Final Report

Results and recommendations towards a conservation plan for the Town of Hudson

January 2020

From:

eco²urb

To:

HUDSON

Eco2urb: The Company

Eco2urb's mission is to apply the latest research in ecology and ecological economics to facilitate conservation planning at local, regional or larger scales.

Professors Dupras, Gonzalez and Messier launched Eco2urb to meet a growing demand for their approach to the analysis and management of biodiversity, habitat connectivity and the ecological services supplied by natural ecosystems and urban green infrastructure. Among the different services offered, Eco2urb provides a holistic approach to the management of landscapes and natural resources, namely by using innovative modelling software and providing targeted recommendations aimed at fostering ecosystems' resilience through diversity and connectivity.

Eco2urb combines nature-based solutions and approaches to support efforts to protect and restore ecosystems. The team places particular emphasis on long-term planning that counters the risks arising from climate change using nature-based solutions.

We offer innovative approaches to the **development of a conservation plan**, and we place special emphasis on **long-term planning** accounting for the changing risks associated with different scenarios of **land-use and global environmental change**.

Project Team

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Executive summary

Global climate change, land development and the arrival of insects or exotic diseases pose great challenges to biodiversity and ecosystems, especially in urbanized areas. Natural ecosystems provide a range of benefits that support human well-being. These services include social, economic and environmental benefits. For example, a diverse forest canopy can improve air quality, buffer extreme temperatures and support animal diversity. To maintain the provisioning of these services and to reconcile the conservation of natural infrastructure with demographic pressures, a streamlined approach for prioritizing the protection of natural areas is required. Such an approach seeks to foster resilience through supporting the biodiversity and landscape connectivity of natural areas.

The work and the findings summarized in the following report aim to support the Town of Hudson in prioritizing natural areas for conservation in terms of their contribution to biodiversity, forest resilience, integrity, ecosystem services, ecological connectivity, recreation and history. To this end, Eco2urb conducted field surveys, estimated values for a range of characteristics relevant for the prioritization of natural areas and developed a range of land-use change scenarios in collaboration with citizens and members of the Town's administration and council. Certain key elements of interest emerge from this extensive work, namely the importance of maintaining and expanding the network of blue-green corridors naturally found within Hudson due to its waterways and surrounding green infrastructure. This would contribute to supporting biodiversity while providing essential ecosystem services in suburban contexts. The following report also provides recommendations to steer conservation efforts, which include guidelines such as:

- Conserving wetlands to improve overall tolerance to waterlogging, especially in the flood zone along the Ottawa River.
- Promoting tree functional group diversity to improve forest resilience.
- Favoring a range of forest management practices (e.g. planting, selective harvests) that contribute to stand- and landscape- level habitat diversity.
- Focusing conservation efforts on forests with higher levels of functional diversity.
- Focusing restoration efforts on forests with poor resilience.
- Sensitizing residents as to vectors of invasion for exotic pests and diseases (e.g. firewood), and on how to identify main biotic threats.
- Restore blue-green corridors between fragmented habitat patches.
- Conserve fragments of quality habitat that can serve as steppingstones facilitating animal movement.
- Protect ecological corridors essential to biodiversity.

Table of Contents

1. Introduction 9
  1.1. Global drivers of environmental change 9
  1.2. Ecosystem services and their importance to society 9
  1.3. Diversity and connectivity for resilience planning 9
  1.4. Context of work and objectives 10
2. Methods 12
  2.1. Outline of Methodology 12
  2.2. Study Area 13
  2.3. History and Demographics 13
  2.4. Natural landscape 14
  2.5. Acquisition of reference data 14
    2.5.1. Reference datasets 14
    2.5.2. Data consolidation and landscape classification 15
    2.5.3. Data validation 17
  2.6. Calculation of conservation indices 21
    2.6.1. Biodiversity 21
    2.6.2. Landscape connectivity 22
    2.6.3. Forest integrity 23
    2.6.4. Forest resilience 23
    2.6.5. Ecosystem services 25
    2.6.6. Recreation and history 26
  2.7. Conservation prioritization 26
  2.8. Land use simulations 28
    2.8.1. Historical land use change 28
    2.8.2. Future land use change 28
  2.9. Municipal and citizen workshops 31
    2.9.1. Workshop 1: Hudson’s administrative council 31
    2.9.2. Workshop 2: Hudson’s citizens 31
3. Results 33
  3.1. Green space composition and configuration 33
  3.2. Summary of field sampling campaign 34
    3.2.1. Composition in sampled sites 35

3.3. Biodiversity, ecosystem services and landscape connectivity ... 36
3.3.1. Biodiversity ... 36
3.3.2. Landscape connectivity ... 39
3.3.3. Forest integrity ... 44
3.3.4. Forest resilience ... 48
3.3.5. Ecosystem services ... 56
3.3.6. Recreation and history ... 58
3.4. Workshops ... 60
3.4.1. Workshop with Town's council and administration ... 60
3.4.2. Workshop with Town residents ... 62
3.5. Synthesizing conservation priorities ... 63
3.5.1. Conservation priority scenarios ... 63
3.6. Landscape Modelling ... 66
3.6.1. Historical development and population trends ... 66
3.6.2. Landscape scenarios ... 69
3.7. Forecasting changes in future connectivity and ecosystem services ... 75
3.7.1. Changes in local connectivity according to development scenarios ... 75
3.7.2. Changes in ecosystem services and biodiversity according to development scenarios ... 76
3.8. Synthesizing results ... 78
4. Discussion and recommendations ... 80
4.1. Synthesis and recommendations ... 80
4.1.1. Biodiversity ... 80
4.1.2. Connectivity ... 82
4.1.3. Integrity ... 83
4.1.4. Forest resilience ... 84
4.1.5. Ecosystem services ... 85
4.1.6. Recreation and history ... 86
4.2. Conservation Tiers ... 87
4.2.1. Tier 1: Core conservation areas ... 87
4.2.2. Tier 2-3: Buffer forest areas ... 88
4.2.3. Tier 4: Regional planning priorities ... 89
4.2.4. Tier 5: Remaining forests ... 90
4.3. Funding conservation planning ... 90

5. Conclusion 91
6. References 92

List of Figures

Figure 1. Analytical workflow 12
Figure 2. Delimitation of the Town of Hudson, its districts and urban core (A), as well as its location in the context of the Montreal Metropolitan Community (B). 13
Figure 3. Population and household trends in Hudson since 1990 14
Figure 4. Diagram of LULC change model. Arrows indicate the transitions between LULC classes (boxes), including: urbanization (grey arrows), forest regeneration (green arrow), agricultural set aside (orange arrow) and forest loss due to agricultural expansion (yellow arrow) 29
Figure 5. Map of Hudson summarizing its trail network, main natural landscape cover and reference points. 33
Figure 6. Distribution of sampling sites across Hudson's natural areas. 35
Figure 7. Summary of species composition for upland forest sites. Percentages represent the proportion of the total basal area measured across all forest sites. Coniferous species are in dark green and deciduous species in light green. 35
Figure 8. Summary of species composition for forested wetlands. Percentages represent the proportion of the total basal area measured across all forest wetland sites. Coniferous species are in dark green and deciduous species in light green. 36
Figure 9. Distribution of bird observation hotspots across Hudson's territory. 37
Figure 10. Distribution of herpetofauna within the municipality of Hudson. 38
Figure 11. Distribution of rare species observations within the territory of Hudson for observations made between 2009 and 2014. 39
Figure 12.Ranking of natural areas according to their importance to regional connectivity within the Saint-Lawrence Lowlands. Source data were originally taken from Rayfield et al. (2019). 39
Figure 13. Ranking of natural areas according to their importance to regional connectivity. Panel A is set to the Vaudreuil Soulanges RCM and panel B the full study extent of the Saint-Lawrence Lowlands. Source data were taken from Rayfield et al. (2019). 40
Figure 14. Ranking of natural areas according to their importance to local connectivity in Hudson. 41
Figure 15. Circuit connectivity analysis results for five focal species, including a) black bear, b) wood frog, c) American pine marten, d) red-backed salamander, e) Northern short-tailed shrew. 42
Figure 16. Betweenness connectivity analysis results for five focal species, including a) black bear, b) wood frog, c) American pine marten, d) red-backed salamander, e) Northern short-tailed shrew. 43
Figure 17. Distribution of forest maturity across the natural landscape in Hudson. 44
Figure 18. Relationship between diameter at breast height (DBH) and age class for upland forests (top) and forested wetlands (bottom). 45
Figure 19. Distribution of average and maximum DBH across all sites in upland forests (top) and forested wetlands (bottom). 45
Figure 20. Distribution of the integrity of forests across the territory of Hudson. 47
Figure 21. Distribution of exotic species across Hudson. Note that areas with darker colors have higher exotic species coverage. 48
Figure 22. Distribution of tree functional diversity across Hudson's landscape. 50

Figure 23.. Distribution of the forested landscape's simulated vulnerability to future biotic threats. 53
Figure 24.. Distribution of the forested landscape according to waterlogging tolerance. 54
Figure 25. Distribution of Hudson's forested landscape according to drought tolerance. 55
Figure 26. Distribution of forested areas most susceptible to urban and rural expansion. 56
Figure 27. Distribution of Hudson's forested landscape according to its importance for flood mitigation. 57
Figure 28. Distribution of Hudson's forested landscape in terms of its importance for carbon storage. .. 58
Figure 29. Distribution of Hudson's forested landscape in terms of its importance for recreation. 59
Figure 30. Distribution of Hudson's forested landscape in terms of its historical importance as prescribed by the Hudson administration and town council 59
Figure 31. Ranking of Hudson's natural areas in terms of their priority for conservation as determined by the town's administration 63
Figure 32. Ranking of Hudson's natural areas in terms of their priority for conservation as determined by the town's citizens. 64
Figure 33. Consensus prioritization of Hudson's natural areas for conservation as per municipal and citizen rankings. 65
Figure 34.Historical and projected urban development area from 1880 to 2070. 67
Figure 35. Natural areas protected under each land use scenario are highlighted in orange. The percentage of the total surface area of the landscape protected is given to the right of each subfigure. 68
Figure 36.Projected land use composition following Business-as-usual and two workshop scenarios. 69
Figure 37. Summary of changes in land use for scenarios a) initial conditions in 2020, b) business-as-usual, c) transit oriented and d) service oriented development. 70
Figure 38. Projected changes in landscape composition for each land use change scenario. 71
Figure 39. Summary of changes in land use for Eco2Urb scenarios, including a) initial conditions in 2020, b) 25% protected, c) PMAD priority areas, d) VS-RMC priority areas 72
Figure 40. Projected changes in landscape composition for each land use change scenario. 73
Figure 41. Summary of changes in land use for Eco2Urb scenarios, including a) initial conditions in 2020, b) 25% protected, c) 20% protected, d) 30% protected. 74
Figure 42. Summary of the different land use change scenarios and their impacts on two connectivity (betweenness, cumulative current) and two habitat availability (habitat patch, suitability) metrics. 75
Figure 43. Average loss for all the measured variables for each of the different land use change scenarios. 76
Figure 44. Average loss for all the measured variables for each of the different land use change scenarios. 77
Figure 45. Synthesized conservation priority tiers as established through the analysis. Tier 1 areas have the highest priority 79

List of Tables

Table 1. Land use – land cover (LULC) classes adapted from Rayfield et al. (2019) and their equivalencies and descriptions used to classify Hudson's land cover. 16
Table 2. Summary of criteria evaluated across upland forest sites. References used include MFFP (2016), GENIVAR (2016) and Martins et al. (2016). 18
Table 3. Summary of criteria evaluated specific to wetlands. References used include Bazoge et al. (2014) and Martins et al. (2016). 19

