0.48
	Laval	0.30	0.88	0.30	0.11
	Longueuil	0.55	1.05	0.35	0.80
	All	0.50	1.05	0.35	0.48
2001	Montreal	0.57	1.16	0.39	0.73
	Laval	0.35	0.87	0.29	0.24
	Longueuil	0.57	1.10	0.37	1.17
	All	0.54	1.10	0.37	0.73
2006	Montreal	0.53	1.12	0.37	0.67
	Laval	0.43	0.97	0.33	0.40
	Longueuil	0.56	1.09	0.36	1.21
	All	0.52	1.08	0.36	0.76
2011	Montreal	0.61	1.18	0.39	1.16
	Laval	0.45	1.00	0.34	0.58
	Longueuil	0.55	1.08	0.36	1.64
	All	0.56	1.11	0.37	1.15
2016	Montreal	0.64	1.31	0.44	1.62
	Laval	0.44	1.01	0.34	0.54
	Longueuil	0.59	1.13	0.38	1.79
	All	0.60	1.21	0.40	1.41

#### 4.3. Improvement in the quality of the cycling network according to the typology

The cycling network in the region is made up of various types of bike paths (cyclist-only bike paths, on-street bike lanes, and multi-use off-street paths). A number of studies have shown that users prefer cyclist-only bike paths (Broach et al., 2012; Lusk et al., 2011; Sahlgvist et al., 2015; Tilahun et al., 2007; Winters and Teschke, 2010). For all study areas, a major growth in cyclist-only bike paths is seen (Fig. 4). So, in taking the typology into account, we find a constant increase in the quality of infrastructures, especially in terms of safety (Bagloe et al., 2016; Broach et al., 2012; Lusk et al., 2011). It is interesting to observe that, for the city of Laval, there has been a phenomenon of transformation of on-street bike lanes into cyclist-only bike paths. It is only in Montreal that we still find a large increase in on-street bike lanes. In the last few years, some boroughs and the central city considerably developed the network in using that type of infrastructure,

which represented more than the half of the network in 2016. As for multi-use infrastructures, they remain a minority in the three areas studied.

#### 4.4. Effect of cycle network expansion on equity in accessibility

The second objective of this study is to determine whether the extension of the cycling network reduced or reinforced inequities in accessibility for the four groups studied. To determine this, we calculated various models.

##### 4.4.1. Distance to the nearest section of the cycling network: OLS regression

For the model where the dependent variable is the distance to the nearest section of cycling network (Table 3), the control variable, that is, the distance to the downtowns, is only not significant ( $p > 0.05$ ) in 1991 and 2011. The dummy variables representing the study areas reflect what we found in our characterization of the network. Compared

