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The impacts of urban sprawl on ecological connectivity in the Montreal Metropolitan Region

Jerôme Dupras[a,d,*], Joan Marull[b], Lluís Parcerisas[a], Francesc Coll[b], Andrew Gonzalez[c,d], Marc Girard[e], Enric Tello[f]

[a] Institut des sciences de la forêt tempérée, Université du Québec en Outaouais, 58, rue Principale, Ripon J0V 1V0, Québec, Canada
[b] Barcelona Institute of Regional and Metropolitan Studies, Edifici MRA, Autonomous University of Barcelona, E-08193 Bellaterra, Barcelona, Spain
[c] Department of Biology, McGill University, 1205 Docteur Penfield ave., Montréal H3A 1B1, Québec, Canada
[d] Quebec Center for Biodiversity Science, Office W6/19, 1205 Ave Docteur Penfield, Montréal H3A 1B1, Québec, Canada
[e] Département de géographie, Université de Montréal, Université de Montréal, 520Chemin de la Côte Ste-Catherine, Montréal H3C 3J7, Québec, Canada
[f] Department of Economic History and Institutions, University of Barcelona, 08034 Barcelona, Spain

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ABSTRACT

Urban sprawl is a widely recognized phenomenon in many major cities worldwide and is a significant land use planning and management issue. This process has many impacts on the ecological function and structure of the landscape. In this article, we analyze the effects of urban sprawl on the ecological patterns and processes in the Montreal Metropolitan Region (MMR) between 1966 and 2010. The dispersed sprawl of low-density urban areas within the territory during this period sharply increased the fragmentation of the territory, isolating the few remaining natural spaces and decreasing their ecological connectivity and, ultimately, biodiversity. The results obtained clearly show that land-use changes that occurred in the MMR have caused profound changes in landscape properties, both structurally and functionally, and especially from 1981 to 2010. In 1966, around 45% of the land had a high or very high level of connectivity, and almost 38% in 1981. By 2010 only 6.5% of the landscape was connected and 73% of the territory possessed no or low connectivity.

1. Introduction

Urban sprawl is a widely recognized phenomenon in many major cities worldwide and is an significant land use planning and management issue (Newman and Kenworthy, 1991; Williams et al., 2000; Grazi et al., 2008). During the last 50 years, urban and transport networks have spread at the expense of former natural or agricultural spaces, frequently occupying the lands most suitable for agriculture (Breheny, 1992; Camagni et al., 2002). In North America, this urbanization of areas around cities for residential, industrial, commercial and infrastructure use has followed a model characterized by a low density of built structures with a strong dependence on the automobile, which has revealed itself as tremendously negative for natural habits (Fahrig, 2003; Turner, 2005; Doucet, 2007). On the other hand, in western societies agriculture has survived and has been able to counter urban pressure mainly by the means of intensification. This is very clear in Europe (Mazoyer and Roudart, 2006) and is also noticeable in North America (Anderson, 2008; Parcerisas and Ruiz, 2014). This strategy of agricultural intensification, however, contributes to environmental degradation (Mazoyer and Roudart, 2006; Krausmann et al., 2013). Indeed, the increased crop yields caused by agricultural intensification have been frequently associated with substantial ecological costs, such as fossil energy inputs, soil degradation, and biodiversity loss (Krausmann et al., 2013; Dupras et al., 2015a).

Although urban built-up areas cover only a small proportion of the land, their impact on ecosystems is significant. For example, in the United States, roads occupy only 1% of the territory, but they highly alter the structures and ecological functions of at least 20% of the territory (Forman, 2000). In Europe, urban areas and infrastructures accounted for a little less than 3% of the whole territory in 2006, while agricultural and forested areas represented almost 71% of the land (EEA, 2013). Despite what these figures may lead to us to think, there has been an increasing and progressive process of European and North American landscape degradation over recent decades due to uncontrolled urban sprawl, especially in the vicinity of large urban and coastal areas (Foley et al., 2005; Gerard et al., 2010).

* Corresponding author.
E-mail address: jerome.dupras@uqo.ca (J. Dupras).

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Ecological landscape theory has provided a set of quantitative tools (namely landscape metrics) needed to characterize landscape heterogeneity (Li, 2000) and to measure landscape change through time (Reed et al., 1996). It is widely accepted that a general association exists between landscape pattern and ecological processes (Turner, 2005). Because of this concepts and methods from landscape ecology also are useful for land planning and design (Corry and Nassauer, 2005). Landscape metrics might be a way to evaluate the consequences arising from a given plan to manage a landscape's structure (Opdam et al., 2001), or they could be used to evaluate outcomes arising from alternative plans for a particular landscape (Gustafson, 1998). In either case, they are evaluative tools for regional planning (Botequilha and Ahen, 2002).

Landscape connectivity is a highly significant landscape attribute for conservation biology, as it is generally accepted that it enhances population viability and species richness at local and regional scales (Gilbert-Norton et al., 2010). Setting up habitat corridors is a classic structural approach to landscape connectivity management (Hobbs, 1992) that has been advocated as a key conservation strategy in human-modified landscapes where urbanization, infrastructure development and other activities frequently sever natural connections (Pino and Marull, 2012).