Table 4. Themes and interpretations for conservation indices, classed as continuous (C), discrete (D) or categorical (CA). 20
Table 5. Functional groups determined according to similarities in functional traits among species found in Hudson's forests. 24
Table 6. Description of land use change scenarios. 30
Table 7. List of activities hosted at the workshop and their descriptions. 32
Table 8. Composition of natural landscape in Hudson. 34
Table 9. Age classes assigned to forests and forested wetlands. Percent values were calculated according to the total surface area of forested areas in Hudson (743 ha), excluding open wetlands. 44
Table 10. Anthropogenic disturbance classes assigned to upland forests and forested wetlands. 46
Table 11. Natural disturbance classes assigned to forests and forested wetlands. 46
Table 12. Exotic species cover classes assigned to forests and forested wetlands. 47
Table 13.Tree functional diversity classes assigned to upland forests and forested wetlands. Classes are defined in terms of the weighted percentage of functional groups present at each site with a total possible score of eight (e.g. 1.5/8=19%). 48
Table 14. Basal area percentage for each functional group and vegetation type. 49
Table 15. Summary of already-established biotic threats to the integrity of Hudson's forested areas. Information retrieved from Lovett et al. (2016) and the Ontario Invading Species Awareness Program. 51
Table 16. Summary of not-yet established biotic threats to the integrity of Hudson's forested areas. Information retrieved from Lovett et al. (2016) and the Ontario Invading Species Awareness Program. 51
Table 17. Summary of the forested area affected by biotic threats for each vegetation type. Percentage values are expressed in terms of the total amount of forested areas in Hudson including forested wetlands. Threats currently observed in Hudson are in in bold. 52
Table 18.Waterlogging tolerance classes assigned to forests and forested wetlands. Classes are defined in terms of waterlogging tolerance on a scale from 0 to a maximum of 1 and evenly distributed among three tolerance classes (low, medium, high). 53
Table 19.Drought tolerance classes assigned to forests and forested wetlands. Classes are defined in terms of drought tolerance on a scale from 0 to a maximum of 1 and evenly distributed among three tolerance classes (low, medium, high). 54
Table 20. Summary of the forested area susceptible to development. Percentage values are expressed in terms of the total amount of forested areas in Hudson including forested wetlands. 55
Table 21. Area distribution of forested areas, including forested wetlands, at increasing distances from the flood zone. 56
Table 22. Mean density of carbon stored per vegetation type. 57
Table 23. Total carbon stored per vegetation type. 58
Table 24. Summary of ranks assigned to ecological characteristics by members of Hudson's administration and council. The consensus column represents the average between the two ranks and was ultimately used in the analysis (Section 3.5.1). 62
Table 25. Land use transition rates in Hudson. 66

1. Introduction

The Town of Hudson mandated Eco2urb to prepare a conservation plan for its natural areas given growing development pressures and a concern for preserving biodiversity, ecosystem services and landscape connectivity. The current report builds off previous work conducted by Teknika HBA (2008) and CIMA+ (2016). We use previously acquired data, current forest inventories and innovative landscape models to prioritize natural areas for conservation and ensure their resilience.

1.1. Global drivers of environmental change

Global drivers of environmental change pose a significant challenge to natural resource management. Climate change threatens the capacity of society and ecosystems to adapt to novel environmental conditions (Djalante and Thomalla 2011; Thompson et al. 2009), such as heavy precipitation and flooding. Uncertainty inherent to climate change further complicates land use planning, as do possible interactions with other environmental stressors such as invasive species, animal pests and disease.

Many of the challenges faced by the Town of Hudson, Quebec, are expected to grow in severity in the next century. A 3.1°C increase in mean annual temperature is predicted for the municipality by year 2070 under a high carbon emissions scenario, which is expected to lead to more frequent flooding and drought events (Ouranos 2019). Invasive pests and diseases, such as the emerald ash borer (*Agrilus planipennis*), are already impacting Hudson's urban canopy. Additional accidental imports, such as the Asian longhorned beetle (*Anoplophora glabripennis*), have been recorded in southern Ontario and threaten the integrity of the Town's forested ecosystems (NRC 2019). Habitat fragmentation caused by urban development facilitates the widespread propagation of exotic plants that displace native species (Fischer and Lindenmayer 2007; Fahrig 2003). In a context of urban expansion and global environmental change, science-based solutions are needed to help maintain key natural areas, biodiversity and ecosystem services (e.g. climate regulation, flood control, recreation).

1.2. Ecosystem services and their importance to society

The concept of ecosystem services is widely used to define and categorize contributions that natural areas make to people. They include provisioning services (e.g. supplying food and water), regulating services (e.g. buffering the effects of climate fluctuations), supporting services (e.g. producing oxygen), and cultural services (e.g. recreation; Millenium Ecosystem Assessment 2005). Ecosystem services are now increasingly quantified by landscape managers to compare the impacts of different urban planning alternatives on human well-being during this time of climate transition (Gómez-Baggethun and Barton 2013; Niemelä et al. 2010)

1.3. Diversity and connectivity for resilience planning

Maintaining ecosystem services when faced with global drivers of environmental change depends on strategic conservation planning that maximizes the resilience of natural areas. Resilience, in this context, is understood as the ability of an ecosystem to recover following a disturbance and reassume its initial "state" (Thompson et al. 2009). For instance, a forest that is burnt down following a fire changes from a "forested" state to a "cleared" state. Fire-resistant trees and seeds can quickly recolonize and return the site to its initial forested state given some time, a hallmark of a resilient ecosystem. Biodiversity can provide a form of ecological insurance policy against possible sources of environmental risks; a diverse forest canopy has a greater chance of featuring species with traits (e.g. fire resistance) less vulnerable to a given risk (e.g. drought) than a less diverse forest (Thompson et al. 2009). Having been extensively planted between the mid-1960s to mid-1990s with ash (*Fraxinus*) trees, the urban forest of the City of Montreal will likely be significantly more impacted by the arrival of the emerald ash borer (*Agrilus planipennis*) than if urban forest planners had favored a diversified assemblage of tree species (Maure et al. 2018). Taking measures to increase the ability of natural areas to resist and adapt to environmental stressors, such as diversifying forest composition, is both an essential and cost-effective means of preparing landscapes for the unpredictable impacts of environmental change.

Resilience planning is an approach that aims to optimize an ecosystem's ability to resist and recover from disturbance. It ensures a natural area's ability to keep providing ecosystem services despite environmental stressors such as invasive pests and disease, drought, and floods. Resilience planning maximizes an ecosystem's biodiversity (including genetic, species and functional diversity) to better adapt to change.

Our approach to resilience planning focuses on diversification in terms of "functional groups" as opposed to the number of species (Messier et al. 2019). Different maple tree species are sensitive to drought to a similar degree and are part of the same functional group. Oak trees are in a distinct functional group given their greater drought tolerance and are unique in terms of additional functional traits (e.g. tolerance to wind) as well. Ensuring that an ecosystem harbors species with a range of functional traits (e.g. tolerance to waterlogging, tolerance to shade) from distinct functional groups can help reduce its vulnerability to many different environmental risks. The more functional traits present in an ecosystem, the greater the likelihood that a single stressor will not have as widespread an impact (Diaz and Cabido 2001).

Finally, favoring the movement of organisms, seeds and other genetic material (e.g. pollen) between patches of forest ensures that they are functionally connected while contributing to their resilience (Ahern 2011; Gonzalez et al. 2011; Gonzalez et al. 2018). For example, maple dominated stands might benefit from neighboring oak dominated stands if a major drought event was to severely impact maple trees. Connectivity between stands ensures that oak seeds (acorns) can disperse (via rodents or birds) to heavily damaged maple stands ensuring recovery with a better adapted species to future drought events. Resilience planning maintains both high levels of diversity within ecosystems and high connectivity among ecosystems. This requires identifying important and priority ecosystems within a network of conservation corridors at the landscape scale.

1.4. Context of work and objectives

Conserving natural areas in urban environments promotes resilient and connected ecosystems. These concepts are integrated within the Metropolitan Land Use and Development Plan (PMAD) adopted in 2012 by the Montreal Metropolitan Community (MMC). PMAD aims to conserve 17% of the surface area of the MMC, an objective first proposed by the United Nations' Convention on Biological Diversity (CMM 2012; SCBD 2010). Considering this goal, the Town of Hudson has funded research to develop and improve its conservation plan. Namely, in 2008, the town mandated field inventories by the firm Teknika HBA to characterize its natural areas and the distribution of vulnerable species. An initial conservation plan was proposed in 2017 by the firm CIMA+ for the town's urban core. The objective of the collaboration between Eco2urb and Hudson in 2019 was to build on past efforts to prioritize and rank natural areas for conservation across the entirety of the town's natural areas. This prioritization will help inform urban planning initiatives and achieve the objectives set by PMAD, promoting biodiversity, ecosystem services, connectivity and resilience.

Specifically, the objectives of the mandate between Eco2urb and the Town of Hudson are as follows:

- **Collate and validate reference data**

The first objective was to consolidate all existing datasets pertaining to the town's natural areas, including the ranking and classification of the town's wetlands (CIMA+ 2017), proposed ecological corridors and conservation hubs (CIMA+ 2017), as well as ecological characterizations (Teknika 2008). To this we added datasets that assessed habitat suitability for different animal species, land use and cadastral maps, ecosystem services and the distribution of vulnerable plants and wildlife.

- **Produce biodiversity, landscape connectivity and ecosystem service maps**

The second objective was to produce maps summarizing the contribution of landscape elements to biodiversity, connectivity and ecosystem service provisioning. Natural areas were evaluated as a function of habitat suitability for a set of vertebrate species. We identified potential biodiversity hotspots and areas essential to ecosystem services such as carbon storage and flood mitigation.

- **Rank green spaces in terms of their conservation and ecosystem service values**

We used landscape planning software to assign conservation priorities to natural areas in the Town of Hudson. The analytical techniques that we employed helped identify natural areas of high importance for biodiversity, ecosystem services and connectivity. Landscape features were ranked according to their conservation value across different scenarios.

- **Define scenarios of landscape change through workshops and forecast future impacts on conservation priorities**

In collaboration with the Town of Hudson and its citizens, we developed conservation and land use change scenarios through a set of workshops. We calculated the impacts of each scenario on ecosystem services, biodiversity and connectivity.

- **Report findings and make recommendations to the town council**

Finally, our findings are summarized in the present report to support the implementation of a conservation plan by the town. The intention of this report is to present our findings and explain clearly how we obtained them. We do not argue for or favor any particular implementation process.

2. Methods

The following section summarizes the steps and methods used by Eco2urb to characterize and prioritize the Town of Hudson's natural areas for conservation.

2.1. Outline of Methodology

To achieve project objectives, the first step in our analytical workflow (Figure 1) was to compile and consolidate existing datasets pertaining to Hudson's natural areas (Section 2.4). Data were validated and updated through field-based surveys (Section 2.5.3), from which we calculated a set of indices that ranked natural areas in terms of biodiversity, ecosystem service and connectivity metrics (Section 2.6). We modeled land use change for the municipality over a 50-year time horizon and quantified expected impacts on conservation metrics (Section 2.8). We held two separate workshops with the town's administrative council and residents to identify conservation priorities and parameterize land use change scenarios (Section 2.9). We compared our results with those resulting from the protection of priority areas as identified by the Vaudreuil-Soulanges Regional Municipal County (RCM) as well as the MMC (Section 3.6.2). Results were synthesized in the form of a final conservation prioritization map to assist with future landscape planning (Section 3.8).

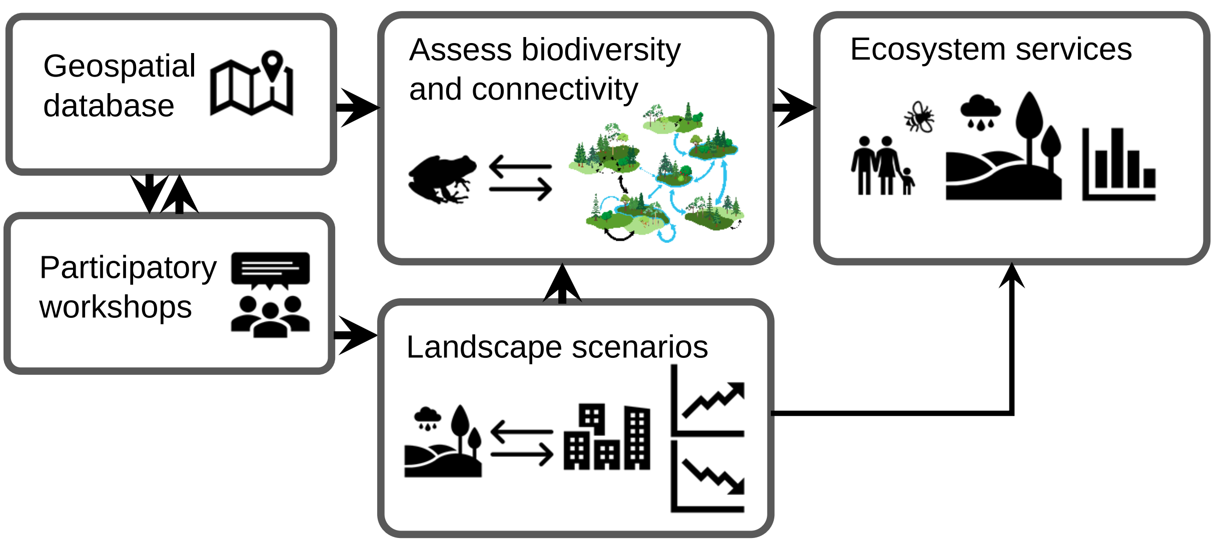

Figure 1. Analytical workflow.