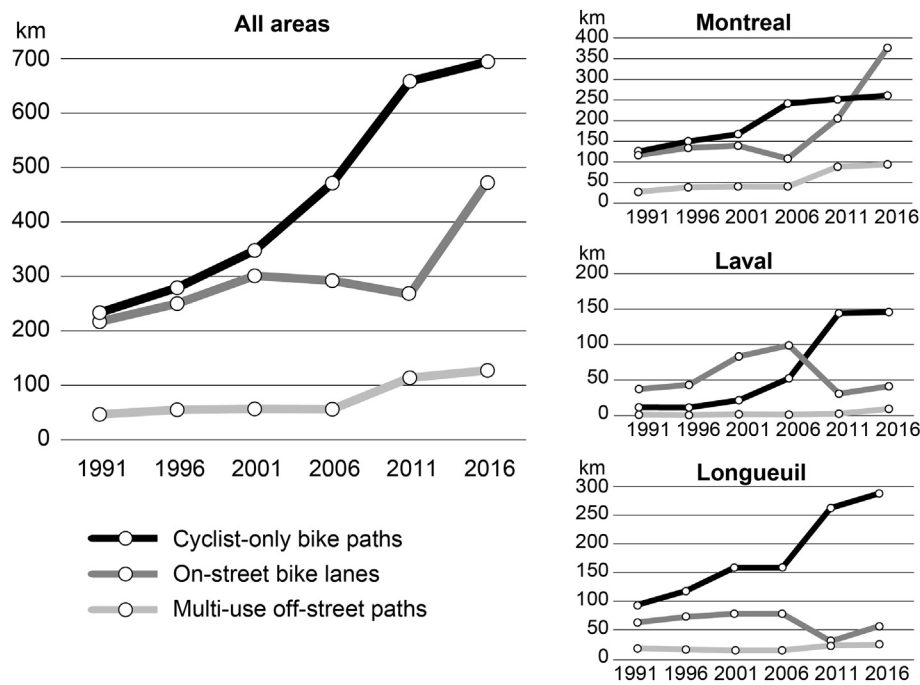


Fig. 4. Expansion according to the typology of the cycling network.

with the Montreal urban area, accessibility was lower in Laval in 1991, 1996 and 2016 (significant and positive coefficients), whereas it was greater than in Montreal in 2006 (significant and negative coefficients). For Longueuil, the accessibility was still greater there than in Montreal until 2006. However, the coefficients had decrease from 1991 to 2006,

with fluctuations during the period, and end up being not significant in 2011 and 2016. Until 2011, the independent variables for the four groups are all significant at a threshold of 5%, except for the percentage of low-income people in 2011 (Table 3). In 2016, only the percentages of children aged 5 to 14 and 65 years old and over are significant. The

Table 3

OLS regression: distance to the nearest section of the cycling network.

Year	1991			1996			2001		
	Coef.	T	Pr	Coef.	T	Pr	Coef.	T	Pr
Intercept	317.40	1.27	0.203	417.93	1.78	0.075	−12.02	−0.06	0.950
Distance to downtown	−19.08	−1.83	0.068	−21.05	−2.14	0.033	−18.23	−2.23	0.026
Montreal	Ref.			Ref.			Ref.		
Laval	355.11	2.30	0.022	341.65	2.36	0.019	−228.26	−1.79	0.073
Longueuil	−382.11	−2.56	0.011	−287.74	−2.08	0.038	−298.93	−2.62	0.009
Low-income pop. (%)	−18.34	−4.89	0.000	−19.14	−5.93	0.000	−15.55	−4.91	0.000
Recent immigrants (%)	79.30	7.00	0.000	64.40	8.02	0.000	76.30	8.58	0.000
5–14 years old (%)	86.05	5.17	0.000	82.88	5.55	0.000	80.21	6.36	0.000
65 years old and over (%)	22.55	3.39	0.001	17.27	2.84	0.005	26.99	5.27	0.000
N	629			630			658		
R <sup>2</sup>	0.169			0.188			0.175		
Pseudo R <sup>2</sup>	0.160			0.179			0.166		
AIC	10,429			10,389			10,722		

Year	2006			2011			2016		
	Coef.	T	Pr	Coef.	T	Pr	Coef.	T	Pr
Intercept	−65.46	−0.35	0.726	31.05	0.27	0.784	−131.80	−1.27	0.206
Distance to downtown	−16.19	−2.12	0.035	1.04	0.22	0.830	0.02	4.13	0.000
Montreal	Ref.			Ref.			Ref.		
Laval	−295.26	−2.50	0.013	−38.27	−0.50	0.618	140.80	2.49	0.013
Longueuil	−277.51	−2.64	0.008	−121.26	−1.78	0.076	21.51	0.42	0.674
Low-income pop. (%)	−14.40	−4.19	0.000	−3.32	−1.25	0.212	1.19	0.43	0.666
Recent immigrants (%)	65.96	8.32	0.000	14.90	2.80	0.005	7.84	1.63	0.103
5–14 years old (%)	74.95	6.21	0.000	42.41	5.48	0.000	20.42	3.26	0.001
65 years old and over (%)	21.04	4.44	0.000	8.01	2.68	0.008	6.67	2.95	0.003
N	661			685			692		
R <sup>2</sup>	0.174			0.091			0.113		
Pseudo R <sup>2</sup>	0.165			0.082			0.104		
AIC	10,685			10,551			10,290		

