The impacts of the Cap Nature real estate project (Pierrefonds West) on ecological connectivity

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Executive Summary

- Development in Pierrefonds West will impact terrestrial biodiversity through a loss of habitat, an increase in landscape fragmentation, and a decrease in functional habitat connectivity.

- We analysed the impacts of development on the habitat networks of five groups of species with different dispersal abilities at the scale of 1 and 5 km buffers around the proposed development area.

- The effects of development were most pronounced within the 1 km buffer for all species but are also detectable at the scale of the 5 km buffer.

- Within the 1 km buffer, approximately 16% of habitat will be lost due to development and the remaining habitat fragments will be 56% smaller on average.

- This habitat loss and structural fragmentation translates into reduced functional habitat connectivity for all species groups.

- The number of isolated groups of patches (i.e. clusters) increases under the development scenario for all species, particularly for the amphibians due to their poor dispersal abilities.

- The average area of clusters (i.e. expected cluster size) decreases due to development for all species, as much as 14% for species groups with intermediate dispersal abilities such as reptiles, small mammals, and small birds. Accordingly, the overall loss in connectivity is about 27% for this group of species.

- Within the 5 km buffer, we see a pattern of decreased north-south connectivity between the Morgan Arboretum and Ile Bizard due to development.

- We conclude that development will have a detrimental impact on the terrestrial biodiversity at multiple scales.

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I. Introduction

Although often unrecognized, biodiversity in cities is very important. Natural and agricultural areas located in urban and suburban environments are habitats for many plant and animal species. However, the numerous pressures encountered in urban settings make this biodiversity highly threatened (Foley et al., 2005; Gerard et al., 2010). Among the pressures threatening biodiversity, the primary one is the conversion of natural habitat to other uses. This phenomenon is often referred to as urban sprawl and is widespread in major cities in North America and elsewhere. Other pressures that impact biodiversity include climate change and invasive species for example.

Greater Montreal is no exception to this global trend. Indeed, urban sprawl has increased exponentially in Montreal since 1951 (Nazarnia et al. 2016). In a recent study on the evolution of the Montreal area from the 1960s to present day, Dupras and Alam (2015) show that urban sprawl has resulted in the loss of nearly 30% of forests, 12% of wetlands, 20 % of agricultural lands and 30% of rangelands. The loss of these natural and semi-natural areas has significantly reduced the environmental benefits received by the population and the potential for ecological resilience. This depreciation of ecological capital results in additional annual costs for municipalities of $ 235 million (Dupras and Alam, 2015).

In addition to direct measurement of natural habitats losses, one way to measure the potential of resilience and survival of biodiversity in a given region is to assess connectivity. Ecological connectivity is the degree to which natural and semi-natural areas are connected by the movement of organisms across a landscape. Ecological connectivity across multi-use landscapes has been correlated with the quality and quantity of biodiversity (Mitchell et al., 2013). The results obtained by Dupras et al. (2016) clearly show that land-use changes that occurred in the Montreal region have caused profound changes in landscape properties and ecological connectivity. 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 was unconnected or had low connectivity.

Faced with this worrying situation, each additional development in the region has the potential to significantly impact regional biodiversity and ecological connectivity. Because of the magnitude of the Pierrefonds-Ouest Cap Nature real estate development project and its location in an area of high ecological value (Roy et al., 2016), this study aims to measure the impact of this project on local and regional ecological connectivity.

II. Study area

Our study area is a close approximation, a circle buffer, of the proposed development zone located in city of Montreal, Pierrefonds-Roxboro borough (see figure 1 inset).

To look at the landscape connectivity we considered 2 scales of analysis: 1 and 5 km buffers around the study area.

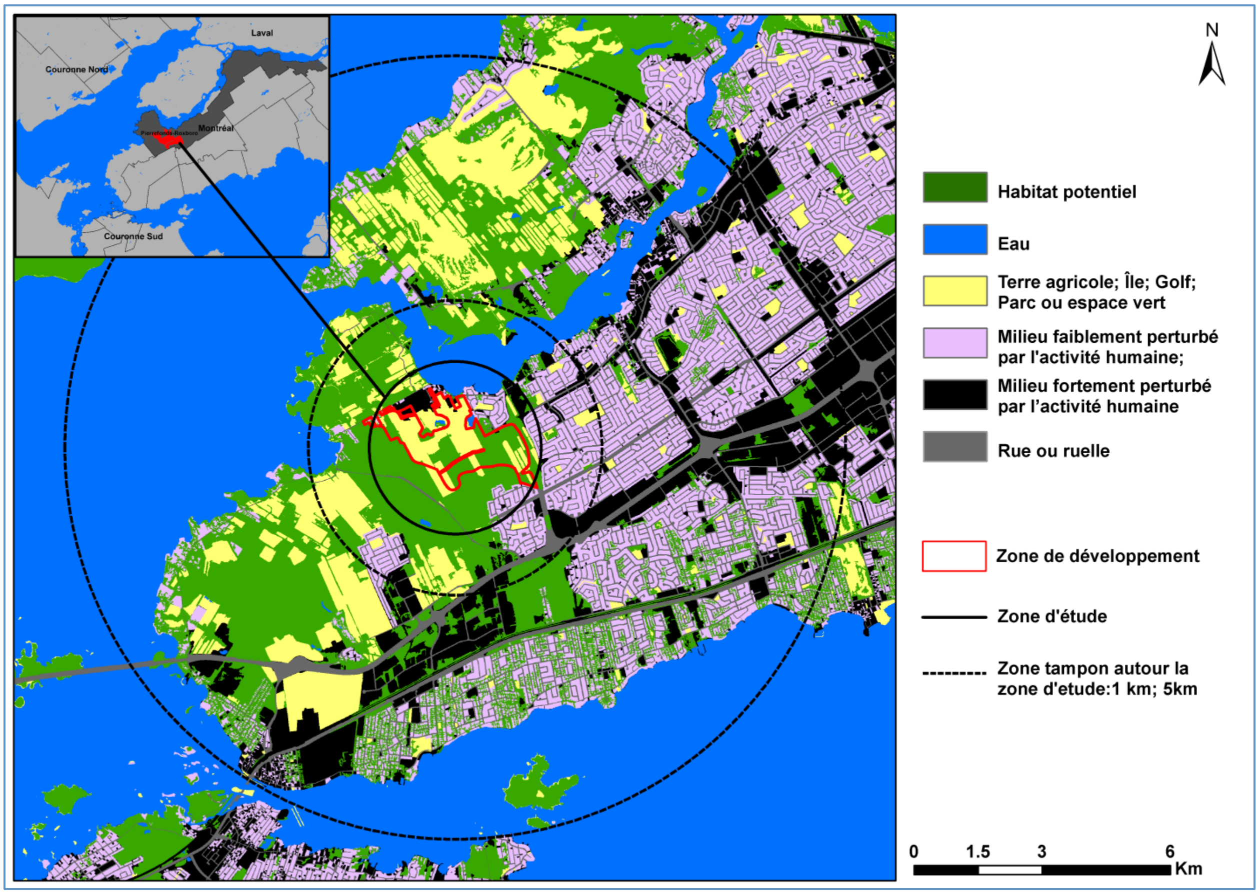

Figure 1 In this figure we can see the generalised land use categories. In green we have the forested areas, in blue - water; yellow - agriculture and open vegetated areas, purple - low density residential, black - high density residential and in grey are the roads. In the figure inset we can see the administrative boundaries of the region: dark grey is the Pierrefonds borough and red indicates the proposed development zone.

III. Data

We assembled land cover and land use information from two databases:

1) SIEF (Le Système d'information écoforestière) the 4th ecoforestry inventory database, 1:20000 m resolution (20m/pixel; MRN 2015). These data were the basis for the land use categories which were subsequently grouped into fewer, general, land use classes.

2) Georeferenced data from l'Observatoire Grand Montréal that contains information used to support the CMM's planning tools, particularly the PMAD (Plan métropolitain d'aménagement et de développement), which came into force March 12, 2012.