To summarize, the analytical workflow developed in the current document uses geospatial data to quantitatively assess biodiversity, ecosystem services and landscape connectivity. We host participatory workshops to engage the community to envision possible landscape scenarios and strategically plan for different conservation outcomes.

2.2. Study Area

The Town of Hudson is a municipality in the Vaudreuil-Soulanges RCM approximately 60 km west of Montreal in southern Quebec, Canada. The town lies along a widening of the Ottawa River known as the Lake of Two Mountains and has an area just over 2100 hectares.

Our study focuses on all natural areas within the municipal delimitation of Hudson (Figure 2A), including areas zoned as agricultural or urban. The scope of the study builds off previous work conducted by Teknika HBA (2008) and CIMA+ (2017), which either focused on natural areas of interest or those associated with urban core (Figure 2A), respectively.

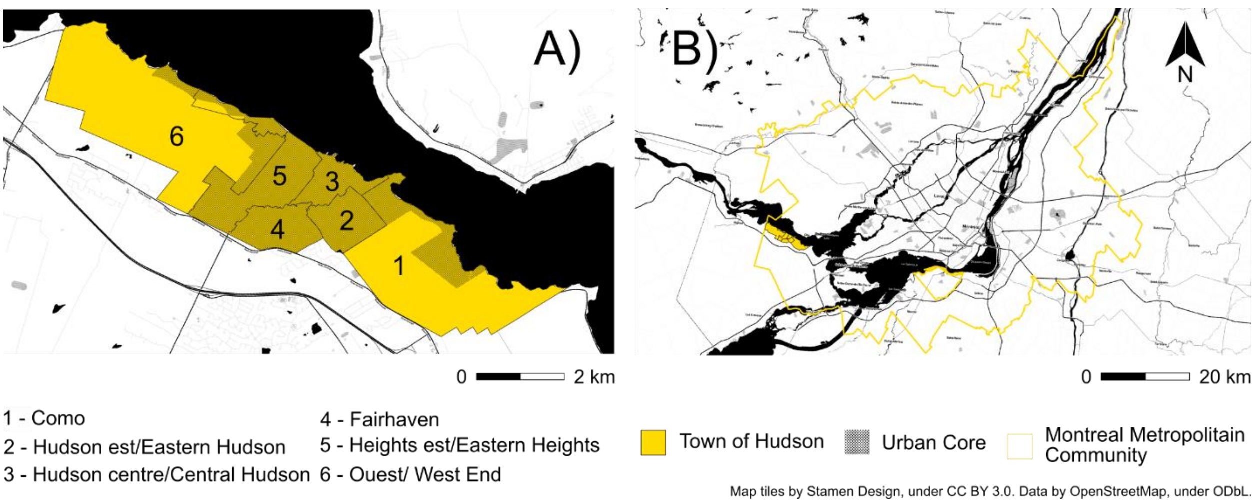

Figure 2. Delimitation of the Town of Hudson, its districts and urban core (A), as well as its location in the context of the Montreal Metropolitan Community (B).

2.3. History and Demographics

First founded in 1877, Hudson's municipal limits only took their current form in 1969. Until that point, the town was subdivided into three different villages: Hudson Heights, Como and Hudson. The population remained stable through the 1970s and 80s at approximately 4300-4400 individuals but has increased sporadically through the 1990s and 2000s (Town of Hudson 2009). Between 1996 and 2016, for instance, Hudson saw an increase in its population by approximately 7.3%, and, as of 2016, had 5185 residents and 2386 households (Statistics Canada 2017). Since 1991, the number of new households in Hudson has increased by at least 511. The ratio between the number of households to the number of residents has been decreasing since the 1990s, suggesting that urbanization is outpacing population increase as fewer people occupy each household than in the past. Projections for population growth in Hudson for the 2016-2036 horizon predict a decrease of 10.7% in the town's population (Institut de la statistique du Québec 2019). Given the town's age structure, urbanization rates, and the number of residential lots currently available, Hudson is expected to undergo modest development (Town of Hudson 2009).

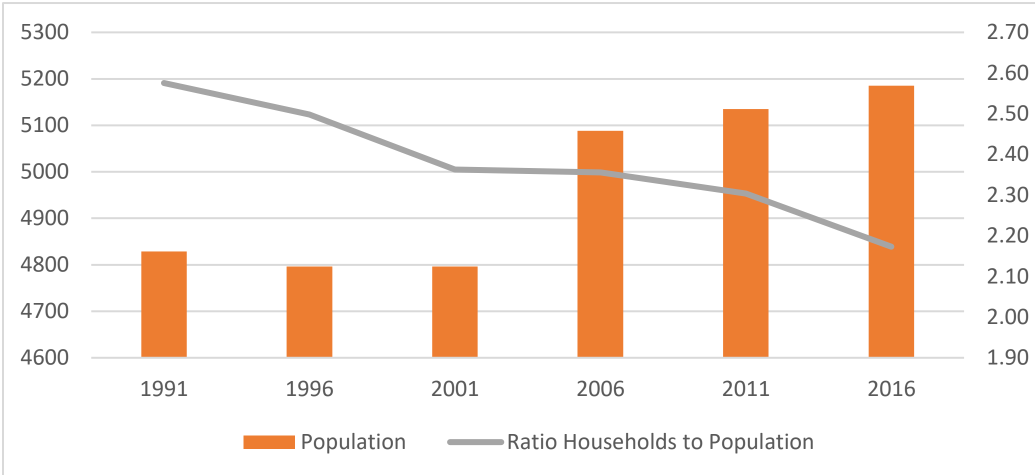

Figure 3. Population and household trends in Hudson since 1990

2.4. Natural landscape

Hudson's soils are predominantly clay or sand; more specifically, the Hudson Heights and central Hudson sectors on located on primarily sandy soils, while the extremities of the town are on clay soils (MAPAQ 2008). Certain exceptions to these trends include the soils along the Viviry valley, which are primarily alluvium, and a pocket of gravelly soils neighboring Parsons Point (MAPAQ 2008). The town's topography is relatively flat, the highest point being the Hudson Heights sector of the town (MAPAQ 2008).

Hudson is located within the sugar maple-bitternut hickory bioclimatic domain, and as such contains many species that are at the northern limit of their range. These species include bitternut hickory (*Carya cordiformis*), shagbark hickory (*Carya ovata*), hackberry (*Celtis occidentalis*) and swamp white oak (*Quercus bicolor*; MFFP 2019a). Most of Hudson's forest cover is deciduous, with the most abundant species being sugar maple (*Acer saccharum*), green ash (*Fraxinus pennsylvanica)*, white pine (*Pinus strobus)* and red maple (*Acer rubrum*). Being a waterfront town, Hudson has many wetlands and tributaries, the most prominent of which is the Viviry River, which runs from the towns of Saint-Lazare and Vaudreuil-Dorion through Hudson to the waterfront where it joins the Ottawa River.

2.5. Acquisition of reference data

Reference data were acquired from various sources and consist of information relating to Hudson's natural landscape. These data are derived from photointerpretation and field sampling and were used as a starting point for subsequent analyses.

2.5.1. Reference datasets

We focused our data acquisition efforts on inventories of plant and animal species, including provincially vulnerable and common species.

2.5.1.1. Vulnerable plants and wildlife

A data acquisition request was filed with the *Centre de données sur le patrimoine naturel du Québec* (CDPNQ) for Hudson's vulnerable plants and wildlife, including a 20-kilometer buffer radius surrounding the town. Transmitted data were originally sourced from herbariums, museums, scientific papers as well as faunal and floristic inventories.

2.5.1.2. Amphibians and reptiles

The Amphibian and Reptile Atlas of Quebec (AARQ) provided georeferenced inventory data on amphibians and reptiles, including vulnerable species present in Hudson. AARQ is a volunteer initiative that provides information about the diversity and distribution of herpetofauna in the province of Quebec. Data can be acquired for a fee by researchers or other professionals.

2.5.1.3. Birds

Georeferenced bird data were downloaded from *eBird*, an online database that compiles observations recorded by both volunteers and scientists. Data acquired from eBird were used to determine key observation points for bird enthusiasts with access to the platform in Hudson.

2.5.1.4. Forests and wetlands

Data regarding the distribution and composition of forests and wetlands in Hudson were taken from multiple sources. More specifically, forest data originate from the fourth ecoforestry inventory conducted by the *Ministère des Forêts, de la Faune et des Parcs* (MFFP) and were downloaded from *Forêt Ouverte*, a regularly updated interactive database. Geospatial layers included information on forest composition, delimitations of various forest stands, as well as natural and anthropogenic disturbances. To these data, we added forest stand polygons delimited by Teknika (2008), which were the same as those used by CIMA+(2017) for the town's urban core. For information on the size and distribution of wetlands on the landscape, data were collated from Ducks Unlimited, CIMA+(2017), the MMC and MFFP (2019b).

2.5.2. Data consolidation and landscape classification

We consolidated data as well as the typology used to classify green space into a database prior to analysis. In doing so, we addressed any discrepancies between the various data sources, especially as it concerned the delimitation of the different vegetation types. MFFP (2019b) and Teknika (2008) forest inventories differed considerably in their delimitation of forested areas, as did the various data sources used for wetland delimitations. In correcting delimitations, we compared them to recent satellite imagery (Google Earth 2018) to ensure their accuracy and favoured those that were supported by field-based validation (e.g. Teknika 2008). We added forests to the dataset when missing and signaled the presence of possible wetlands for data validation (Section 2.5.3). Using contemporary satellite imagery (Google Earth 2018.), cadastral data (Town of Hudson 2019) and geospatial data sources (MFFP 2019b; CIMA+ 2017; Teknika 2008), we delimited additional land cover classes (Table 1) within the entire municipal boundary of Hudson. Land cover maps for the town were used in our connectivity analysis (Section 2.6.2) and landscape simulations (Section 2.8). We based our land use classification categories off those developed by Rayfield et al. (2019) for southern Quebec, as we adopted their approach to quantifying landscape connectivity.

Table 1. Land use – land cover (LULC) classes adapted from Rayfield et al. (2019) and their equivalencies and descriptions used to classify Hudson's land cover.

Rayfield et al. *(*2019) LULC Category	Martins et al. (2020) LULC Category	Description
Agriculture	Agriculture	Agricultural land, including all cash crops (corn, soy)
Agriculture, linear elements	Ditch	Ditches often filled with herbaceous vegetation and running parallel to agricultural fields
Built, non-urban	Built	Bare soil
Disturbed: Areas2	Orchards and Golf	Golf courses and orchards
Fallow	Fallow	Scrubland, fallow fields or early-succession regeneration
Fallow: Linear Elements	Hedgerow	Row of shrubs or trees separating agricultural or fallow land
Forest: Coniferous	Coniferous forest	Forest dominated by conifers
Forest: Deciduous	Deciduous forest	Forest dominated by deciduous trees
Forest: Mixed	Mixed forest	Forest composed of coniferous and deciduous trees
Roads: Minor	Roads	Paved or gravel roads; all roads belong to the same land use class
Urban	Urban	All built urban areas characterized by individual households or commercial centres irrespective of density or tree cover
Water	Water	Open water, including ponds, rivers and streams
Wetlands: Open	Open wetlands	Wetlands without tree cover, including marshes
Wetlands: Treed	Forested wetlands	Wetlands with tree cover, including treed bogs and swamps

2.5.3. Data validation

We conducted fieldwork to validate consolidated geospatial information available for natural areas in Hudson, as many data sources had not been updated in the recent past.

2.5.3.1. Priority areas for field-based validation

Due to time and resource constraints, the entirety of Hudson could not be characterized through fieldwork alone. Field-based validation was conducted using sampling plots representative of each forest stand and wetland, as delimited using data sources previously described (Section 1.3.1). To ensure that key sampling objectives were met, we prioritized sites for field validation according to several criteria:

- those classed as natural areas "of interest" (Teknika 2008);
- those identified as priority by the Hudson town council;
- mature forests;
- those with unknown composition and age data;
- lowland forest sites to verify if they could qualify as possible wetlands;
- the top 30% of forests with the greatest surface area.

2.5.3.2. Description of sampling methodology

Given that Eco2urb's objective was to acquire a broad overview of Hudson's natural areas to guide conservation planning, we chose sites to sample that were as representative as possible of the town's natural areas. We limited our inventory to forests and forested wetlands (swamps, bogs). Open wetlands (marshes) were not generally subject to field sampling given that their presence was more readily validated through photointerpretation. We adopted a stratified random sampling approach to select forest stands (wetland or terrestrial) for field-based validation. Stands were classed a priori according to tree composition and age categories; we then selected a random subsample in each category for field sampling while maintaining an even distribution of sites across the landscape. This cost-effective approach is commonly used in research to ensure that samples are representative while also reducing biases.