**Table 4**  
OLS regression: the distance to the nearest cyclist-only path.

Year	1991			1996			2001		
	Coef.	T	Pr	Coef.	T	Pr	Coef.	T	Pr
Intercept	608.02	1.91	0.056	691.58	2.04	0.042	289.68	1.25	0.213
Distance to downtown	−20.54	−1.54	0.123	−0.94	−0.07	0.947	6.38	0.64	0.521
Montreal	Ref.			Ref.			Ref.		
Laval	808.82	4.11	0.000	1076.67	5.13	0.000	389.88	2.52	0.012
Longueuil	−489.04	−2.57	0.010	−572.28	−2.85	0.005	−319.32	−2.30	0.022
Low-income pop. (%)	−26.46	−5.54	0.000	−22.09	−4.72	0.000	−14.85	−3.86	0.000
Recent immigrants (%)	103.58	7.17	0.000	81.93	7.04	0.000	87.23	8.08	0.000
5–14 years old (%)	104.26	4.91	0.000	96.81	4.48	0.000	56.17	3.67	0.000
65 years old and over (%)	37.88	4.47	0.000	21.92	2.49	0.013	30.61	4.92	0.000
N	629			630			658		
R <sup>2</sup>	0.210			0.213			0.170		
Pseudo R <sup>2</sup>	0.201			0.204			0.161		
AIC	10,734			10,857			10,977		

Year	2006			2011			2016		
	Coef.	T	Pr	Coef.	T	Pr	Coef.	T	Pr
Intercept	−49.13	−0.23	0.816	119.98	0.85	0.396	21.67	0.13	0.897
Distance to downtown	10.77	1.24	0.215	1.64	0.27	0.786	0.02	2.92	0.004
Montreal	Ref.			Ref.			Ref.		
Laval	306.96	2.30	0.022	−353.67	−3.69	0.000	−220.30	−2.42	0.016
Longueuil	−59.08	−0.50	0.619	−376.87	−4.42	0.000	−364.70	−4.43	0.000
Low-income pop. (%)	−11.62	−2.99	0.003	−8.81	−2.65	0.008	−2.09	−0.47	0.638
Recent immigrants (%)	64.77	7.21	0.000	32.14	4.83	0.000	26.92	3.48	0.001
5–14 years old (%)	59.88	4.38	0.000	60.17	6.22	0.000	41.19	4.08	0.000
65 years old and over (%)	17.52	3.26	0.001	12.69	3.40	0.001	8.88	2.43	0.015
N	661			685			692		
R <sup>2</sup>	0.155			0.162			0.142		
Pseudo R <sup>2</sup>	0.145			0.153			0.133		
AIC	10,849			10,856			10,951		

percentage of children aged 5 to 14 is the independent variable with the most influence on the distance to the nearest cycling network. The more the percentage of children increases, the greater is the distance to the cycling network. For example, in 1991, for each additional percentage point of children per census tract, the distance to the cycling network increases by 86 m, all other things being equal ( $B = 86.05$ ,  $p = 0.000$ ). This indicates that children are in a situation of inequity. The same finding applies for recent immigrants and older people, though with lower coefficients for the latter. Conversely, the percentage of low-income individuals is negatively correlated with the distance to the cycling network from 1991 to 2006, which indicates a favourable situation for this group. It should be noted that the  $R^2$  values are relatively stable from 1991 to 2006, and then strongly decline in 2011. This indicates a decrease in the inequities at the end of the period.