- Forested areas layer that contain all the forests (including urban treed areas) at a very fine resolution 10 cm/pixel.
- Vacant spaces and spaces to develop (Espaces vacants et espaces à développer) that are areas assigned for optimal urbanization, including commercial, industrial or residential areas, the latter being the designation for the development zone in your study area
- Land use data 2014 that includes very refined categories (25 groups). We've used only few land use types that were complementary to SIEF categories: golf courses, parks and green spaces, residential areas that contained only one housing and streets.

We used a resolution of 0.0025 ha/cell (5m x 5m), small enough to accomplish the most detailed landscape analysis.

IV. Methods

A. Groups of species considered

We considered 5 groups of species (see table 1) to represent the habitat requirements of the terrestrial biodiversity within the study area. These species groups were identified and documented in the study area during field surveys:

- Breeding birds
- Small mammals (mink, rodent)
- Big mammals (white-tailed deer)
- Amphibians (frogs, salamanders, toads)
- Reptiles (snakes and turtles)

Table 1 Groups of species considered in the landscape analysis (*Source* **:** Roy et al., 2016)

Espèces	Description	Déplacement moyen (m)
Oiseaux nicheurs	Déplacement annuelle à partir du domaine vital dans la période de nidification	1421
Petits mammifères (vison, rongeur)	Déplacement à partir de leurs habitats (terre ferme ou cours d'eau)	1250
Grands mammifères (cerf de Virginie)	Déplacement à partir de son domaine vital	2250
Amphibiens (rainettes, salamandres, grenouilles et crapauds)	Déplacement (moyenne à partir du domaine vital et des informations disponibles)	460
Reptiles (principalement couleuvres et ensuite tortues)	Déplacement sur la terre ferme	845

B. Selecting the habitat

We defined habitat for all species groups as the forested areas and wildlands "friche" areas from both SIEF and CMM databases.

To assess functional habitat connectivity for the focal specie groups, we included habitat patches that were within the 1 and 5 km buffers. We also included patches that intersected the boundary of the buffer (i.e. that were only partially within the buffer). For patches that intersected the buffer boundary, their full area (both inside and outside the buffer) was included in functional connectivity metrics (see below).

C. Landscape resistance map

The landscape resistance map quantified the potential for species groups to travel from one habitat patch to another through the intervening matrix. Therefore, each pixel received a resistance value based on its permeability to species dispersal (Adriaensen et al. 2003). The resistance map was the same for all groups of species and it was a generalized resistance surface derived from previous studies based on extensive literature review for 14 focal species (Gonzalez et al. 2012, Rayfield et al. 2015, Albert et al. in prep). We identified 5 general land use classes that received a resistance value of 1, 8, 16 or 32, as follows:

- Habitat; high permeability (value 1)
- Agriculture, willow brush, wet barren and dry barren areas, treed islands less than 1 ha, golf courses, park and green spaces (value 8)
- Disturbed areas by human activities (e.g residential areas with 1 housing) (value 16)
- Very disturbed areas by human activities like dense residential areas, industrial/commercial zones, roads; low permeability (value 32)
- Large bodies of water (value 32)

D. Two land-use scenarios (developed and undeveloped)

We analyzed habitat connectivity under 2 land use scenarios: one that depicts the current pattern of land use and another that includes the potential future development in the region. To identify the development areas we used the vacant spaces and spaces to develop that contain polygons designated as optimal areas for urbanization (Figure 2). One of several development polygons, and also the biggest, considers L'Anse à l'Orme sector in Pierrefonds West.

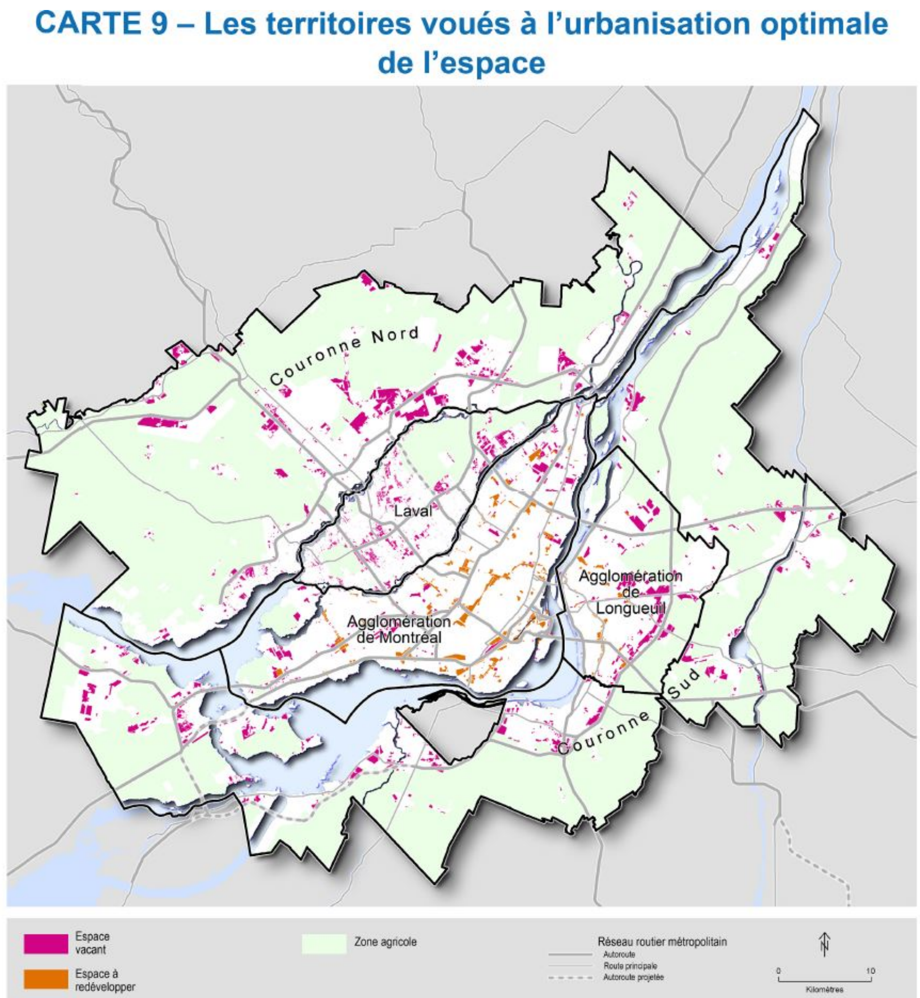

Figure 2 Area designated as optimal areas for urbanization (*Source CMM, PMAD plan*)

E. Spatial graph theory to quantify landscape fragmentation and habitat connectivity

Landscape connectivity is defined as "the degree to which the landscape facilitates or impedes movement among resource patches" (Taylor et al.1993)

To assess the structural fragmentation of the landscape and the functional connectivity of the habitat, we used a landscape analysis based on spatial graph theory (Fall et al. 2007) which models the habitat as a network. Each **node** in the habitat network represents a georeferenced habitat patch and each **link** that connects two habitat patches, represents a georeferenced potential dispersal pathway. Links between nodes can follow straight-line paths to model structural fragmentation of the network or least-cost paths to model functional connectivity of the network. A least-cost link is a link between two habitat nodes that minimizes the cumulative resistance along its length.

Figure 3 A small portion of a habitat network. Habitat nodes (green) are connected by the potential movements of species along links (red), across the resistance surface (low to high resistance in greyscale).

There are different types of spatial graphs used to connect the nodes. In our analysis we used the *minimum planar graph* (MPG) that connects nodes in a stepping-stone pattern (Fall et al. 2007). We identified the minimum planar graph representing the habitat network for each group of species based on straight-line and least-cost links, at two scales of analysis (1 and 5km buffers) for two land use scenarios (undeveloped and developed). The habitat network for each group of species was identified by removing links longer than the dispersal threshold for the species group (Table 1). When straight-line links were used, the threshold was applied to the length of the links. When least-cost links were used, the threshold was applied to the cumulative resistance of each link.

Structural fragmentation: Habitat networks with straight-line links were used to estimate structural fragmentation of the landscape which does not depend on the dispersal abilities of the focal species groups. The distance between habitat patches was estimated by the length of straight-line links in the minimum planar graph (this is as approximation, because links in the minimum planar graph may not exactly correspond to the minimum inter-patch distance due to the influence of surrounding habitat patches; Fall et al. 2007).