We employed a standardized methodology to characterize natural areas and collect data that could be used in our conservation ranking. To the extent possible, one sampling site was established at the center of each forest stand to limit edge effects, located at least 50 to 100 meters away from the site margin and removed from intercepting roads or residential areas. Each sampling plot was georeferenced and given a code associated with the forest stand in which it was located. At each site, we measured variables outlined in Table 2 as per best practices in biology (MFFP 2016; Bazoge et al. 2014) and to correspond with previous work (Teknika 2008; GENIVAR 2011; CIMA+ 2017; MFFP 2019b; Martins et al. 2016a). Forested wetlands were evaluated using the same criteria as upland forests (Table 2), in addition to wetland-specific variables (Table 3). These wetland-specific variables were adapted from Bazoge et al. (2014) and concern understory vegetation and topographic markers used to classify sites as wetlands.

Our assessment was not a formal evaluation of the presence or delimitation of wetlands in Hudson following the norms described by Bazoge et al. (2014). Rather, we adopted many of the variables described by Bazoge et al. (2014) for the purposes of field-based validation and to incorporate ecological data into our analyses and conservation ranking. Development project proposals concerning all wetlands mentioned in the present report will require a formal wetland characterization by a trained biologist prior to approval by municipal officials as well as the Quebec Ministry of the Environment.

Table 2. Summary of criteria evaluated across upland forest sites. References used include MFFP (2016), GENIVAR (2016) and Martins et al. (2016).

Criteria	Description and method	MFFP	GENIVAR	Martins
Basal area (m^2)	Total area occupied by tree stems within a sample plot, measured using a wedge prism with a basal area factor of 2. Used as an indicator of stand density, total biomass and structural complexity.	X		
Percent cover of each species (%)	The percent of total area occupied by each species included in total basal area.		X	X
Forest composition	Class of 'deciduous', 'mixed', 'coniferous', or 'fallow' based on tree composition.	X	X	X
Canopy closure	Density class of the forest canopy in terms of amount of light potentially reaching the understory. Based on a visual estimate of percent canopy closure.	X		
Maturity	Age classed as young (0-40 years), intermediate (40-80 years) or mature (80+ years). Estimated using tree diameter at breast height (DBH) and species composition.	X	X	X
Successional state	Succession classed into three categories: first (pioneer species), second (pioneer species dominant with shade-tolerant species co-dominant) and advanced (late successional shade-tolerant species dominant).	X		
Site heterogeneity	Structural complexity of the sample plot, as determined using the number of distinct strata (1-3) and the amount of woody debris.	X		
Drainage	Drainage level classed into three categories (high to very high, moderate to low, low to very low). Estimates based on slope, soil, and species composition.	X	X	
DBH and species of largest tree (cm)	Species identification of the largest tree and its diameter at 1.3 meters above ground level. Measured using a DBH measuring tape.	X		
DBH and species of average tree (cm)	Species identification of an average sized tree and its diameter at 1.3 meters above ground level. Measured using a DBH measuring tape.	X		
Old growth characteristics	Old growth forest indicators including the presence of standing or fallen dead wood and the amount of large shade-tolerant trees.			X
Type and intensity of anthropogenic disturbance	The type of anthropogenic disturbance (trails, roads, construction, etc.) and the degree of impact on the integrity of the site (little to none or moderate to high)	X	X	X
Type and intensity of natural disturbance	The type of natural disturbance (windthrow, fire, insects, etc.) as well as the degree of impact on the integrity of the site (little to none, or moderate to high)	X	X	X
Percent cover of exotic-invasive species (%)	Percent cover (estimated visually) and name of exotic-invasive plant species present at the site.			X

Table 3. Summary of criteria evaluated specific to wetlands. References used include Bazoge et al. (2014) and Martins et al. (2016).

Criteria	Description	Bazoge	Martins
Site context	Wetland, estuarian, riparian, lacustrine or marine.	X	
Terrain	Flat, at the top or bottom of a slope, open or closed depression.	X	
Disturbed elements	Physical or biological aspects of the wetland (soil, vegetation, waterway) that have been affected by either anthropogenic or natural disturbances.	X	
Percent cover of dominant shrub species	List of three to five of the most dominant shrub species and their percent cover at the site.		X
Percent cover of dominant herbaceous species	List of three to five of the most dominant herb species and their percent cover at the site		X
Wetland class	Final designation as a wetland and associated type (marsh, bog, swamp, pond) as based on biophysical and hydrological indicators.	X	

Table 4. Themes and interpretations for conservation indices, classed as continuous (C), discrete (D) or categorical (CA).

Theme	Variable	Type	Unit	Interpretation
Biodiversity	Avifauna observation hotspots	C	%	Spatial interception with high concentrations (probability distribution) of bird observations
	Herpetofauna observation hotspots	C	%	Spatial interception with high concentrations (probability distribution) of reptile and amphibian observations.
	Species at risk	D	P/A	Presence or absence of plant or animal species at risk, as designated by the CDNPQ (2019).
Landscape Connectivity	Regional connectivity	C	%	Contribution to the connectivity and habitat requirements of focal animal species at the scale of the Saint-Lawrence-Lowlands, as calculated by Rayfield et al. (2019).
	Local connectivity	C	%	Contribution to the connectivity and habitat requirements of focal animal species at the scale of Hudson, Quebec.
Forest Integrity	Anthropogenic disturbance	D	P/A	Presence or absence of anthropogenic disturbance that poses a significant threat to the ecological integrity of the site.
	Abundance of exotic species	C	%	Percent cover of exotic invasive species.
	Maturity	CA	N/A	Maturity class of the forest, be it young (0-40 years), intermediate (40-80 years) or mature (80+ years).
Forest Resilience	Tree diversity	C	%	The diversity of tree functional groups comprising the forest canopy
	Vulnerability to future threats	C	%	Simulated percentage of the forest vulnerable to the arrival of biotic threats either posing an immediate or potential threat to the urban canopy.
	Waterlogging tolerance	C	%	Tree community weighted proportion of the forest tolerant to flooding and waterlogging.
	Drought tolerance	C	%	Tree community weighted proportion of the forest tolerant to drought
	Development susceptibility	C	%	Simulated probability of development under a Business-as-usual scenario.
Ecosystem Services	Carbon storage	C	t/ha	The density per hectare of aboveground carbon stored in tree woody tissue.
	Flood mitigation	C	M	Spatial proximity to the flood zone along the Ottawa River as defined by the *Ministre des Affaires municipales et Habitation* (MAMH) for the Special Intervention Zone (ZIS). Natural areas within the flood zone have the highest value.
Recreation and History	Recreational importance	D	P/A	Natural areas of recreational importance (e.g. skiing, hiking, dog walking) as defined by Hudson's Council and Administration.
	Historical importance	D	P/A	Natural areas of historical importance as defined by Hudson's Council and Administration.

2.6. Calculation of conservation indices

Data were consolidated into a set of variables, collectively referred to as "conservation indices", to prioritize natural areas for conservation in Hudson. Variables have been grouped into six themes to facilitate their interpretation, as outlined below and in Table 4. Variable groupings did not have a direct influence on subsequent analyses. Our assessment focused exclusively on upland forests and forested wetlands (swamps, bogs); open wetlands were treated separately in the conservation ranking (Section 2.7). All variables were calculated at a 9x9 meter resolution for precision. Analysis were conducted in an R statistical environment unless otherwise stated (R Core Team 2018).

2.6.1. Biodiversity

We identified areas in the town where high densities of animal have been observed. Moreover, we classed forest stands in terms of the presence-absence of plant or animal species at risk.

We drew on collated bird, herpetofauna and species at risk records inventoried in Hudson using three data sources: eBird, AARQ, and CDNPQ (Section 2.5). Herpetofauna records included all those available for reptiles and amphibians except for the common garter snake since it tends to occupy a distinct habitat type, preferring upland forests and fields instead of moist woods, wetlands, ponds, rivers and lakes. All bird records were taken together indiscriminately of their habitat preferences. eBird records were tabulated in terms of the number of distinct observation events at different times, places and species. Multiple observations of the same species for a given time and location by the same individual were counted as a single observation. We proceeded to calculate the concentration of observations for each animal group (birds, herpetofauna), hereafter referred to as "observation hotspots". To do so, we used a 9 x 9 m grid overlaid on a geographic delimitation of the town boundary. Hotspots were interpolated by estimating the kernel home-range of each animal group separately (Calenge 2019). More specifically, we calculated the probability density that an animal group can be found at a given point, using its geographical coordinates as a reference. Forest importance to animal biodiversity was calculated in terms of their spatial interception with observation hotspots.

Hotspots are not the result of a systematic inventory of the distribution of animal life across the town. In the case of eBird data, observations are gathered by the public and generally biased towards accessible land (e.g. parks, shoreline). Moreover, eBird records do not make a distinction between simple flyovers and birds using a piece of habitat. The dataset is also vulnerable to double-counts of the same birds by multiple individuals. Bird observation hotspots thus reflect recreational observations of bird life at publicly accessible points in the town. Data from the AARQ were gathered by trained biologists across private and public land, so observation bias is of less concern. However, a systematic sampling of birds and herpetofauna across the entire extent of Hudson would be required to formally assess important habitats for these two groups.

We complemented our assessment of animal observation hotspots by identifying the spatial distribution of species at risk in Hudson. We drew on records from the CDNPQ and AARQ inventories to georeferenced all plant and animal observations with at-risk status, whether provincially or federally. To be eligible for our analyses, we limited records to those observed within the past 40 years for plants (since 1979) and 20 years for animals (since 1999), as recommended by CDNPQ guidelines. Moreover, observation points were included only if they were located within a 500 m radius surrounding the municipal limit of Hudson. A buffer area was included to capture amphibian records located along the town's shoreline.

2.6.2. Landscape connectivity

Landscape connectivity grades forests in terms of the spatial configuration of habitat patches that facilitate animal migration and dispersal. Forests and wetlands in Hudson were evaluated first in terms of their importance for maintaining a regionally connected network of habitat patches at the scale of the Saint-Lawrence-Lowlands using the results from Rayfield et al. (2019). We then refined estimates by examining connectivity at a much finer resolution within the municipal limits of Hudson, Quebec. Regionally, connectivity was calculated using a grid cell resolution of 30 x 30 m, whereas locally it was quantified at a resolution of 9 x 9 m. Local estimates were also derived using ground-truthed delimitations of forests and wetlands whereas regional estimates were not, relying instead on geospatial data sources by MFFP (2019b). The combination of approaches ensures both the accuracy and applicability of connectivity estimates.

Both local and regional connectivity values were calculated using the same analytical framework first described by Albert et al. (2017). The approach identifies networks of habitat patches that satisfy the connectivity needs of multiple animal species. Those selected include the black bear (*Ursus americanus*), red-backed salamander (*Plethodon cinereus*), common shrew (*Sorex araneus*), American pine marten (*Martes americana*) and wood frog (*Lithobates sylvaticus*). Taken together, they capture the habitat requirements for species in both terrestrial and aquatic environments, multiple forest types (coniferous, mixed, deciduous) as well as diverse life history traits (short-lived, long-lived) and dispersal capacities (short and long). This choice of species reflects a range of habitat needs; these species are not necessarily found in Hudson.

To assess landscape connectivity, two indices are adopted with complementary approaches to understanding animal dispersal in a fragmented landscape: betweenness centrality and cumulative current. To calculate these indices, land classes (e.g. forest, swamp, urban) were graded in terms of their habitat suitability for each species as well as their potential for impeding animal dispersal. For instance, coniferous forests received high suitability scores for the American pine marten while roads were classed as an impediment to animal movement for all species. For betweenness centrality, the degree to which patches are connected is calculated as the number of shortest paths passing through each patch in the habitat network. The analysis is restricted to patches with habitat suitability scores greater than 60 of an appropriate size and that are within the species' inter-patch dispersal distance. As for cumulative current, we used the software Circuitscape to quantify connectivity, which employs algorithms from electrical circuit theory to model connectivity (McRae et al. 2013). Habitat patches are treated as nodes in an electrical circuit between which current flow is inversely related to the resistance of the intervening landscape. Taken together, the analysis results in two landscape connectivity indices for five focal study species (Meurant et al. 2018) highlighting landscape elements essential to animal dispersal.