For the model where the dependent variable is the distance to the nearest cyclist-only bike path, all the independent variables are significant except for the distance to the downtowns (1991–2011), the dummy variable for Longueuil in 2006, and the percentage of low-income population in 2016 (Table 4). As with the previous model, it is low-income people who benefit from better accessibility (negative and significant coefficients). For recent immigrants and seniors, we see a reduction in their low accessibility. Despite a decrease in their poor accessibility at the start of the 2000s, it is children that had the least access to a cyclist-only bike path network over all the period. The  $R^2$  declines throughout the period studied, except in 1996, which indicates an overall decrease in inequities.

Thanks to the standardized coefficients in Fig. 5, it is easy to compare the importance of each of the independent variables during the period for the two regression models: a positive standardized coefficient indicates a situation of inequity, and a negative coefficient indicates an advantageous situation, whereas a coefficient close to zero expresses

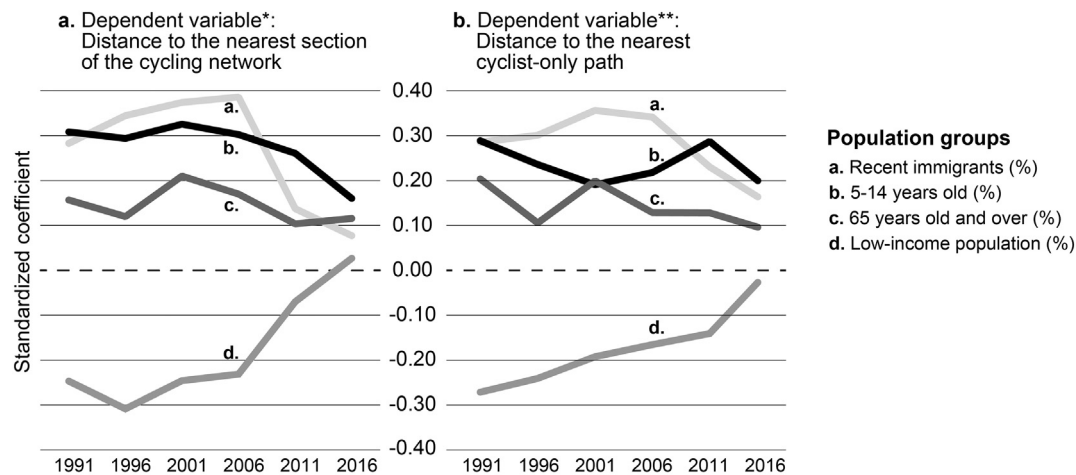
that there are no inequities. If we look at the left part of Fig. 5.a, we can advance several interesting observations as to the accessibility of the cycling network. First, we find a reduction in inequities for older people and recent immigrants, but with fluctuations between 1991 and 2016. Secondly, low-income populations that enjoyed an advantageous situation in 1991 saw this tendency decrease starting in 1996, with a standardized coefficient close to 0 from 2011. Thirdly, the curve for children remained relatively stable from 1991 to 2011, which shows that the situation of inequity of the latter had barely improved in 20 years. However, the standardized coefficient suggest an improvement in the five last years.

As for the curves in the second model (Fig. 5b), concerning cyclist-only bike paths, they are similar to those in the first model in terms of the accessibility for seniors and low-income populations. It is interesting to observe the parabolic form representing children's accessibility. It seems to indicate that their accessibility increased up to 2001, and then subsequently deteriorated, except for 2016.

#### 4.4.2. Accessibility to the cycling network within 500 m: logistic regressions

With the help of this regression, it is a matter of determining whether the probability of having access to the cycling network within a 500-metre radius for each of the four groups increased or decreased from 1991 to 2011 (Table 5 and Fig. 6a). We see that only low-income people had a greater probability of having access to the cycling network within a 500-metre radius, although this probability very slightly declined. Recent immigrants saw their probability of not having access to the network diminish over the years, but they still have more limited access, since the values of the odds ratios (OR) and the 95% confidence intervals of these ratios are still below 1 (ranging from 0.89 in 1991 to 0.94 in 2016). The situation is more of a concern for children (OR stable around 0.85), indicating that with each 1% increase in children aged 5





Note: \* See Table 3. \*\* See Table 4.