Functional habitat connectivity: Habitat networks with least-cost links were used to estimate functional habitat connectivity for each of the focal species groups. We measured the **number of clusters** and the **expected cluster size** (ECS) for each habitat network (for a review of network connectivity metrics see Rayfield et al. 2011). These connectivity metrics describe the degree to which the habitat network is divided into clusters, where nodes within a cluster are connected but nodes between clusters are not. ECS is a measure of the average area of clusters in a habitat network. More precisely, it corresponds to the total area of connected habitat that an individual organism would be expected to experience if it were placed randomly in the habitat present in the landscape (Fall et al. 2007, O'Brien et al. 2007). As dispersal ability increases, the number of clusters decreases, and the ECS increases. The habitat within the landscape becomes fully connected when all habitat patches belong to a single cluster.

V. Results

A. Area loss

The development in the region will lead to a significant loss of habitat at both 1 and 5km buffer scales.

Table 2 and Figures 4 and 5 depict the current state of the habitat and the potential loss associated with the development scenario. We looked at the habitat per se and also considered an edge effect of 50 and 100m to identify habitat core areas. Core areas are important for interior species that are sensitive to edge-effects associated with disturbance at the edge of their habitat patches. The width of edge-effects varies from species to species, going from 50 meters to several hundred meters. For example, the ovenbird (*Seiurus aurocapilla*) can have an edge effect up to 100m (Smith et al. 2011).

Absolute loss of habitat area amounts to 119.5 ha at the 1 km scale and 230.4 ha at the 5 km scale. Relative habitat area loss is greater within the 1 km buffer. The development scenario leads to a **loss of 15.53 % of the habitat within the 1km buffer** and **8.28% of the habitat within the 5km buffer**.

Table 2. Total habitat patch area and total habitat core area in the undeveloped and developed land use scenarios

Buffer around the study area	1 km		5 km	
Scenario	**Undeveloped**	**Developed**	**Undeveloped**	**Developed**
Potential habitat (ha)	769.37	649.89	2782.90	2552.54
Edge effect of 50 m (ha)	509.12	433.42	1155.19	1042.56
Edge effect of 100 m (ha)	360.25	312.62	709.58	645.54

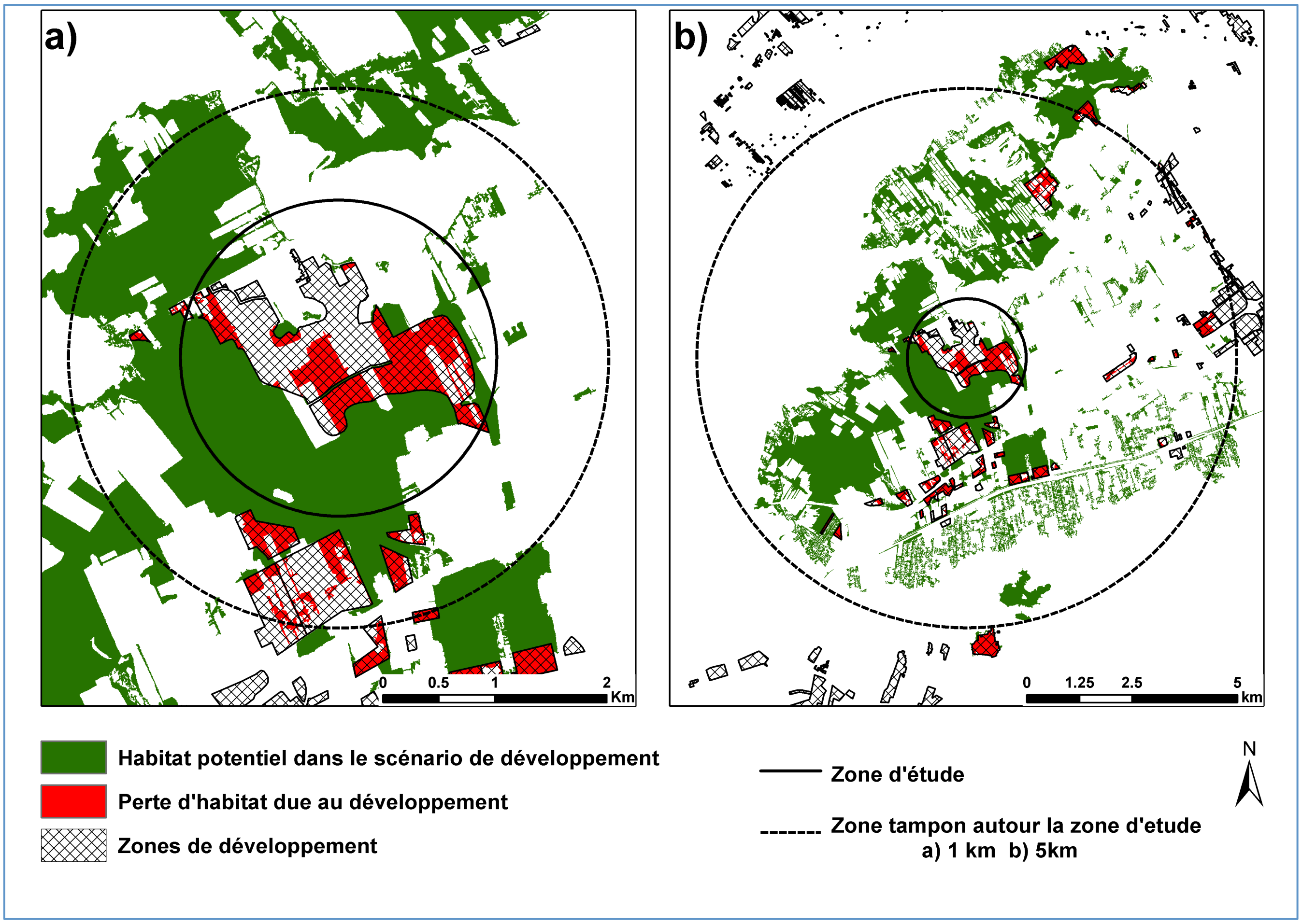

Figure 4 Comparison of habitat area in the undeveloped and developed land use scenarios at the a) 1km and b) 5km buffer scales.