To synthesize results across index and species combinations, we employed the decision support tool, Zonation (Moilanen et al. 2011). This freely available software is used for landscape prioritization and conservation planning, identify areas in the landscape integral for multiple biodiversity features while maintaining the connectivity of high-quality habitat patches. In this case, Zonation ranked forests and wetlands (scale 0-1) in Hudson in terms of their conservation value for maintaining a connected habitat network for the five focal species as based on results for circuit flow and betweenness centrality. All input variables were given equal weight in this iteration of the analysis. As the regional connectivity estimates were calculated at a larger spatial scale, we calculated average regional conservation values for each forest and wetland polygon delimited for the town. Averages were calculated after having recoded conservation values to their corresponding quartile values to mark clearer distinctions between low and high priority habitat patches (B. Rayfield, pers. com. 2019)

2.6.3. Forest integrity

Forest integrity examines the degree to which natural areas are free of the following sources of disturbance, each one treated as a distinct variable: anthropogenic disturbance and the abundance of exotic species. The first grades natural areas as either being significantly affected by human intervention or not. Sources of anthropogenic disturbance (Table 4) included walking trails, electric wires and residential waste. As for exotic species, we estimated the percent cover of eight exotic species (*Alliaria petiolate, Berberis thunbergii, Chelidonium majus, Reynoutria japonica, Lonicera tatarica, Lythrum salicaria, Phragmites australis, Rhamnus* spp.) at each study site. The total percent cover of exotic species is used to estimate the degree to which natural areas are invaded and is graded according to four classes: low (<30%), medium (30-60%), medium-high (60-80%), high (>80%; Table 2).

Forest integrity also considers the maturity of each forested area, which was measured in terms of forest age. Three age classes were defined and are as follows: young (0 to 40 years), intermediate (40 to 80 years) or mature (>80 years; Table 2). The largest tree per plot was used as an indicator of successional state, which can help determine forest maturity. For instance, sites dominated by trembling aspen (*Populus tremuloides*) are typically undergoing secondary succession and the result of a major disturbance event within the past 80 years. Sites dominated by late-successional shade-tolerant species (e.g. maple, eastern hemlock) can be up to 250 years old. The composition of dominant species along with measures of total tree basal area and the DBH of trees were used to estimate forest maturity.

2.6.4. Forest resilience

Forests were evaluated using five complementary variables to capture their potential resilience to global drivers of environmental change, including: tree functional diversity, vulnerability to future biotic threats, waterlogging tolerance, drought tolerance and simulated development pressure. Resilient forests are those with high tree functional diversity, low vulnerability to future threats (insects and diseases), as well as high waterlogging and drought tolerance. We quantify development pressures as a strategy of identifying priority resilient natural areas most susceptible to urban and agricultural expansion.

All variables but simulated development susceptibility were calculated using forest inventory data that we collected from across the town (Section 2.5.3). At each site, we tabulated the number of tree species with a trunk diameter of at least 10 cm at breast height. We then constructed a table populated with the abundance of each species per site, expressed as a percentage of the total basal area per site.

When calculating tree functional diversity, trees species were grouped into their corresponding functional groups according to their similarities in terms of eight functional traits as obtained from Niinemets and Valladares (2016) and Aubin et al. (2012). Traits included drought tolerance, shade tolerance, waterlogging tolerance, main seed dispersal vector, seed mass, wood density, leaf mass per area and taxonomic division. Functional groupings and their respective descriptions can be consulted in

Table 5. The approach for determining functional groups was adapted from Paquette (2016) and Aquilué et al. 2020 (submitted). *Alnus* and *Amelanchier* were omitted from the analysis as they had not been grouped into functional groups in the original reference classification. From these data, we calculated the Effective Shannon Diversity Index of the number of functional groups for each site (Jost 2006). This index calculates the effective number of equally-common tree functional groups required to give a value of the "effective diversity of functional groups".

Table 5. Functional groups determined according to similarities in functional traits among species found in Hudson's forests.

1	Conifers, shade tolerant, moderately drought and flood tolerant,wind dispersed.	White pine, hemlock, fir
2	Deciduous, shade tolerant, moderately drought and flood tolerant, wind dispersed.	Maple, ash, elm
3	Deciduous, shade intolerant with moderate flood tolerance, wind dispersed.	Poplar
4	Deciduous, moderately shade intolerant, tolerant to drought and intolerant to flooding, animal dispersed.	Red oak and hawthorn
5	Deciduous, moderately shade tolerant, moderately tolerant to drought and flooding, wind dispersed.	Birch and willow
6	Large trees, moderate shade tolerance, drought tolerant and moderate flood tolerance, animal dispersed.	Oak, hickory, walnut, basswood
7	Smaller trees, moderate shade tolerance, high drought tolerance, moderate flood tolerance, animal dispersed.	Cherry, apple, buckthorn
8	Conifers, shade intolerant, drought tolerant, moderate flood tolerance, wind dispersed.	Spruce, Scots pine, white cedar

To estimate the vulnerability of the forest canopy to future biotic threats, we drew on data from Lovett et al. (2016) to associate each tree species in our sample with a list of harmful insects and pathogens. These all pose a significant risk to tree mortality (Lovett et al. 2016) and are either already present in Hudson (e.g. emerald ash borer, beech bark disease) or may invade in the future (e.g. Asian longhorn beetle). We then calculated the percentage of the canopy of each forest site vulnerable to each insect or pathogen. It was possible for a given species to be vulnerable to more than one biotic threat.

Over the course of the next 50 years, it is highly likely that globalization and climate change will continue to facilitate the introduction and spread of exotic pests and diseases (Ramsfield et al. 2016; Tubby and Webber 2010). In fact, over the past century and a half, exotic pests and disease have invaded the United States at a rate of 2.5 exotic species per year (Lovett et al. 2016). Given that it is impossible to predict with certainty the size and scale of these impacts, we estimated the percentage of each forest stand that would be affected by the arrival of every combination of two threats not currently in the town. These simulations were developed to assess forest resilience at each site as a function of tree composition and functional diversity. This was added to the percentage of the canopy affected by threats already present, including beech bark scale (*Cryptococcus fagisuga*), butternut canker (*Sirococcus clavigignenti-juglandacearum*), Dutch elm disease (*Ophiostoma ulmi*) and emerald ash borer (*Agrilus planipennis*). We ran these simulations for every pairwise combination of threats not already present, resulting in 240 permutations. From these data, we used the mean percentage of the canopy affected by potential and current threats as a metric of forest vulnerability.

To estimate the vulnerability of the urban forest to extreme weather events including flooding and drought, we ranked all tree species in our inventory in terms of their waterlogging and drought tolerance using data taken from Niinemets et al. (2006). We then calculated the community weighted mean of drought and waterlogging tolerance of the trees at each site using methods described by Laliberté and Legendre (2010). Higher values indicate that the current tree community at each site tends to be more tolerant to waterlogging and drought on average.

Finally, we simulated development susceptibility through landscape modeling (Section 2.8) based on historical land use transition rates for Hudson. Specifically, we modeled urbanization and agricultural intensification in Hudson over a 50-year time horizon (2020-2070) for 40 replicate runs. Development susceptibility is the probability of any given forested area being lost either through agricultural expansion or urbanization at the end of the time series. It is not used as a prescription for how development should unfold in Hudson and cannot be used to validate or promote any given development project or proposal. Rather, our index of simulated development susceptibility must be strictly interpreted as the probability of forest loss using the set of parameters defined in our land use transition models.

2.6.5. Ecosystem services

Two ecosystem services were included in our analysis: carbon storage and flood mitigation.

We deduced the amount of carbon stored in aboveground woody tissue of trees for each site using data taken from our sample plots (Section 2.5.3). We began by estimating the percent surface area (m^2 per hectare) of each species at each site. We then calculated wood volume using the maximum height of each species, as tabulated by Farrar (2006). In two cases (*Crataegus* sp. and *Malus domestica*), mean height values were taken for species of the same genus (8 m for *Crataegus* sp.) or for similar cultivars (12 m for *Malus* sp.). We adjusted maximal height values as a function of the maturity of each forest stand. For mature forests (80+ years), the maximal height was used, whereas 85% of the maximal height was used for intermediate forests (40 to 80 years) and 66% for young forests (0 to 40 years). Wood volume per species was estimated as the adjusted height of each species multiplied by their basal area and a conversion factor of 0.42 (Adekunle et al. 2013; Ung and Ouellet 1991). This conversion factor can range between 0.4 and 0.5 and is used to account for the flare of tree trunks in stand volume calculations, given that trees are not perfect cylinders. Dry biomass (tonne per hectares) was calculated from wood volume estimates using the biomass calculator (https://nfi.nfis.org/en/biomass), an online tool made available through Canada's National Forest Inventory. We then converted biomass estimates to kilograms of stored carbon using the following equation from the IPCC (2006):

$$Cp = DM * CF$$

Where C_p = carbon stock in plot (t C ha^{-1})

DM = dry biomass in plot (t dry matter ha^{-1})

CF = carbon fraction (t C t^{-1} dry matter)

Stored carbon was then converted to CO_2 equivalent using a conversion factor of 3.67 (Clark 1982) as a final measure of carbon storage expressed in t CO_2 ha^{-1}.

We estimated the buffering potential of natural areas in Hudson against spring flood events. Natural areas within the flood zone along the Ottawa River mitigate the impacts of flooding, acting as physical barriers and having a greater water retention capacity than other land use types, including agricultural land or parks (Pellerin and Poulin 2013). In this regard, we identified which natural areas are within Hudson's flood zone along the Ottawa River as defined by the MELCC (2019). These are the most up to date flood zone delimitations available and were derived based on the extent of flooding observed in the spring of 2017 and 2019. Flood zones are subject to the governmental moratorium in July 2019 on any new constructions or renovation. For this index, natural areas within Hudson's flood zone were attributed the highest values; the value of natural areas outside of the flood zone decrease as a function of the shortest distance between them and the inland perimeter of the flood zone.

2.6.6. Recreation and history

To capture the sociocultural importance of natural areas in the town, we focused on their value for recreation and history. Both these variables were developed during a workshop in consultation with members of the Town of Hudson's administration and council (Section 2.9.1). For the first, we asked town officials to identify areas in the town used by citizens recreationally during all seasons and including self-organized or event-based outdoor activities (e.g. ATV, biking, cross-country skiing, dog walking, hiking). Areas could include those accessible via public or private trails. For the second, historically important natural areas were identified in terms of their significance for place-based events in the recent or distant past and concerning human societies occupying the territory currently delimited as Hudson. Both recreational and historical natural areas were limited to the forests (terrestrial or wetlands) being evaluated as opposed to adjacent parks or landmarks. All natural areas identified were given a value of one for this index and all other areas a value of zero.

2.7. Conservation prioritization

We conducted a multi-criteria analysis to identify priority areas for conservation using the landscape planning software, Zonation. This freely available software is used for landscape prioritization and conservation planning, identifying areas in the landscape integral for multiple biodiversity features while maintaining the connectivity of high-quality habitat patches. The software takes as its input a set of georeferenced criteria and provides as its output a map of natural areas where each pixel is ranked from 0 to 1 in terms of its importance for conservation.

In total, we used 17 variables (Table 4; Section 2.6) to rank natural areas in Hudson. Prior to analysis, all variables were rescaled from 0 to 1 as they were calculated using different units and methods. We also ensured that higher values for each variable indicated greater importance for conservation. For instance, we flipped the axis of Anthropogenic Disturbance, as undisturbed forests have higher conservation priority than disturbed ones in this study.

We specified a hierarchical removal mask to dictate whether certain natural features in the landscape should be given high conservation values by default. The algorithm implemented through Zonation then prioritizes nearby natural features to maximize the connectivity of priority areas with those that have de facto protective status, a measure of securing the spatial contiguity of forested land. The areas that we included in the conservation mask met the following criteria, as per the planning program (Town of Hudson 2009) currently in effect in Hudson as well as associated bylaws currently or potentially governing the conservation of natural areas (Text Box 1):

- All steep embankments in excess of 20%;
- All natural areas within the flood zone of the Ottawa River;
- All forested and open wetlands and associated 10 m buffers;
- All currently protected areas or parks that include forested land or wetlands;
- 10 to 15 meter buffers on either side of all streams, including intermittent and permanent streams.

Text box 1. Bylaws and legal documents.