Fig. 5. Standardized coefficients for the OLS regression models.

to 14 in a census tract, the probability of benefiting from a bike path within a 500-metre radius fell by 13 to 16%.

As for the logistic model, where the dependent variable is access to a cyclist-only bike path within a 500-metre radius (Table 6 and Fig. 6b). The percentage of children was negatively significant from 2006 to 2016. This model shows that recent immigrants saw their probability of not having access to a cyclist-only bicycle path within a 500-metre radius decline until 2011, but that they were still in a situation of inequity even though this inequity was low (OR = 0.947, OR

95% = 0.906–0.989).

The graphic representation of the odds ratios in Fig. 6 shows tendencies similar to the OLS models throughout the period: a reduction in inequities for recent immigrants, a stability in the inequities for children, and a slight decrease in the advantages for low-income people. It should however be noted that, in Fig. 6b, many odds ratios are not significant.

Table 5

Logistic regression: access to the cycling network within 500 m.

Year	1991				1996				2001			
	Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>		Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>		Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>	
Intercept	−0.370	0.691	0.220	2.152	0.337	1.400	0.475	4.173	1.216	3.374	1.277	9.126
Distance to downtown Montreal	0.042	1.043	0.991	1.098	0.054	1.055	1.006	1.109	0.043	1.044	1.001	1.091
Laval	0.227	1.254	0.580	2.645	−0.016	0.984	0.471	2.007	0.516	1.676	0.878	3.196
Longueuil	1.227	3.411	1.741	6.758	1.004	2.728	1.443	5.213	0.776	2.172	1.233	3.855
Low-income pop. (%)	0.037	1.038	1.020	1.057	0.027	1.028	1.012	1.044	0.020	1.020	1.004	1.037
Recent immigrants (%)	−0.121	0.886	0.833	0.938	−0.072	0.931	0.893	0.968	−0.091	0.913	0.867	0.958
5–14 years old (%)	−0.136	0.873	0.805	0.944	−0.174	0.840	0.779	0.904	−0.170	0.843	0.786	0.902
65 years old and over (%)	−0.006	0.994	0.965	1.025	−0.015	0.986	0.959	1.013	−0.035	0.965	0.940	0.990
N	629				630				658			
Cox and Snell R <sup>2</sup>	0.086				0.083				0.070			
Nagelkerke R <sup>2</sup>	0.120				0.114				0.095			
AIC	758				792				850			

Year	2006				2011				2016			
	Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>		Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>		Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>	
Intercept	1.143	3.138	1.174	8.526	1.977	7.224	2.933	18.252	3.819	45.572	11.273	191.448
Distance to downtown Montreal	0.038	1.039	0.997	1.084	0.005	1.005	0.969	1.044	0.000	1.000	1.000	1.000
Laval	0.746	2.110	1.133	3.964	0.220	1.246	0.697	2.245	−0.506	0.603	0.335	1.087
Longueuil	0.823	2.278	1.312	3.997	0.730	2.075	1.208	3.641	0.080	1.084	0.620	1.930
Low-income pop. (%)	0.029	1.029	1.010	1.049	0.019	1.019	0.998	1.041	0.028	1.028	0.993	1.068
Recent immigrants (%)	−0.087	0.917	0.876	0.958	−0.042	0.959	0.919	1.000	−0.062	0.939	0.887	0.993
5–14 years old (%)	−0.156	0.855	0.799	0.914	−0.153	0.858	0.806	0.913	−0.160	0.852	0.788	0.921
65 years old and over (%)	−0.035	0.966	0.942	0.990	−0.030	0.971	0.948	0.993	−0.043	0.958	0.933	0.984
N	661				685				692			
Cox and Snell R <sup>2</sup>	0.077				0.077				0.123			
Nagelkerke R <sup>2</sup>	0.104				0.103				0.177			
AIC	872				889				753			

<sup>a</sup> Odds ratio.