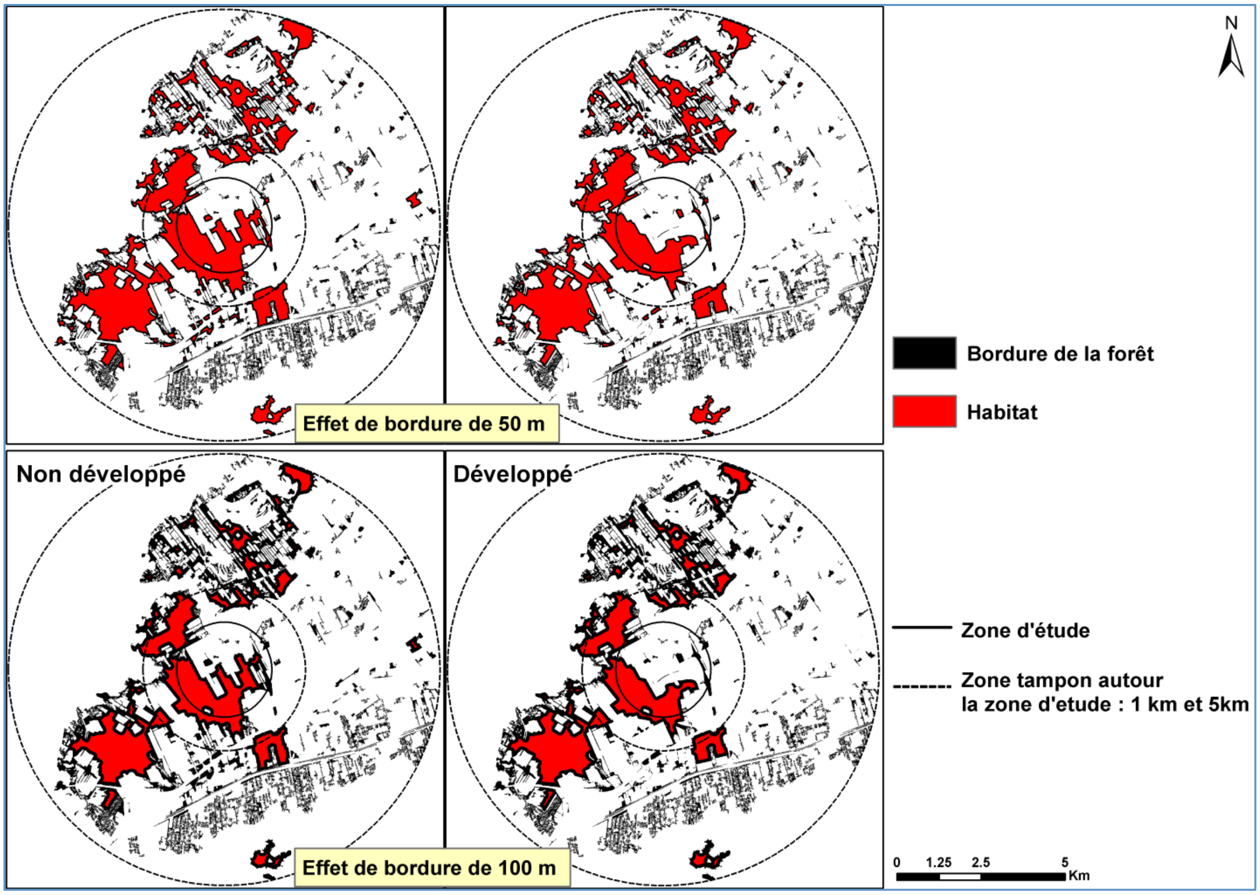

Figure 5 The distribution of the core habitat areas in the undeveloped scenario (left-hand panels) and the developed scenario (right-hand panels). Red represents the core habitat and black indicates the width of the edge effect: 50 m edge effect (upper row) and 100 m edge effect (bottom row). Within the development area (solid circle), a small, central core area is lost. A large core area in the south (l'Anse-à-l'Orme forest) also loses a lot of its area.

B. Structural fragmentation

The habitat area loss leads to an increase in structural landscape fragmentation. Structural fragmentation is more pronounced at the 1 km than the 5 km buffer scale. At the scale of the 1km buffer, the number of habitat patches increases from 24 to 46 patches (90% increase) and the mean patch size decreases from 32.06 to 14.13 ha (44% decrease; Table 3). The average distance between patches decreases within the 1 km buffer due to forest fragmentation that leads to the formation of smaller links that connect the residual habitat patches. See figures 6 and 7 for the distance between the habitat patches and forest fragmentation.

Table 3 Habitat fragmentation main results

Buffer around the study area	1 km		5 km	
Scenario	**Undeveloped**	**Developed**	**Undeveloped**	**Developed**
Number of patches	24	46	353	421
Average distance between patches (m)	354.39	280.99	216.40	218.81
Average size of patches (ha)	32.06	14.13	7.88	6.06
Size of smallest patch (ha)	0.03	0.007	0.007	0.005
Size of largest patch (ha)	663.28	521.82	1260.30	1105.98

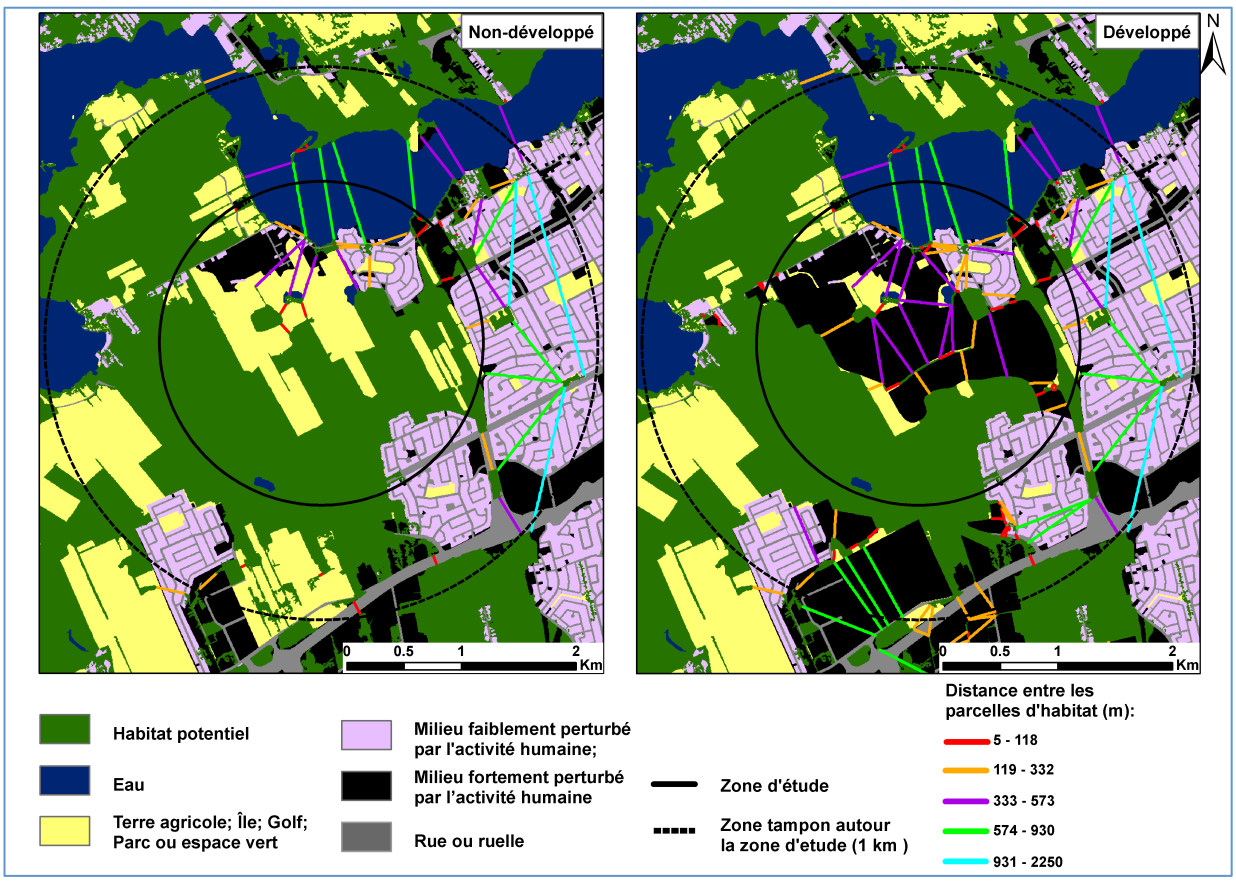

Figure 6 Structural fragmentation within the 1 km buffer. In the right panel we notice an important loss in habitat and an increased forest fragmentation. Due to the increased number of habitat fragments resulting from development, more links are required to connect the fragments. These straight-line links do

not reflect potential movement costs associated with different land use types (see section on functional connectivity below).