Listed below are the main bylaws and legal documents used as references by Eco2Urb in determining the conservation mask:

- Hudson Bylaw No. 525: Planning Program.
- Hudson Bylaw No. 526: Zoning.
- Quebec Bill 132: Act Respecting the Conservation of Wetlands and Bodies of Water, 2017.
- Quebec Environment Quality Act, Chapter Q-2, r. 35: Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains Environment Quality Act, 2019

Steep slopes were identified using a digital land model made available by the town. Wetlands were those identified using previously described data sources (Section 2.5.1) as well as through field-based inventories (Section 2.5.3). Conservation areas (e.g. Clark-Sydenham Conservation Area) and stream delimitations were provided by the Town of Hudson. We used these five layers together in building the conservation area mask; natural areas within the mask were given as default the highest conservation ranking score possible (1). We then adjusted model parameters, namely the Boundary Length Parameter (BLP), in Zonation to maximize spatial clustering of priority zones with those identified in the conservation area mask. We used a BLP value of 0.05 for all model runs, as recommended by the software's guidelines (Moilanen et al. 2011). We assessed visually that BLP settings were not having a disproportionate effect on the clustering of priority cells with the conservation mask. Only natural areas (forests, wetlands) were included in the conservation ranking across all scenarios; the intervening landscape matrix (e.g. surrounding agricultural fields, urban areas) was omitted.

By adjusting the parameters used to rank landscape features, Zonation allows for the possibility of generating conservation scenarios reflecting a variety of stakeholder priorities. For instance, modifying the weights associated with the individual variables in the analysis will influence their leverage in ranking natural areas for conservation. We adopted two scenarios, namely citizen and municipal conservation rankings, by modifying the weights associated with individual variables. Variable weights were defined through a set of workshops developed in collaboration with the town administration and its citizens (Section 2.9).

2.8. Land use simulations

Central to resilience planning is the ability to bolster natural ecosystems against anticipated environmental risks. This involves a certain degree of forecasting -- preparing for and predicting future disturbances before they occur. By adjusting contemporary planning in light of future landscape change scenarios, we are better able to identify sensitive areas requiring immediate conservation now should their loss have a disproportionate effect on the integrity of the landscape as a whole. As such, in collaboration with the Town of Hudson, we developed a set of scenarios forecasting landscape change over a 50-year time horizon and evaluated impacts on variables used to rank green space for conservation. Scenarios were based on historical land use and land cover (LULC) data (Section 2.8.1) as well as a workshop with town officials (Section 2.8.2).

2.8.1. Historical land use change

To calibrate our models according to observed patterns of landscape change in Hudson, we analysed historical cadastral and LULC data. Cadastral data were provided by the town and included information on when each lot had been subdivided. By comparing the date indicating when new cadastral lots were added and the surface area of each lot, we calculated precise urbanization rates for the town. Seeing as Hudson is primarily residential, we studied urban expansion in terms of the addition of new housing as opposed to the clearing of land for industrial or commercial areas, or golf courses. Rates were calculated on five-year intervals starting in 1900 until today and were derived separately for areas also zoned for agriculture (green zoning) and as residential (white zoning). We limited our assessment to lots smaller than five hectares to avoid erroneously including larger properties that were for the most part forested or agricultural.

We validated urbanization rates calculated from cadastral data with historical LULC data from Agricultural and Agri-Food Canada (AAFC) for the years 1990, 2000 and 2010 (AAFC 2015). LULC maps from the AAFC cover the entirety of the study extent at a resolution of 30 x 30 m. We added an additional 2020 timestep to the AAFC LULC timeseries using contemporary landscape delimitations (Section 2.5.2). By comparing differences in landscape composition across years, we identified the primary transitions include in our land use transition models (Section 2.8.2) as well as associated land use transition rates. Transitions in LULC were calculated separately for areas currently zoned for agriculture or as residential.

2.8.2. Future land use change

We used SyncroSim (Apex RMS 2019) to model future landscape change as a function of historical LULC data as well as scenarios developed during a workshop with the town administration (Section 2.9). SyncroSim is a freely available software (https://syncrosim.com/) that streamlines the process of making predictions from a variety of data sources. We began by developing a stochastic model focusing on four LULC classes: agriculture, forests (upland, swamps, bogs), fallow areas and urban land (Figure 4). Urban areas expand as they displace agriculture, forests and fallow land via urbanization (grey areas). Forest can also be lost to agriculture via agricultural intensification (yellow arrow). Agriculture is set aside as fallow land (orange arrow). Fallow land can transition into forested land through natural regeneration (green arrow).

Several assumptions were made in developing the LULC model. For instance, it presumes that the loss of natural areas arises at a constant rate as a result of agricultural intensification and urbanization. Moreover, that urban, agricultural and fallow land spreads out radially from existing portions of the landscape with the same cover type. This restriction is not imposed on natural forest regeneration in fallow land, as tree succession is generally discontinuous in its spatial distribution (Cramer et al. 2008; Myster 1993). Moreover, the model does not allow for the loss of natural areas that comply with at least one of the criteria governing their protection in Section 2.7. These regulations apply to all wetlands as well as natural areas within a certain distance of rivers and streams, those associated with steep slopes, those currently classed as parks or conservation areas as well as those within the flood zone of the Ottawa River. Additional natural areas are retained throughout the model simulations depending on the scenario being considered.

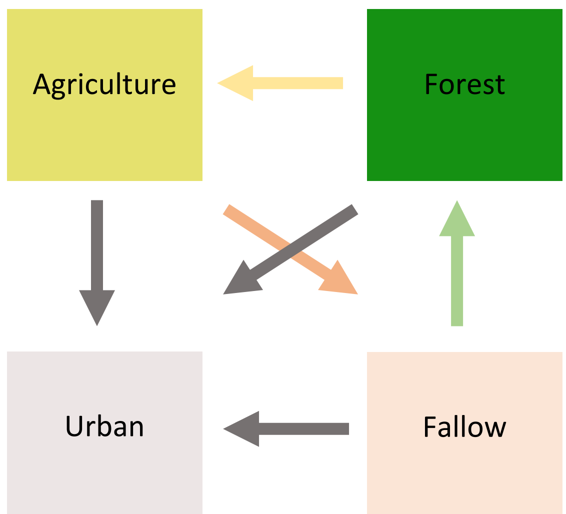

Figure 4. Diagram of LULC change model. Arrows indicate the transitions between LULC classes (boxes), including: urbanization (grey arrows), forest regeneration (green arrow), agricultural set aside (orange arrow) and forest loss due to agricultural expansion (yellow arrow).

Historical reference data (e.g. AAFC 2015) could not be used to establish rates of agricultural land transitioning into fallow land or forest regeneration from fallow land. Instead, we presumed that fallow land currently in Hudson is at least 25 years old. We then calculated the area of fallow land currently in the town and divided it by its predicted age to calculate a yearly rate for this transition type. This assumption was validated by reviewing pertinent literature (Pellerin et al. 2016) and examining aerial images of the town dating back to ca. 1985 (Google Earth 2018). We presumed that all fallow land currently in the landscape would transition to deciduous forest after 50 years to calculate yearly transition rates for forest regeneration (Myster 1993). Note that the same rates were applied to transitions from fallow land to urban as with forest to urban.

The model was sensitive to current zoning governing land use in the town. For instance, forested segments of parks and conservation areas were not permitted to transition to any other cover class.

Moreover, differential urbanization and forest loss rates were applied in areas zoned as residential or agricultural. Cover classes not included in the model but present in the landscape (e.g. golf courses; Table 1) remained static through time unless included in a land use scenario established by the town (Section 2.9). All model simulations were run over a fifty-year time horizon and generated using the SyncroSim software version 3.0.44 (ApexRMS 2019).

We built a set of scenarios to study the consequences of landscape change on natural areas in the town, including metrics of habitat connectivity, ecosystem services and biodiversity. Table 6 details the study design used for scenario development. In total, we developed eight scenarios that compare the outcomes of not protecting any additional forested land (Scenario 1), as well as protecting natural areas based on regional conservation plans (Scenarios 2-3) or conservation priorities identified through our analyses (Scenarios 4-6; Table 6). Moreover, we modeled the consequences of two land use change scenarios proposed by Hudson's administration (Scenarios 7-8). Scenarios 2 and 3 were based on regional conservation plans established by the MMC (PMAD) and the RCM Vaudreuil-Soulanges (*Politique de l'arbre et des boisés de Vaudreuil-Soulanges*), respectively (MRC Vaudreuil-Soulanges 2008, CMM 2012). In them, all forests classed as priority for conservation were not permitted to transition to any other cover class. We contrasted these two scenarios with results from our own assessment of priority conservation areas. Specifically, we calculated the percentage of the landscape protected in Scenarios 2 and 3, and classed equivalent proportions of the landscape as protected but based on Eco2urb's landscape prioritization. As such, we avoided confounding the affects of total area protected with conservation design. In Scenarios 1-5, areas not classed as protected were subject to transition rates calculated from historical data. In Scenarios 6 and 7 developed by the town's administration, transition rates and model parameters were adjusted to ensure that the entirety of the landscape reflected the administration's specification by the final timestep. This included adjusting the transition pathways presented in Figure 4 as needed.

Table 6. Description of land use change scenarios.

No.	Title	Description
1	Business-as-usual	Simulates historical development rates projected into the future.
2	PMAD Conservation Areas	Simulates protecting priority forested areas according to PMAD for the MMC (CMM 2012).
3	VS-RCM Conservation Areas	Simulates protecting priority forested (rank > 5) areas according to Vaudreuil-Soulanges (2008).
4	20% Protected	Protection of 20%, 25% and 30% of Hudson's landscape corresponding to priority conservation areas identified through the current analysis (Section 2.7).
5	25% Protected	
6	30% Protected	
7	Transit Oriented Development	Urban development occurs at the extremities of town as per pressure from neighboring municipalities and is concentrated along major transport axes. This scenario is in no way related to transit-oriented development as defined by PMAD (CMM 2012). The title was assigned to the scenario by the town's council and administration.
8	Service Oriented Development	Urban development emanates from Hudson's downtown core and follows the distribution of existing infrastructure.

Finally, for each timestep in each model scenario, we calculated the impacts on all conservation indices included in our analysis, including ecosystem services, biodiversity and connectivity metrics. This was done first by re-calculating each metric for the landscape generated through each timestep and scenario. We then quantified the percent change in the total value of each metric at the landscape scale, as defined by the municipal limits of Hudson. Changes in landscape metrics are not sensitive to the time elapsed from one timestep to the next. For instance, we examined the loss of existing forests based on contemporary maturity patterns; young and intermediate forests do not age throughout the timeseries. Moreover, when studying conservation indices, we limited ourselves to quantifying the anticipated impacts of land use change on current forest cover as opposed to the possible compensatory effects of forest regeneration through time.

2.9. Municipal and citizen workshops

We held two separate workshops with members of the town council and administration as well as with Hudson's citizens to better understand local conservation priorities. Workshops were exploratory in nature and do not reflect an exhaustive inventory of citizen or municipal perspectives on conservation planning in Hudson. Results should not be interpreted as a prescription for anticipated development trajectories in the town or a thorough assessment of historical or recreational places of importance. Rather, they represent the experiences and opinions of attendees, a subsample of Hudson's population.

2.9.1. Workshop 1: Hudson's administrative council

The workshop held with the Town's council and administration took place on October 11, 2019, from 9AM to 5PM. This workshop included four different activities aimed at acquiring local insight on preliminary analyses conducted by Eco2urb on conservation priorities. We gave a presentation on work accomplished until that point as well as an overview of preliminary results for the prioritization of Hudson's natural areas for conservation.

With regard to the activities that took place during the workshop, two were aimed at identifying areas of high value for recreation and history, and two were aimed at prioritizing natural areas and associated ecological features for conservation (Table 7). Information collected during the workshop was used to define land use change scenarios (Section 2.8.2) and the weights assigned to conservation indices in our landscape prioritization (Section 2.7). Maps annotated by workshop participants were scanned and georeferenced so that results could be integrated into our geographical information system for subsequent analysis.

2.9.2. Workshop 2: Hudson's citizens

The workshop held for the residents of Hudson took place on November 11, 2019. Invitations to the workshop were sent out by the Town Administration. Given the allotted time (approximately 2 hours), the format of the workshop was modified accordingly. More specifically, the citizen workshop was focused on the two activities that aimed to prioritize the characteristics of natural areas and to rank forests for conservation. To simplify the ranking of forest characteristics given the higher anticipated number of participants in the citizen workshop, we regrouped the number of variables from nine to four.

Table 7. List of activities hosted at the workshop and their descriptions.

Activity	Description
Identify natural areas important for recreation and history	Participants were asked to identify on a map natural areas in Hudson that are used for recreational purposes or that have historical significance.
Identify natural areas potentially subject to land use change	Participants were asked to identify on a map natural areas in Hudson likely to be subject to urban development or agricultural expansion.
Rank natural area features	Participants were given nine variables (a regrouping of those in Table 4) and asked to rank them in order of importance. Assigning the same rank to multiple variables was permitted.
Rank forests for conservation or development	Participants were given six cards representing forests and their characteristics and asked to rank them in order of importance, then asked which example forests to develop or conserve.