<sup>b</sup> 95% Wald confidence limits.

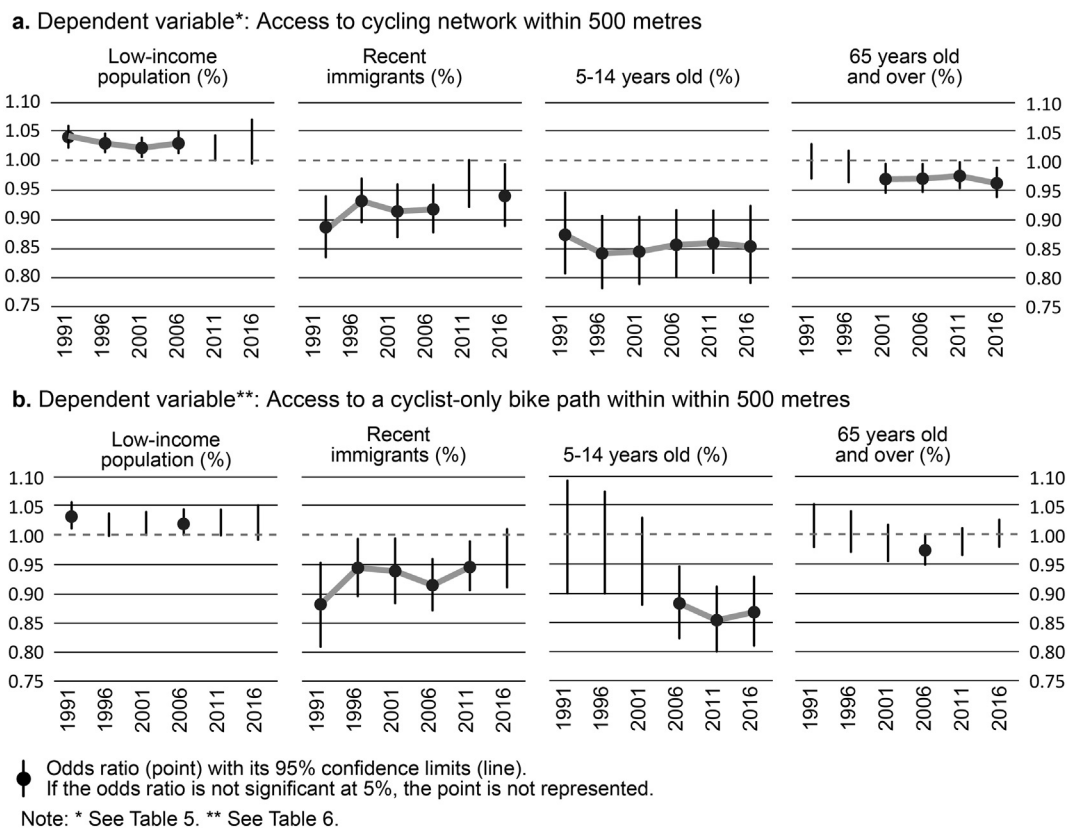


Fig. 6. Odds ratios for the logistic regression models.

## 5. Discussion

Contrary to what studies conducted elsewhere in the world have suggested (Lusk et al., 2017; Tucker and Manaugh, 2017), low-income people have good access to the cycling network in our study area. In the Montreal area, some of the oldest cycling paths were developed in disadvantaged neighbourhoods where space was available for this after transformation of the area in connection with industrial decline. In other cases, the bike paths resulted from demands by pro-cycling pressure groups. For example, the first bicycle path created on the territory of the Island of Montreal was the Lachine Canal linear park bike path, in a former industrial area where the nearby neighbourhoods had long housed impoverished, working class populations. As well, in the 1970s, the militant group *le Monde à bicyclette* spoke out strongly for the rights of cyclists in urban settings. The group pushed for the development of a major north-south cycling route. The group was comprised of young cyclists and militants based in the central neighbourhoods of Milton Park, Mile End and Plateau Mont-Royal, all neighbourhoods where one could then find inexpensive apartments (Morissette, 1994; Ross, 2015).