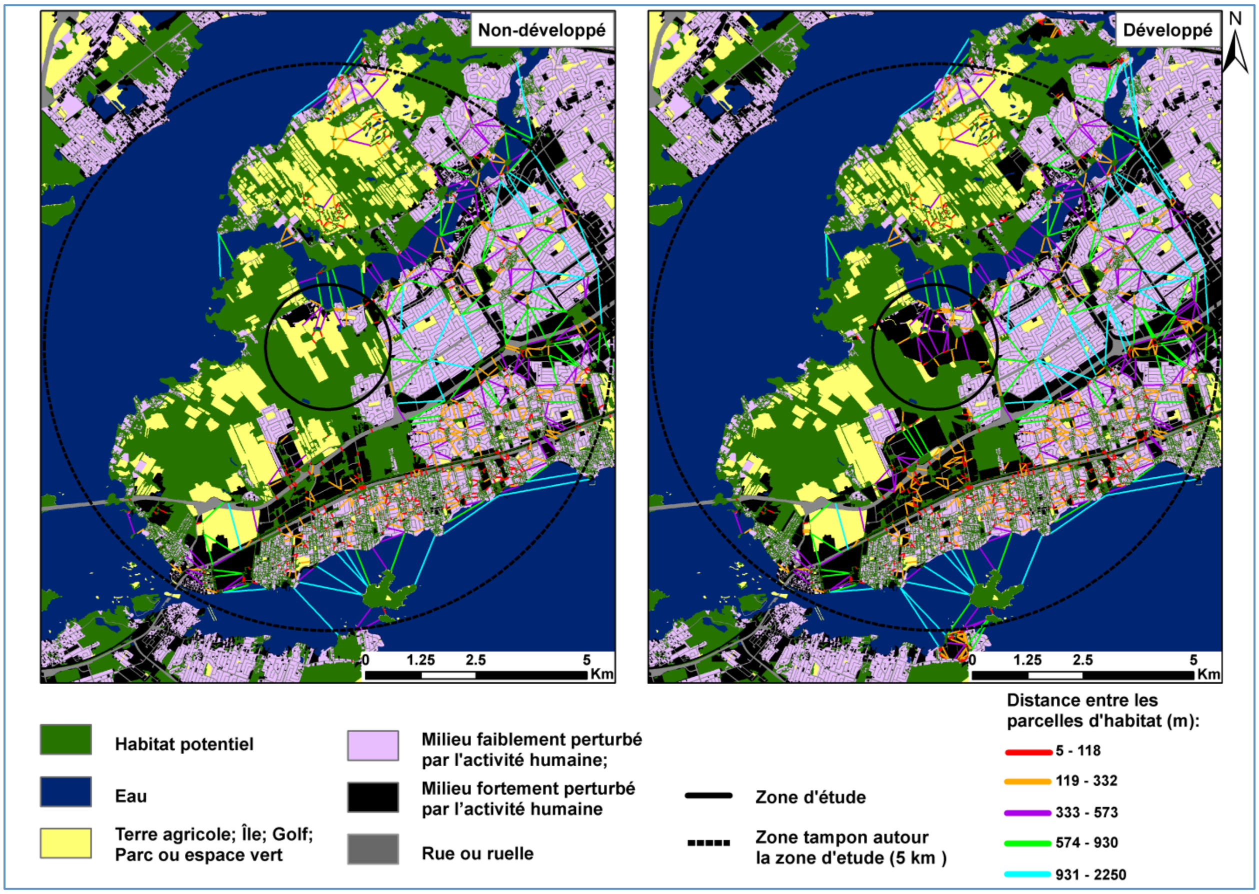

Figure 7 Structural fragmentation within the 5 km buffer. In the developed land use scenario (right panel) the fragmentation increases more at the north and south part of the l'Anse-à-l'Orme sector (the big forest patch in the middle of the study area) where most of the development would take place.

C. Functional connectivity

The increased structural fragmentation under the development scenario results in decreased functional habitat connectivity for all focal species groups. Low and intermediate dispersers (i.e. amphibians, reptiles, small mammals, and small birds) lose the most functional connectivity compared with high dispersers (i.e. large mammals). All species experience a larger decrease in functional connectivity at the 1 km buffer scale.

Habitat networks with least-cost links are dramatically altered within the 1 km buffer by development (Figs. 8, 9). For example, a central habitat patch within the proposed development area becomes functionally isolated from the surrounding habitat for almost all species groups under the developed land use scenario (Figs. 8, 9). Habitat connectivity is also altered at the broader spatial scale by development (Figs. 10, 11). Connectivity along the North-South axis is much weaker under the developed scenario which impacts the potential for species to move among habitat patches in the Morgan Arboretum, Parc-agricole du Bois-de-la-Roche, Parc-nature du Cap-Saint Jaques, and Ile Bizard. In the development scenario, potential N-S movement is channelled along the north-western shore of Montreal Island which may act as a bottleneck, limiting habitat connectivity for multiple species (Figs 10, 11).

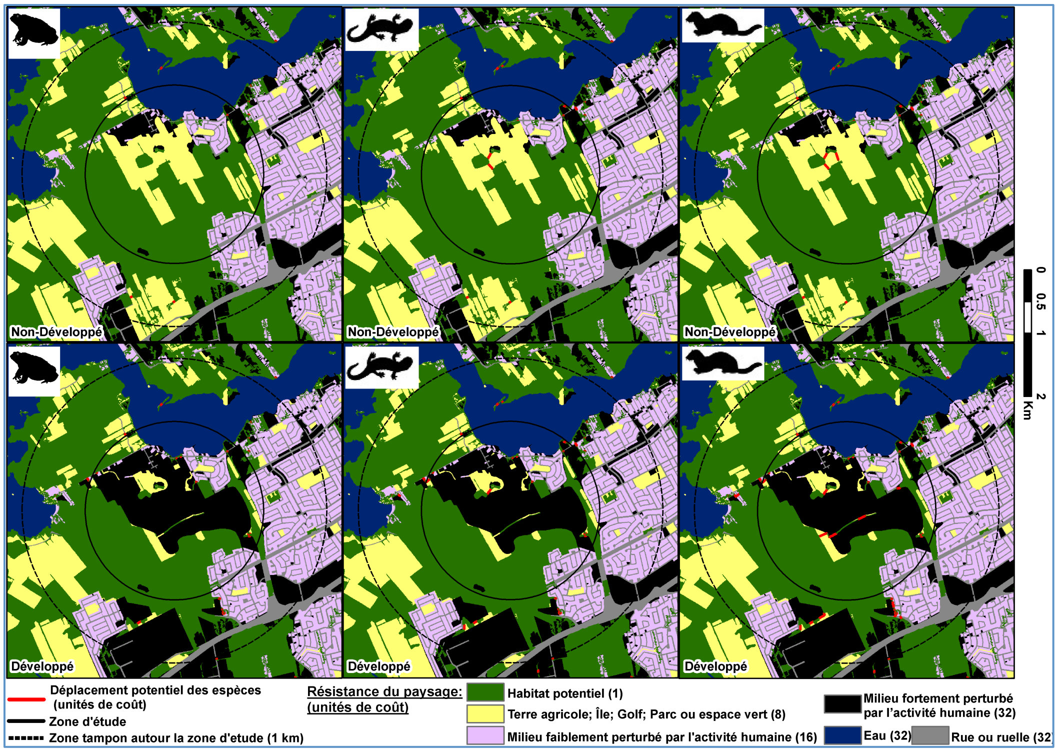

Figure 8 Habitat networks with least-cost links for amphibians, reptiles, and small mammals within the 1 km buffer under the undeveloped (top row) and developed (bottom row) scenarios.