3. Results

In the interest of facilitating the interpretation of results, we have identified nine landmarks to help situate the reader in the context of the municipality (Figure 5). Landmarks follow the distribution of major forests and wetlands, as well as parks and nature trails. Maps summarized in the results have been rotated 30° northwest to position the municipality on a horizonal axis. We divided natural area into either upland forests (deciduous, mixed, coniferous), forested wetlands (swamps, treed bogs) and open wetlands (marshes). Note that the Viviry River passes through Hudson along Point 5.

We begin by summarizing Hudson's landscape composition (Section 3.1) and then detail results for each of the conservation indices (Section 3.3) and scenarios (Section 3.6.2). Conservation priorities are described in Section 3.5.

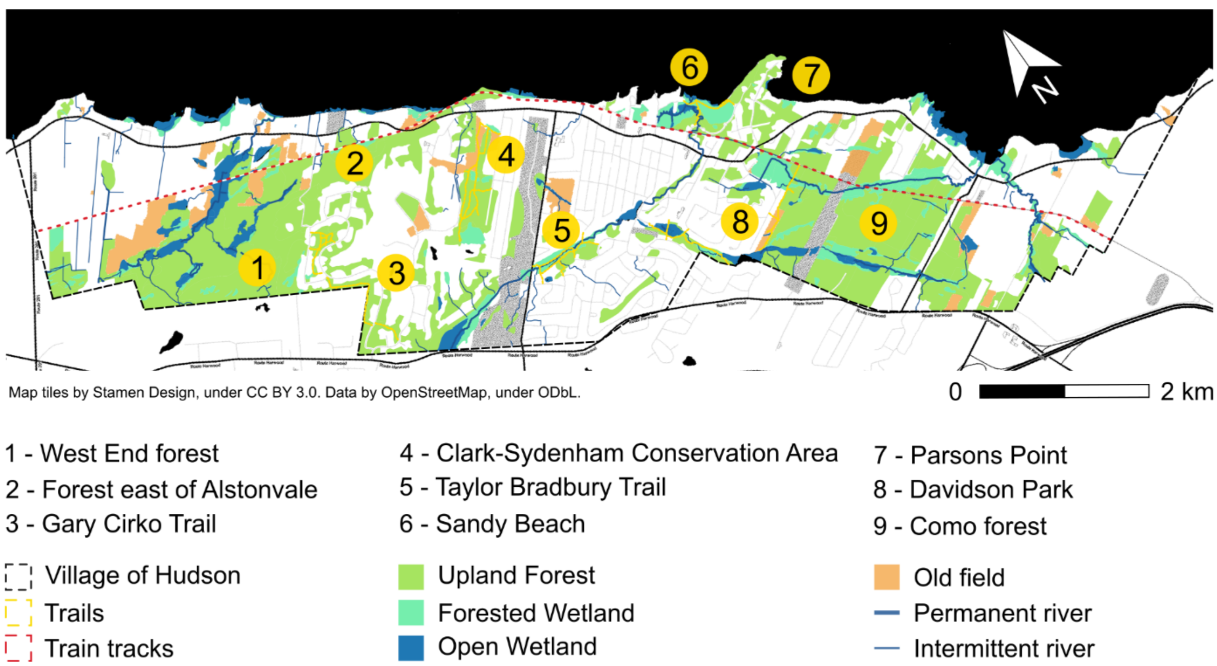

Figure 5. Map of Hudson summarizing its trail network, main natural landscape cover and reference points.

3.1. Green space composition and configuration

The natural areas in Hudson cover approximately 37% (825 ha) of the municipality's total area, excluding the forest canopy in urban areas. These are divided into wetlands (24%, 195 ha) and upland forests (76%, 629 ha; Table 8). Slightly more than half of Hudson's wetlands are forested (swamps, forested peatlands) while the remainder are open (marshes, ponds; Table 8). Upland forests are primarily deciduous or mixed, with a small percentage being coniferous (Table 8). In terms of tree basal area measured at sampling sites, the most common tree species are red maple (15%; *Acer rubrum*), red ash (15%; *Fraxinus pennsylvanica*), white pine (9%, *Pinus strobus*) and sugar maple (8%; *Acer saccharum*; Figures 7-8). This corresponds well with tree species composition data calculated by MFFP (2019b) through photointerpretation, which showed that Hudson's forests are predominantly composed of red maple and other shade intolerant species of intermediate age, and, to a lesser degree, of intermediate to mature sugar maple stands.

Table 8. Composition of natural landscape in Hudson.

Natural Cover	Area (ha)	Proportion of Natural Areas	Proportion of Hudson's Areas
Deciduous Forest	457	55%	21%
Mixed Forest	137	17%	6%
Coniferous Forest	36	4%	2%
Forested Wetland	114	14%	5%
Open Wetland	82	10%	4%
Total	825	100%	37%

Our results on landscape composition differ from those published by CIMA+ (2017) and Teknika (2008). Whereas wetlands (forested, open) identified in the current study cover a total area of 196 ha, those identified by CIMA+ (2017) cover 110 ha within the municipal boundary of Hudson, while those identified by Teknika (2008) cover 132 hectares. This discrepancy in cover area can not be attributed to the time elapsed since the publication of previous consulting reports alone. This is especially true as we report more wetland area than in the past, running contrary to trends of wetland loss observed at the MRC scale (Pellerin and Poulin 2013) and through our own assessment of historical land cover change (Section 3.6.1). We observed similar discrepancies in total forest cover values for the town, Teknika (2008) estimating coverage at 342 ha compared with the 629 ha cited here (Table 8). For both wetlands and forests, the primary source of discrepancy resides in differences in scope amongst studies: Teknika (2008) focused on forests and wetlands located in urban areas and excluded those in agricultural zones or those designated as fallow land, while CIMA+ (2017) was limited to the urban core. Our study examined natural areas throughout Hudson irrespective of zoning, collating geospatial data from CIMA+ (2017), Teknika (2008), additional data sources (Section 2.5.1) and field-based inventories (Section 2.5.3), thus explaining the generally higher coverage estimates.

3.2. Summary of field sampling campaign

Eco2urb sampled 128 sites across Hudson in July-August 2019 to validate geospatial delimitations of the town's natural areas as well as to collect data used to prioritize these areas for conservation. Sites were evenly distributed across the town, including public land, private land and areas zoned as urban or for agriculture. Of these sites, 40% were sampled in forested wetlands and 60% were sampled in upland forests (Figure 6). The forest stands in which sites were located corresponded to 559 ha or 68% of the total cover of natural areas in the town. We extrapolated upland forest and forested wetland field data to an additional 145 sites, covering 266 ha, of the same vegetation types that had not been inventoried due to time and resource constraints. Extrapolations were based on the spatial proximity of sites, aerial photo interpretation as well as forest composition and age. Open wetland delimitations were validated primarily through aerial photo interpretation.

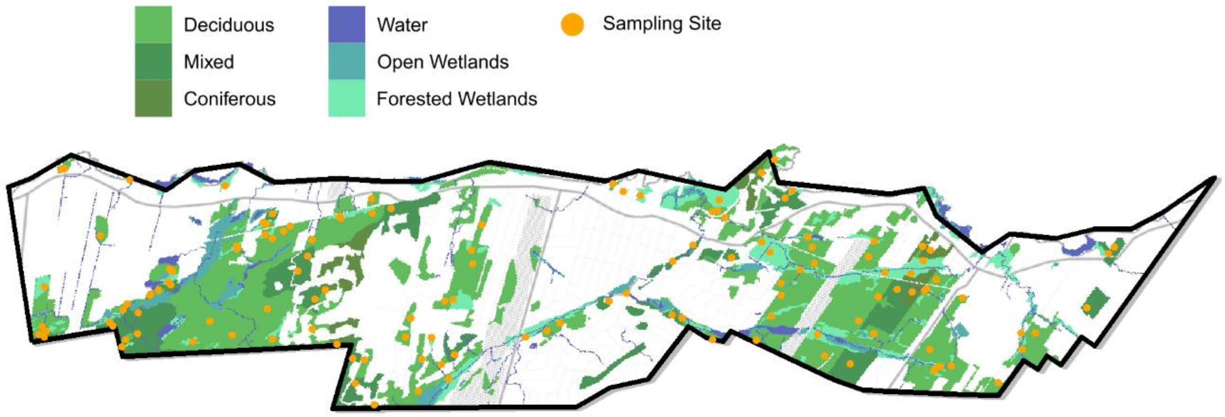

Figure 6. Distribution of sampling sites across Hudson's natural areas.

3.2.1. Composition in sampled sites

Forests and forested wetlands were comprised primarily of red maple (*Acer rubrum*), white pine (*Pinus strobus*), sugar maple (*Acer saccharum*), red oak (*Quercus rubra*) and red ash (*Fraxinus pennsylvanica*; Figures 7-8; refer to Appendix 1 for a full list of species and their total basal areas). Red oak (*Quercus rubra*) and white pine (*Pinus strobus*) were most frequently found to have the largest DBH measures across sites, but a cottonwood (*Populus deltoides*) had the largest DBH measure overall (159 cm). Red ash and red maple were most frequently the largest trees in forested wetland sites. DBH measures varied on average between 19 – 48 cm across sites irrespective of vegetation type with an average DBH of 37 cm across all sites (Figure 18).

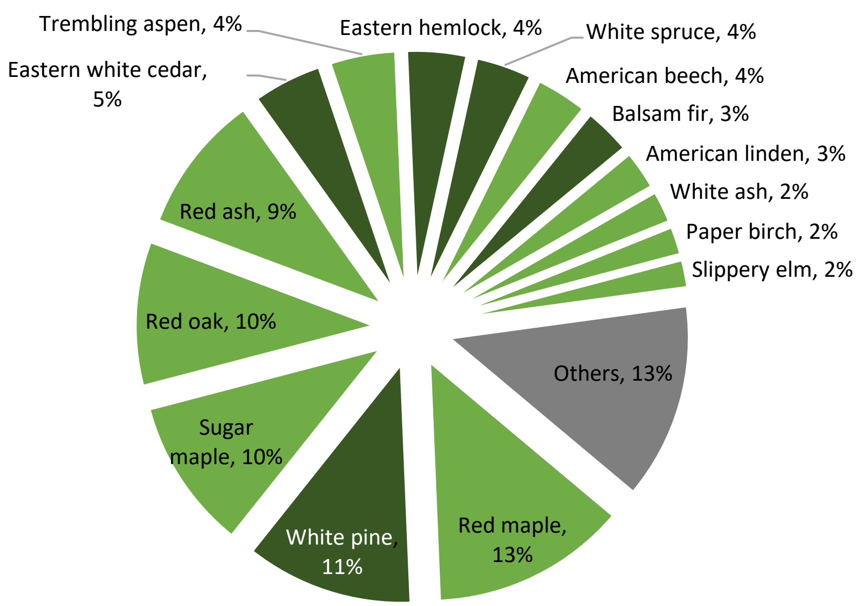

Figure 7. Summary of species composition for upland forest sites. Percentages represent the proportion of the total basal area measured across all forest sites. Coniferous species are in dark green and deciduous species in light green.

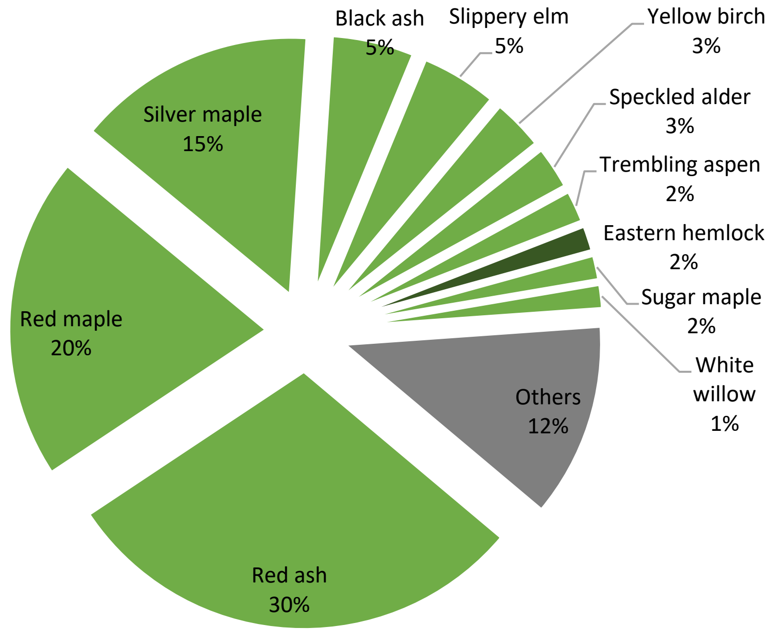

Figure 8. Summary of species composition for forested wetlands. Percentages represent the proportion of the total basal area measured across all forest wetland sites. Coniferous species are in dark green and deciduous species in light green.