Over the period studied, we see increasingly-declining positive associations between the percentage of low-income people and the proximity of bike paths. We can offer two hypotheses to explain this. First, it can be said that the expansion of the cycling network reached, over time, areas with populations with more diversified income levels. Secondly, we can say, as other authors have observed in the United States (Flanagan et al., 2016; Stehlin, 2015; Stein, 2011), that many disadvantaged sectors with access to the cycling network became more gentrified over the years.

Another important element is that the expansion of the cycling network has improved access to this network for recent immigrants. However, as with other groups, it is difficult to conclude whether or not this expansion allows them to reach their chosen destinations (job sites, shopping destinations, etc.).

Of all the results, the inequity affecting children is the most surprising. Since 1991, children have never benefited from good access to the cycling network, despite the advantages that this type of infrastructure offers, especially in the area of safety. Nevertheless, in 2015, children represented one quarter of all Québec cyclists, and two utility cyclists out of three were children (*Vélo Québec*, 2016). What is astounding is that the expansion of the cycling network over the study area had no influence on its accessibility for children. On the one hand, this may be explained by the form that the extension of the network took, as it was largely developed over the years in central neighbourhoods in Montreal and in neighbourhoods with low proportions of children in Laval and Longueuil (Flanagan et al., 2016; Pucher et al., 2011).

On the other hand, due to the population aging affecting the entire territory, from 1991 to 2011, the proportion of the population under 15 years of age fell from 20% to 15% in the city of Laval and in the Longueuil urban area, whereas, during the same period, the proportion of the population aged 65 and over rose from about 9% to 15% (CMM, 2012). This phenomenon was also experienced in the Montreal urban area, but with much smaller variations. This population aging could also explain why the accessibility of the cycling network improved for seniors starting in 2001 (Fig. 6).

Since access to property ownership is becoming increasingly expensive in the entire metropolitan area, we can hypothesize that families are moving ever further outside the study area or into new neighbourhoods where it was not considered appropriate to set up a cycling network. Moreover, suburban streets may be deemed safe enough for cycling by local authorities, as is often assumed, but as mentioned by Aldred (2015), “the combination of through motor traffic and parked cars restricting visibility and manoeuvring may prove hostile for children, in residential streets”. We can also suppose that it is a question of an issue of procedural equity. Children rarely have input into city planning, even though they make up the segment of the population with the highest level of cyclists: that is, nearly 90% (*Vélo Québec*,

**Table 6**

Logistic regression: access to an exclusive bike path within 500 m.

Year	1991				1996				2001			
	Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>		Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>		Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>	
Intercept	−2.416	0.089	0.021	0.363	−1.863	0.155	0.039	0.598	−1.212	0.298	0.094	0.928
Distance to downtown	0.026	1.027	0.966	1.089	0.020	1.020	0.963	1.080	0.036	1.037	0.986	1.089
Montreal	Ref.				Ref.				Ref.			
Laval	−0.595	0.552	0.169	1.525	−1.381	0.251	0.056	0.790	−0.553	0.575	0.213	1.387
Longueuil	0.441	1.554	0.674	3.463	0.591	1.806	0.855	3.737	0.562	1.753	0.910	3.329
Low-income pop. (%)	0.031	1.032	1.010	1.055	0.016	1.016	0.998	1.035	0.018	1.019	0.999	1.038
Recent immigrants (%)	−0.124	0.883	0.810	0.952	−0.056	0.945	0.895	0.993	−0.063	0.939	0.884	0.993
5–14 years old (%)	−0.011	0.989	0.898	1.089	−0.019	0.981	0.898	1.070	−0.051	0.950	0.879	1.026
65 years old and over (%)	0.013	1.013	0.976	1.050	0.003	1.003	0.968	1.038	−0.017	0.984	0.952	1.014
N	629				630				658			
Cox and Snell R <sup>2</sup>	0.035				0.030				0.023			
Nagelkerke R <sup>2</sup>	0.060				0.051				0.037			
AIC	548				564				649			