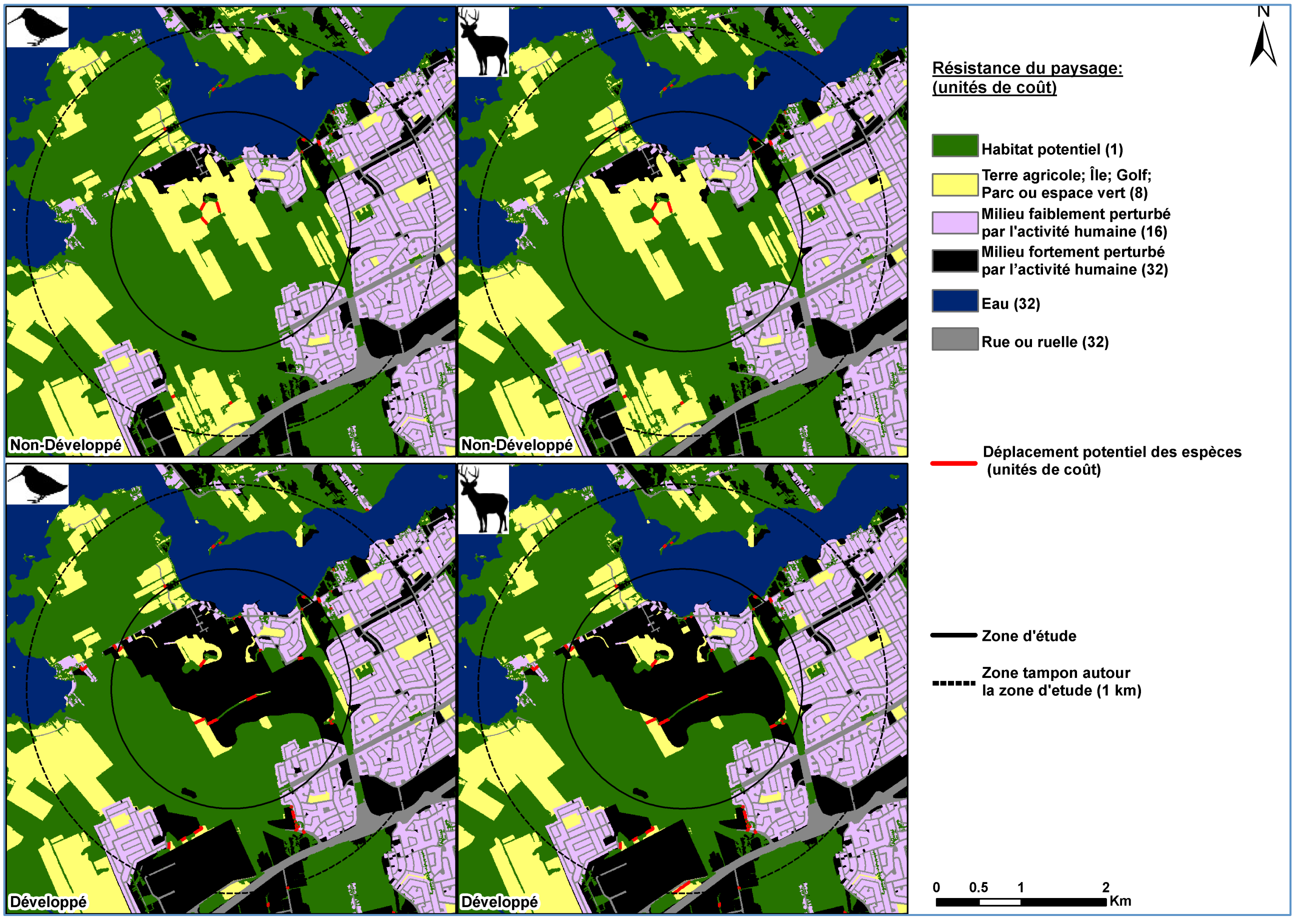

Figure 9 Habitat networks with least-cost links for birds and large mammals within the 1 km buffer under the undeveloped (top row) and developed (bottom row) scenarios.

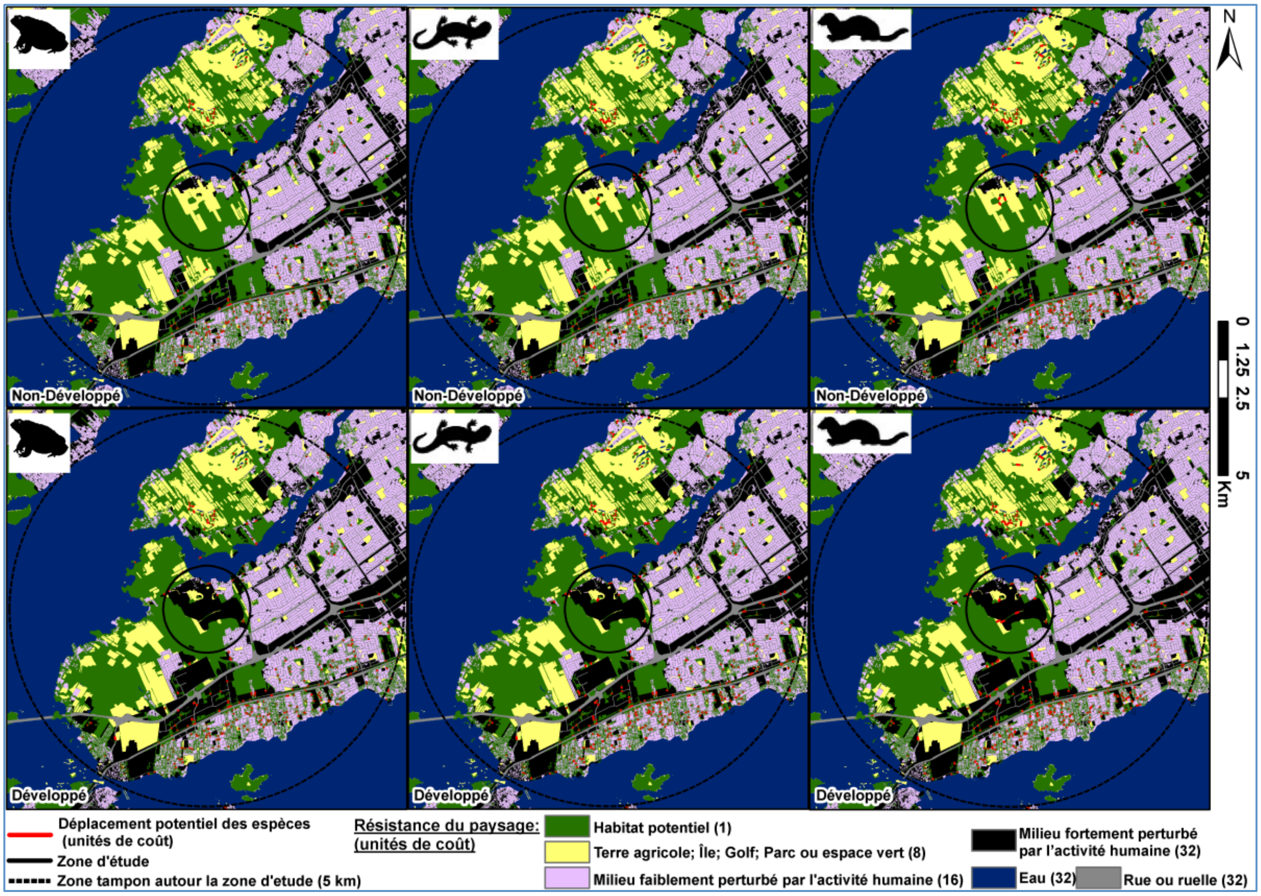

Figure 10 Habitat networks with least-cost links for amphibians, reptiles, and small mammals within the 5 km buffer under the undeveloped (top row) and developed (bottom row) scenarios.