Manning et al. (2004) highlighted the limitation of corridor networks for the understanding and management of ecological functionality at landscape scale. A more general approach focused on ecological connectivity, integrates the value of remaining land matrix which might provide habitats for many species and enhance patch connectivity by providing a positive ecological context for patches of natural habitat (Ricketts, 2001). Consequently, some research proposes a network view which augments corridors with stepping-stone like structures of habitat distributed throughout the landscape (Pino and Marull, 2012).

The important outcome of urban sprawl is the fragmentation of natural and semi-natural habitats, which is the isolation of the different parts of the territorial matrix and that, ultimately, can bring about long-term loss of biodiversity (EEA, 2011). Mitigating the effects of fragmentation requires re-establishing connectivity across the territory and treating it as a functioning whole (Loreau et al., 2003; Gonzalez et al., 2011). Emphasis on connectivity challenges the idea that protecting a number of isolated natural and semi-natural spaces will be sufficient to maintain the ecological integrity of the region (Pino and Marull, 2012). High levels of fragmentation resulting from urban sprawl can move a region past thresholds of connectivity that make restoration politically challenging and economically costly. For example, Marull and Mallarach (2005) showed that the artificial barriers that cover 18% of the Barcelona Metropolitan area have direct negative impacts on 57% of the ecological connectivity of the area.

The goal of this article is to analyze the impact of urban sprawl on the ecological patterns and processes of the Montreal Metropolitan Region (MMR) from 1966 to 2010. Several landscape metrics, like the Effective Mesh Size and Shannon indexes, and the Ecological Connectivity index were calculated from land cover maps of the area of 1966, 1981, and 2010. This last index (ECI) has been recently developed and has already been successfully applied in some European (Parcerisas et al., 2012; Marull et al., 2010, 2014) and North-American (Dazzini, 2007; Marull and Cunfer, in press) cases.

After a brief presentation of the study area in Section 2, we present the methodology in Section 3 and results in Section 4. First, land-use changes during the period analysed are detailed, then a number of landscape properties are analyzed and, finally, the evolution of the ecological connectivity during the time frame is assessed. We discuss the results in section 5 before presenting our conclusion.

2. Study area

The MMR is located southwest of the Province of Quebec following the Saint-Lawrence River, comprising a total of 82 municipalities and covering an area of 4260 km^2 (Fig. 1). The core of the MMR is the City of Montreal, situated on the Island of Montreal, which is the most populated city in the province and second in Canada following Toronto, with a total population of 1,649,519 inhabitants in 2011 (Ville de Montréal, 2013).

As seen in Table 1, between 1966 and 2011 the population of the Province of Quebec has increased 37% while population growth rate within the MMR has been of 49%, though in an irregular fashion within the territory over time. The population of the island of Montreal has followed a different path, showing a clear standstill, even a decrease until the 1990's, largely due to the migration of urban residents to the suburbs (Sénécal et al., 2001). Therefore, it may be established that the population boost in the Province of Quebec during the last decades mainly occurred in the MMR with a dispersion of population within the MMR, especially between 1996 and 2010, when growth rates were higher.

On the other hand, the urban area in the MMR has spread along the territory at a much higher rate than the population, more than doubling the surface area occupied in 1966. Despite the fact that the population increased by 49% during this time, urban spaces in the metropolitan area grew by around 119%, passing from 610 km^2 to 1340 km^2. The result has been the creation of low-density dispersed towns. The process of migration to the suburbs started in the 1950s, provoking the construction of infrastructure and transport networks. Despite the plans adopted by the local governments in 1978 to stop this process and protect agriculture and agroforested spaces, since the 1990s, urban pressure on agricultural land heightened, resulting in a new period of agricultural abandonment and speculation (Dumoulin and Marois, 2003; Dupras and Alam, 2015; Nazarnia et al., 2016).

3. Methodology

3.1. Conceptual approach

The land matrix – and the landscapes it contains – can be seen as a heterogeneous, dynamic and multi-scalar system organized in hierarchical levels of complexity depending on their scales of space and time. In order to understand the organization of this complexity, and its evolution, we believe it necessary to use a

Table 1
Change in population and urban built-up area, 1966–2011.

Year	Quebec		MMR			Island of Montreal			MMR urban built-up area	
	Inhab.	1966 = 100	*Inhab.*	1966 = 100	*Québec* (%)	*Inhab.*	1966 = 100	*MMR* (%)	ha	1966 = 100
1966	5,780,845	100	2,570,985	100	44.5	1,923,171	100	74.8	61,058	100
1981	6,438,403	111	2,862,286	111	44.5	1,760,120	92	61.5	77,529	127
1996	7,138,795	123	3,326,447	129	46.6	1,775,788	92	53.4	116,100	190
2011	7,903,001	137	3,824,221	149	48.4	1,886,481	98	49.3	133,926	219

Source: Ville de Montréal (2013),Statistics Canada (1971) and Dupras and Alam (2014).