Year	2006				2011				2016			
	Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>		Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>		Coef.	OR <sup>a</sup>	OR 95% <sup>b</sup>	
Intercept	1.006	2.736	0.994	7.689	1.002	2.725	1.131	6.692	0.935	2.548	0.886	7.496
Distance to downtown	−0.001	0.999	0.956	1.044	0.005	1.005	0.965	1.046	0.000	1.000	1.000	1.000
Montreal	Ref.				Ref.				Ref.			
Laval	−0.318	0.727	0.359	1.431	0.888	2.429	1.337	4.452	0.828	2.288	1.292	4.073
Longueuil	−0.015	0.985	0.547	1.750	1.236	3.441	2.018	5.964	1.211	3.358	2.000	5.713
Low-income pop. (%)	0.019	1.019	1.000	1.039	0.020	1.020	0.999	1.042	0.020	1.020	0.991	1.050
Recent immigrants (%)	−0.089	0.915	0.872	0.958	−0.055	0.947	0.906	0.989	−0.042	0.959	0.911	1.009
5–14 years old (%)	−0.126	0.882	0.822	0.944	−0.158	0.854	0.800	0.909	−0.143	0.867	0.810	0.926
65 years old and over (%)	−0.029	0.972	0.946	0.998	−0.015	0.985	0.963	1.009	0.000	1.000	0.977	1.023
N	661				685				692			
Cox and Snell R <sup>2</sup>	0.067				0.099				0.103			
Nagelkerke R <sup>2</sup>	0.093				0.132				0.138			
AIC	807				880				887			

<sup>a</sup> Odds ratio.<sup>b</sup> 95% Wald confidence limits.

2016). This level falls with the onset of adulthood and continues to decline over the years (Vélo Québec, 2016). It should be remembered that the modal share of cycling is currently only 2.5%, and that this share only rises very little from year to year. In a context of combating climate change, all efforts that foster an increase in this modal share will have beneficial effects on everyone's quality of life. Improving the accessibility of the cycling network favours use of the bicycle by young people (Emond and Handy, 2012; Kaplan et al., 2016), which encourages the continuation of the practice of cycling after childhood (Emond et al., 2009; Fernández-Heredia et al., 2014).

## 6. Conclusion

In conclusion, our longitudinal approach has enabled us to observe that the cycling network has more than doubled in size during the period under study. However, in looking at the spreading of the network over the study area, we see that certain areas are still very poorly served, and that they would benefit from better connectivity. In terms of accessibility, low-income individuals have generally had a good degree of accessibility, but one that slightly declined toward the end of the period. For their part, recent immigrants have seen their accessibility improve, so that in 2016, we can no longer point to any flagrant inequity. The most important result is clearly that there has been little or no improvement for children, who remain in a situation of inequity. The literature shows that children's safety, mobility and health could benefit from better access to the cycling network (Emond and Handy, 2012; Fitch et al., 2016; Kaplan et al., 2016; McDonald et al., 2016). Various levels of government are spending large sums of money to encourage physical activity among children in order to combat sedentariness. One sustainable contribution could be to give them access to

a high-quality cycling network. It is all the more important to target children, as we also know that child cyclists have greater chances to understand the benefits associated with bicycling once adult (Aldred et al., 2016; Fernández-Heredia et al., 2014; Kaplan et al., 2016).

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