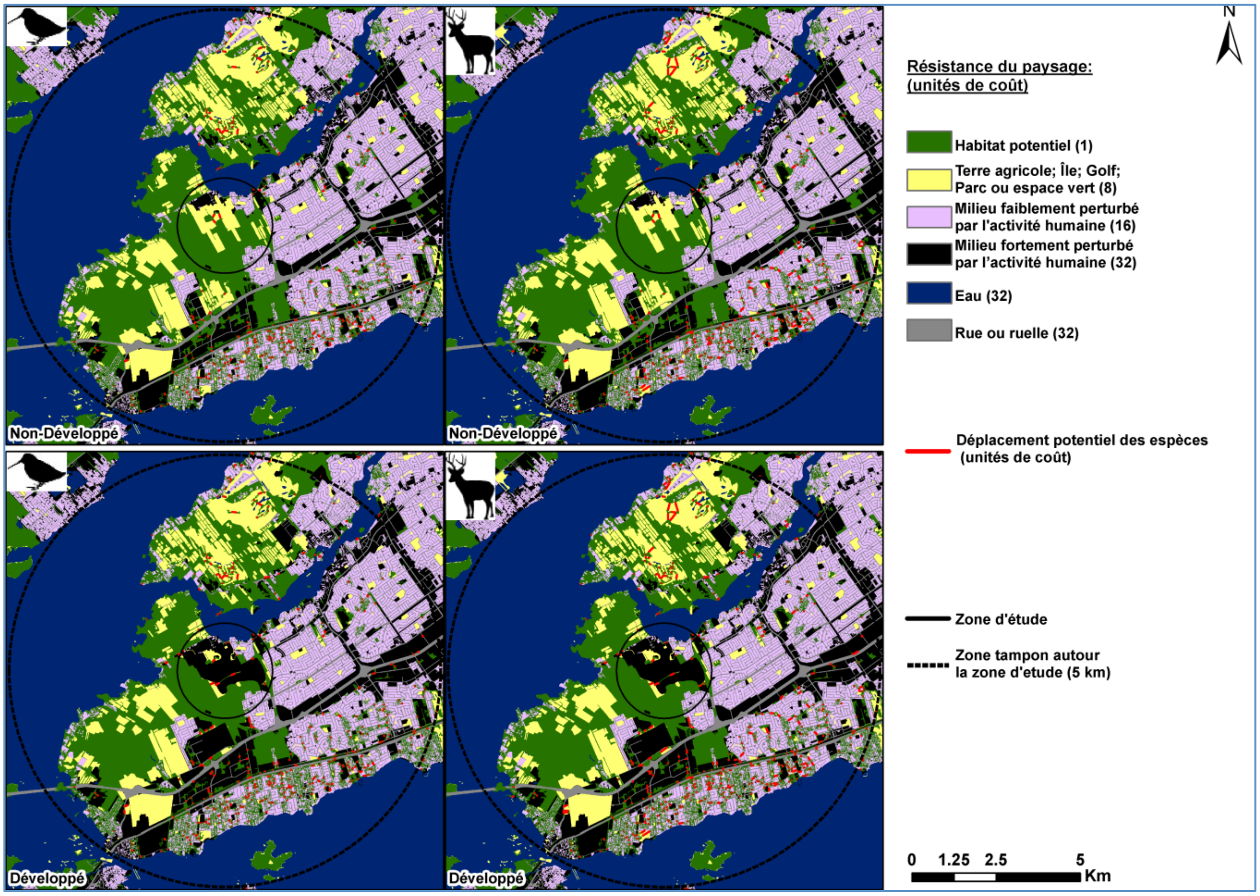

Figure 11 Habitat networks with least-cost links for birds and large mammals within the 5 km buffer under the undeveloped (top row) and developed (bottom row) scenarios.

These habitat networks based on least-cost links were robust to the resistance value assigned to the development class in the developed scenario. We ran a sensitivity analysis to compare the networks based on a development resistance value of 32 and 16, and found no major differences between the resulting habitat networks.

Habitat network connectivity metrics confirm the spatial connectivity patterns seen across species' habitat networks with and without development (Figures 12 to 15). The number of clusters, representing isolated groups of patches, increases for all species under development. The dispersal limited species undergo the greatest increase in isolated clusters under the development (an increase from 15 to 35 clusters due to development within the 1 km buffer; Figure 12). The expected cluster size (ECS), which is similar to the average accessible habitat area within clusters, decreases for all species under development. Intermediate dispersers undergo a **decrease of approximately 14% in ECS** within the 1 km buffer (Figure 13). When the loss of within-patch connectivity due to the loss of habitat (Deslauriers et al., in prep.) is included in the calculation of ECS, then the overall loss in connectivity amounts to approximately 27% within the 1 km buffer (not shown in Fig. 13).

In both developed and undeveloped scenarios, the habitat network becomes connected, i.e. a single cluster, at the threshold of 10,850 cost units for 1 km buffer and 17,500 cost units for 5 km buffer. Therefore, the network is not fully connected even for large mammals that have an average dispersal distance of 2,250 m (one cost unit corresponds to 1 m movement distance at resistance of 1). Note that the functional connectivity analyses included all habitat patches that intersected the 1 and 5 km buffers. Habitat patch areas were not clipped within the buffers to better reflect the amount of functionally connected habitat at these scales. The structural fragmentation metrics (e.g. total habitat and mean patch size; Tables 2 and 3) were based on patches clipped within the buffers.

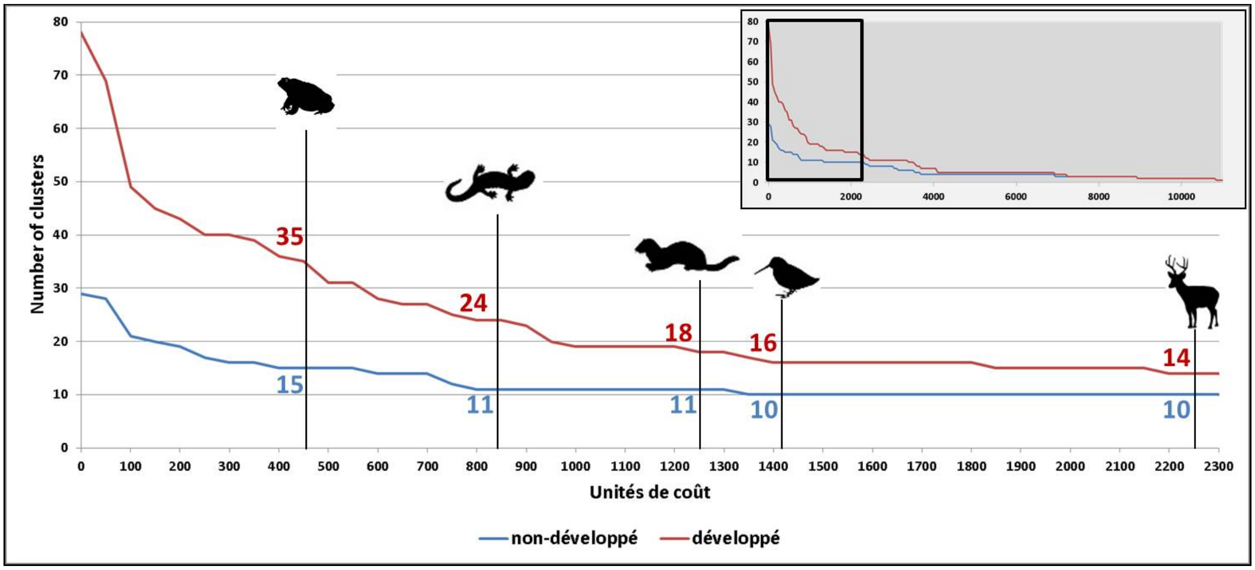

Figure 12 Number of clusters per group of species within the 1 km buffer based on their average dispersal distance: 460 m for amphibians; 845 m for reptiles; 1,250 m for small mammals; 1,421 m for birds; and 2,250 m for large mammals. The area becomes fully connected, i.e. one cluster, at 10,850 cost units (see figure inset)

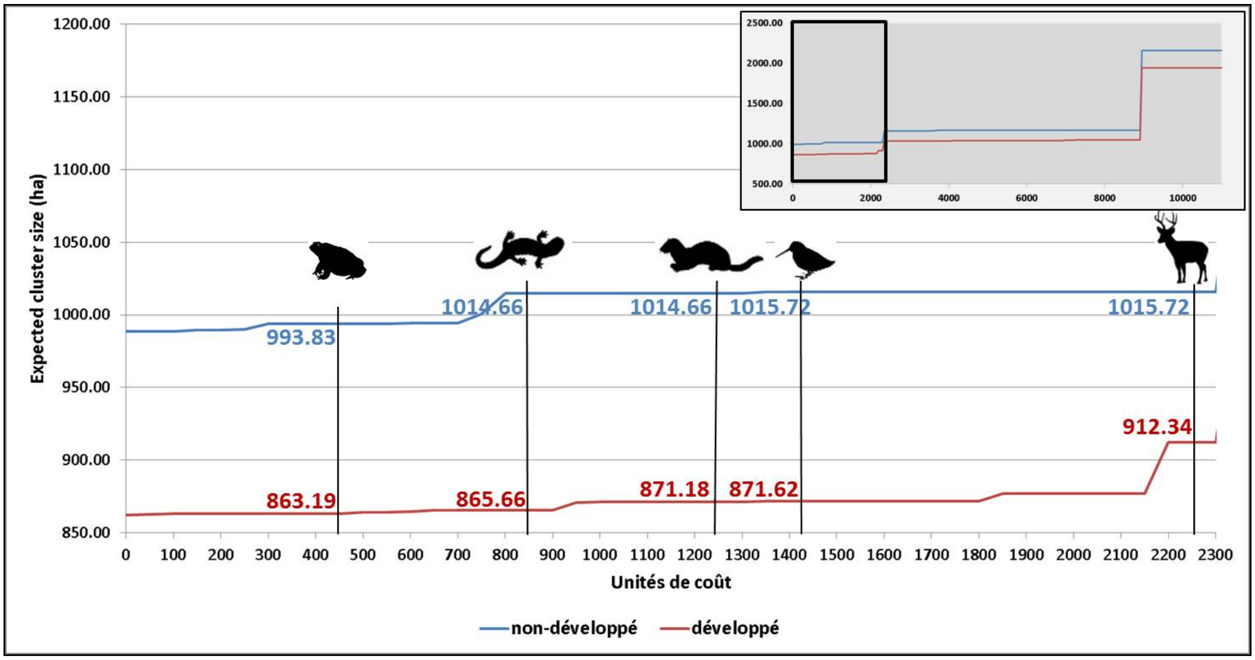

Figure 13 Expected cluster size (ECS) per group of species within the 1 km buffer based on their average dispersal distance: 460 m for amphibians; 845 m for reptiles; 1,250 m for small mammals; 1,421 m for birds; and 2,250 m for large mammals. At 10,850 cost units, the network is fully connected and the ECS is 2,156.47 ha in the undeveloped scenario and 1,941.46 ha in the developed scenario, corresponding to the total habitat area in each scenario (see figure inset).

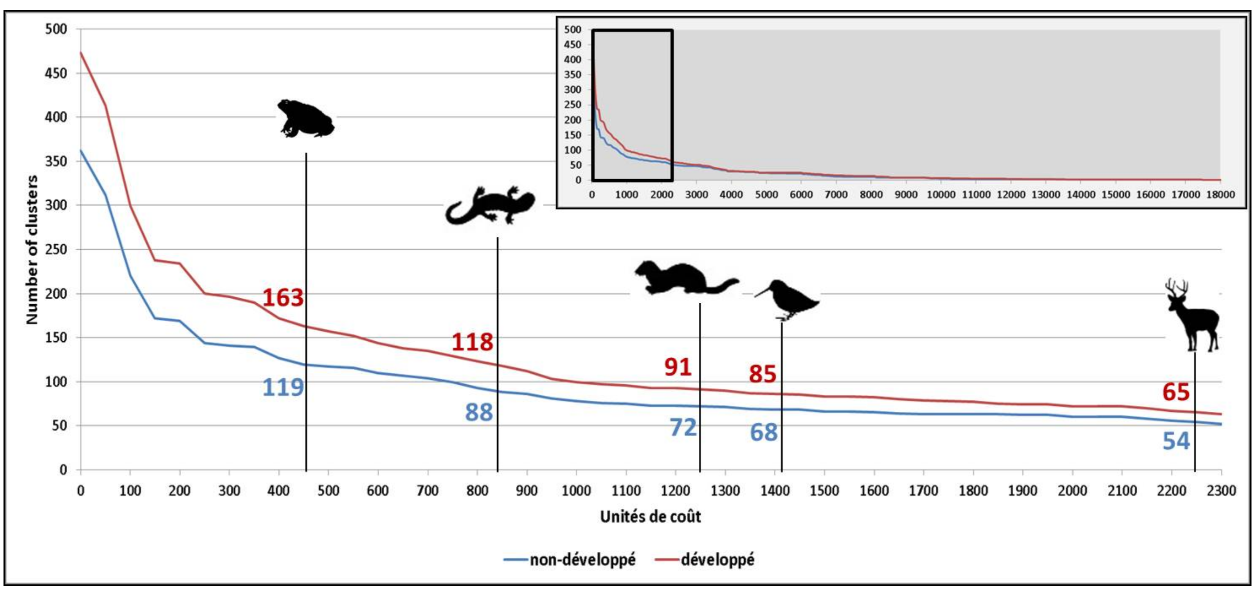

Figure 14 Number of clusters per group of species within the 5 km buffer based on their average dispersal distance: 460 m for amphibians; 845 m for reptiles; 1,250 m for small mammals; 1,421 m for

birds; and 2,250 m for large mammals. The habitat network becomes fully connected, i.e. one cluster, at 17,500 cost units (see figure inset).

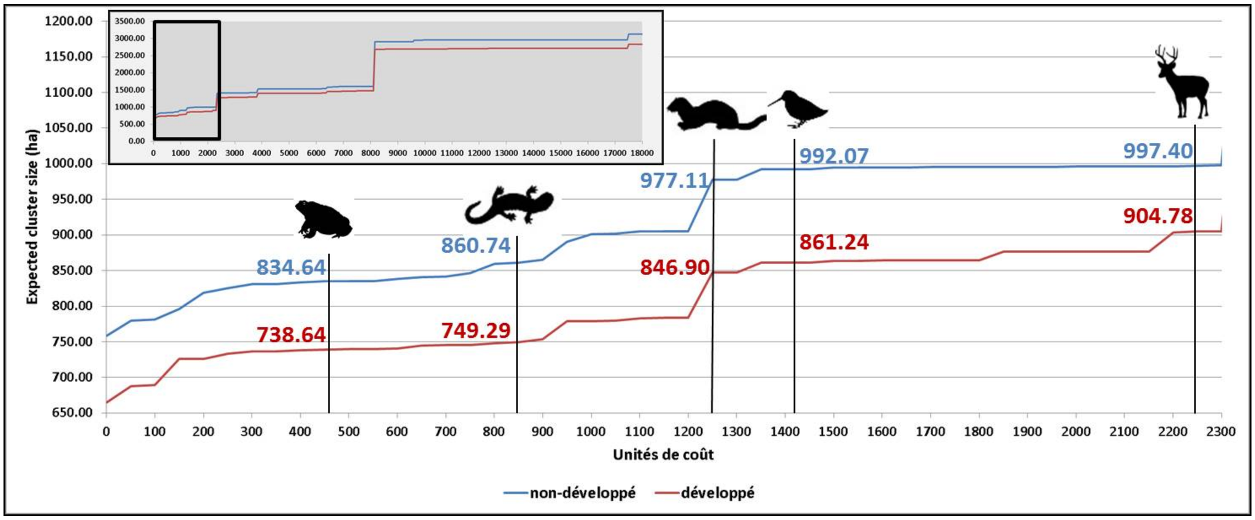

Figure 15 Expected cluster size (ECS) per group of species within the 5 km buffer based on their average dispersal distance: 460 m for amphibians; 845 m for reptiles; 1,250 m for small mammals; 1,421 m for birds; and 2,250 m for large mammals. At 17,500 cost units, the network is fully connected and the ECS is 3,125.98 ha in the undeveloped scenario and 2,824.71 ha in the developed scenario (see figure inset)

VI. Conclusions

Development in the study area will significantly impact terrestrial biodiversity through a loss of habitat, an increase in landscape fragmentation, and a decrease in functional habitat connectivity. We analyzed the impacts of the proposed development on the habitat networks of five groups of species with different dispersal abilities at the scales of 1 and 5 km buffers around the proposed development area. The effects of development were most pronounced within the 1 km buffer for all species but are also considerable at the scale of the 5 km buffer. Within the 1 km buffer, approximately 120 ha (16%) of habitat will be lost due to development and the remaining habitat fragments will be 56% smaller on average. This habitat loss and structural fragmentation translates into reduced functional habitat connectivity for all species groups. The number of isolated groups of patches (i.e. clusters) increases substantially under the development scenario for all species, particularly for the amphibians due to their poor dispersal abilities. The average area of clusters (i.e. expected cluster size) decreases due to development for all species, as much as 14% for species groups with intermediate dispersal abilities such as reptiles, small mammals, and small birds. Accordingly, the overall loss in connectivity is about 27% for this group of species. Within the 5 km buffer, we see a pattern of decreased north-south connectivity between the Morgan Arboretum and Ile Bizard due to development. We conclude that the proposed development will have a significant detrimental impact on the terrestrial biodiversity at multiple scales.

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