With regards to sampled sites in forested wetlands, species composition differed considerably from that of the forest sample plots (Appendix 2 for details on understory composition). Where in forest sites 33% of the total measured basal area was coniferous (Figure 7), that number dropped to 6% for wetlands, the vast majority being deciduous (Figure 8). The dominant species for forested wetlands also differed from those for upland forest sites; although red maple (*Acer rubrum*) remains a significant component of these sites, red ash (Fr*axinus pennsylvanica*) is the most dominant, with silver maple coming in third (*Acer saccharinum*).

3.3. Biodiversity, ecosystem services and landscape connectivity

Index values are grouped into six major themes to facilitate their interpretation, namely: biodiversity, landscape connectivity, forest integrity, forest resilience, ecosystem services, recreation and history. The grouping of indices into themes did not influence the calculation of results.

3.3.1. Biodiversity

3.3.1.1. Avifauna observation hotspots

We identified hotspots based on 29 678 bird sightings collated by eBird since 2010, comprising 230 bird species. The most common bird species in the data set include the black-capped chickadee (*Poecile atricapillus*; 1318 observations, 4.4%), the American crow (*Corvus brachyrhynchos*; 1160, 3.9%), the blue jay (*Cyanocitta cristata*; 1033, 3.48%) and the American robin (*Turdus migratorius*; 988, 3.33%; see

Appendix 3 for a full list of bird species analyzed). Bird inventories were primarily conducted by members of the general public and are therefore biased towards particular species (e.g. charismatic species) or towards areas to which they would have had access. As previously stated in Section 2.6.1, hotspots are not the result of a systematic inventory of the distribution of animal life across the town. Bird observation hotspots reflect recreational sightings of bird life at publicly accessible areas.

We pinpointed four bird observation hotspots in the Town of Hudson associated with the following landmarks (Figures 5, 9): the northern edge of the West End forest, the Clark-Sydenham Conservation Area, the Taylor Bradbury Trail, Sandy Beach. The concentration of observations in these four areas can be best explained by their ease of access for birding as well as the availability of habitats suitable for bird biodiversity, including forests, wetlands and open fields.

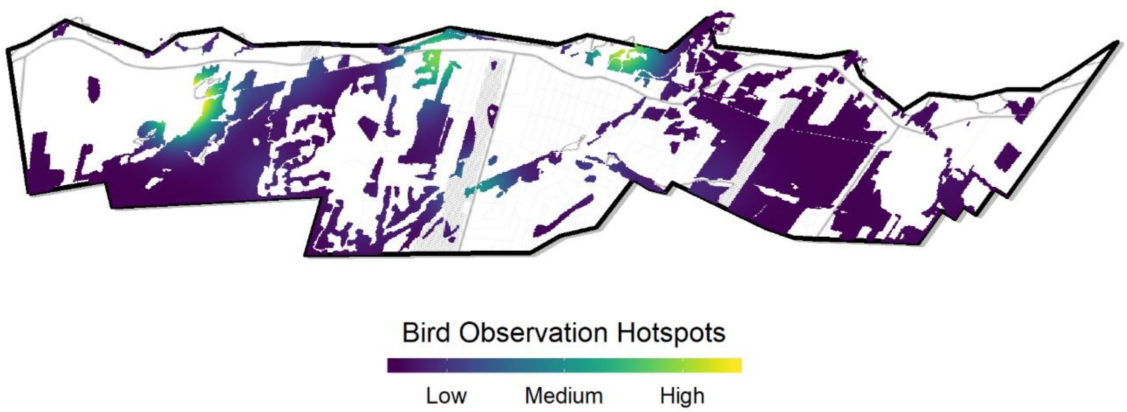

Figure 9. Distribution of bird observation hotspots across Hudson's territory.

3.3.1.2. Herpetofauna observation hotspots

The AARQ herpetofauna dataset comprised 553 observations of 22 species made between 1953 and 2017 within a 5 km radius of the municipal limit of Hudson (Appendix 4). We limited our observation hotspot analysis to 258 observations of 14 species made since 2010 within 500 m of the municipal limit of Hudson. The most common species in the analysis was the northern map turtle (*Graptemys geographica*; 209 observations), followed by the green frog (*Rana clamitans*; 10 observations), wood frog (*Lithobates sylvaticus*; 6 observations) and blue-spotted salamander (*Ambystoma laterale*; 6 observations). The northern map turtle is also listed as a vulnerable species according to the *Loi sur les espèces menacées ou vulnérables*, so associated observations were included in the index quantifying the occurrence of rare species (Section 3.3.1.3).

Our subsample captured an observation hotspot centered around an offshore population of reptiles and amphibians in a marsh complex adjacent to the Willow Inn, throughout the marshes, swamps and bogs of Como forest as well as the shoreline area of Parsons Point (Figures 5, 10). The distribution of herpetofauna extends south-westward through wetland and forest habitats along Rue Bellevue. This area is rich in swamps and bogs, satisfying the habitat requirements for various reptile and amphibian species (Figure 10). A second observation hotspot was identified on the western most point of the town along the Ottawa River at a marsh complex adjacent to the corner of Montée Lavigne and Rue Main.

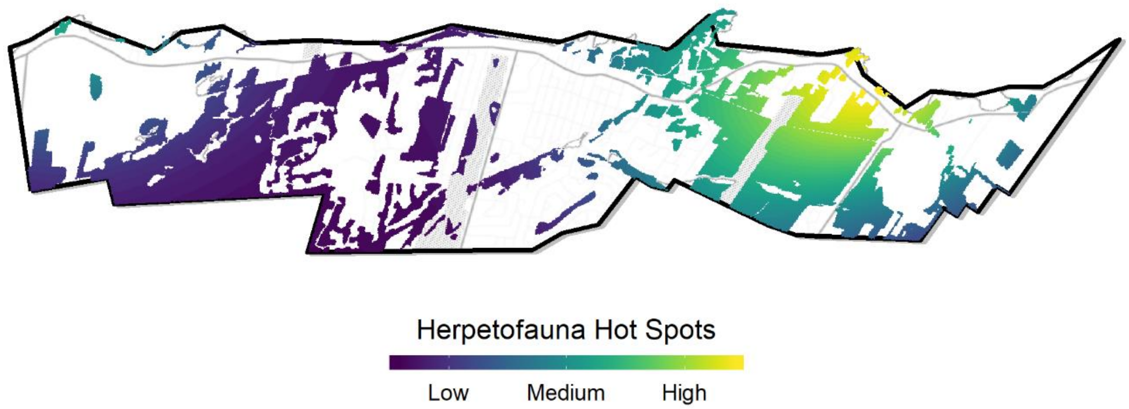

Figure 10. Distribution of herpetofauna within the municipality of Hudson.

3.3.1.3. Species at risk

The CDNPQ recognizes 473 occurrences of 116 at-risk plant species within a 20-kilometer radius of Hudson. Similarly, 38 animal species with 163 observations in total are registered in the database for the same area. Tables summarizing the full list of potential threatened or vulnerable species within the vicinity of Hudson are included in Appendices 5-6.

Within the municipal bounds of Hudson, however, only three plant species designated as near threatened ("*susceptible*" in French) are registered with the CDNPQ with five observations in total made between 1998 and 2015. These include the greater straw sedge (*Carex normalis*), shagbark hickory (*Carya ovata*) and butternut (*Juglans cinerea*). Of these, butternut is registered on the endangered species list at the federal level (COSEWIC 2017). In terms of threatened wildlife species, the AARQ has recorded extensive information on the northern map turtle (*Graptemys geographica*) in Hudson, with 209 observations recorded between 2009 and 2014.

We graded natural areas in Hudson in terms of their importance as habitat for threatened or vulnerable species recorded by the CDNPQ and AARQ databases. Natural areas are graded as important if within 100 m of a species observation, as highlighted in yellow in Figure 11. This approach for grading the importance of natural areas for rare species is very conservative, as the Act Respecting Threatened or Vulnerable Species (E-12.01) governing their protection pertains only to listed fauna and flora and the habitats required to sustain their populations. There is no formal requirement to protect associated forest stands within 100 m of an observation unless that stand was used as habitat essential to the survival of at-risk species. We adopted this approach to underscore the potential of adjacent forest stands in supporting additional observations of species at risk. This was deemed necessary as few observations of species at risk were registered with the CDNPQ and AARQ overall, fewer than would be expected given the diversity and extent of natural areas available in Hudson.

Natural areas of importance for the northern map turtle were primarily distributed along the Ottawa River shoreline. Near threatened plant species, however, were found further inland in Como forest and the natural areas adjacent to Davidson Park (Figures 5, 11).

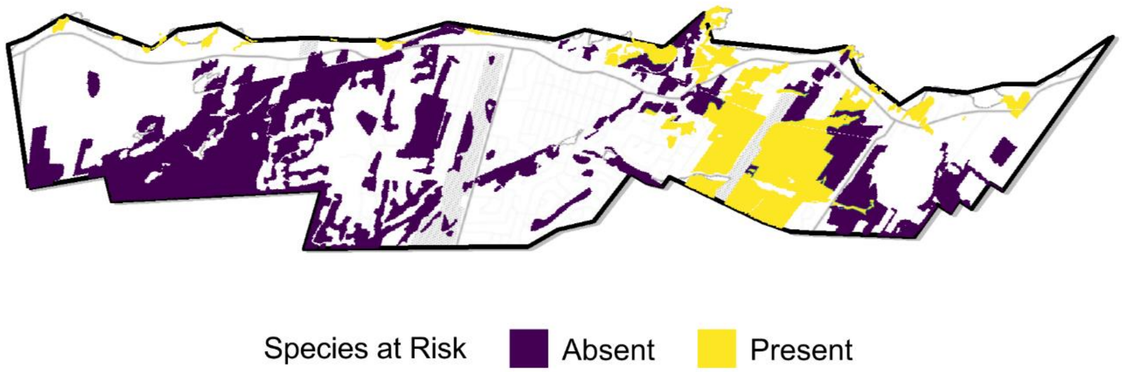

Figure 11. Distribution of rare species observations within the territory of Hudson for observations made between 2009 and 2014.

3.3.2. Landscape connectivity

3.3.2.1. Regional connectivity

The natural areas in Hudson are part of a set of conservation corridors identified by Rayfield et al. (2019) for the Saint-Lawrence Lowlands, extending across the Vaudreuil-Soulanges RCM and continuing northward across the Ottawa River and through the Parc National d'Oka. One of such corridors extends through eastern Hudson, originating in Vaudreuil-Dorion at the intersection of highways 20 and 30 and running westward along Route Harwood. Forests in western Hudson are part of a second corridor contiguous with Mont Saint-Grégoire and the forests of Saint-Lazare adjacent to Côte Saint-Charles. Natural areas in Hudson critical to regional landscape connectivity include the Clark-Sydenham Conservation Area, natural areas along the Viviry River and Taylor Bradbury Trail, and large forested fragments in the West End forest and Como forest (Figure 12).

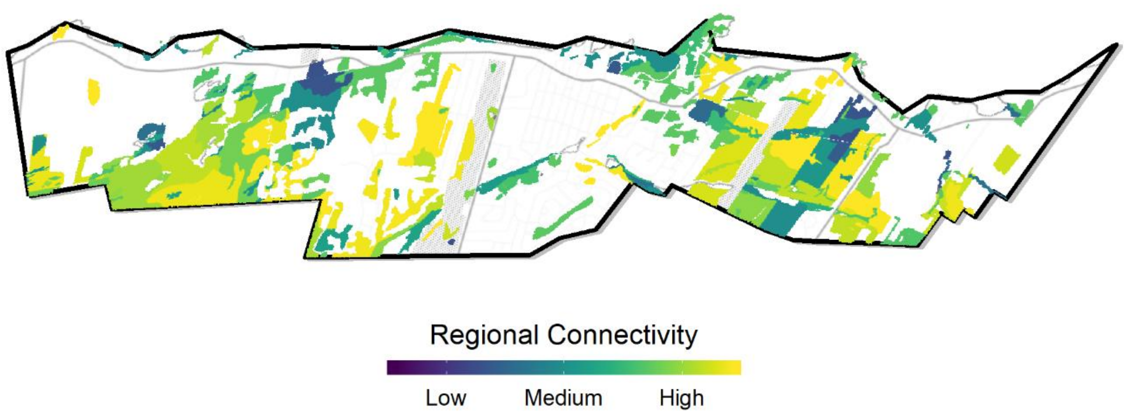

Figure 12.Ranking of natural areas according to their importance to regional connectivity within the Saint-Lawrence Lowlands. Source data were originally taken from Rayfield et al. (2019).

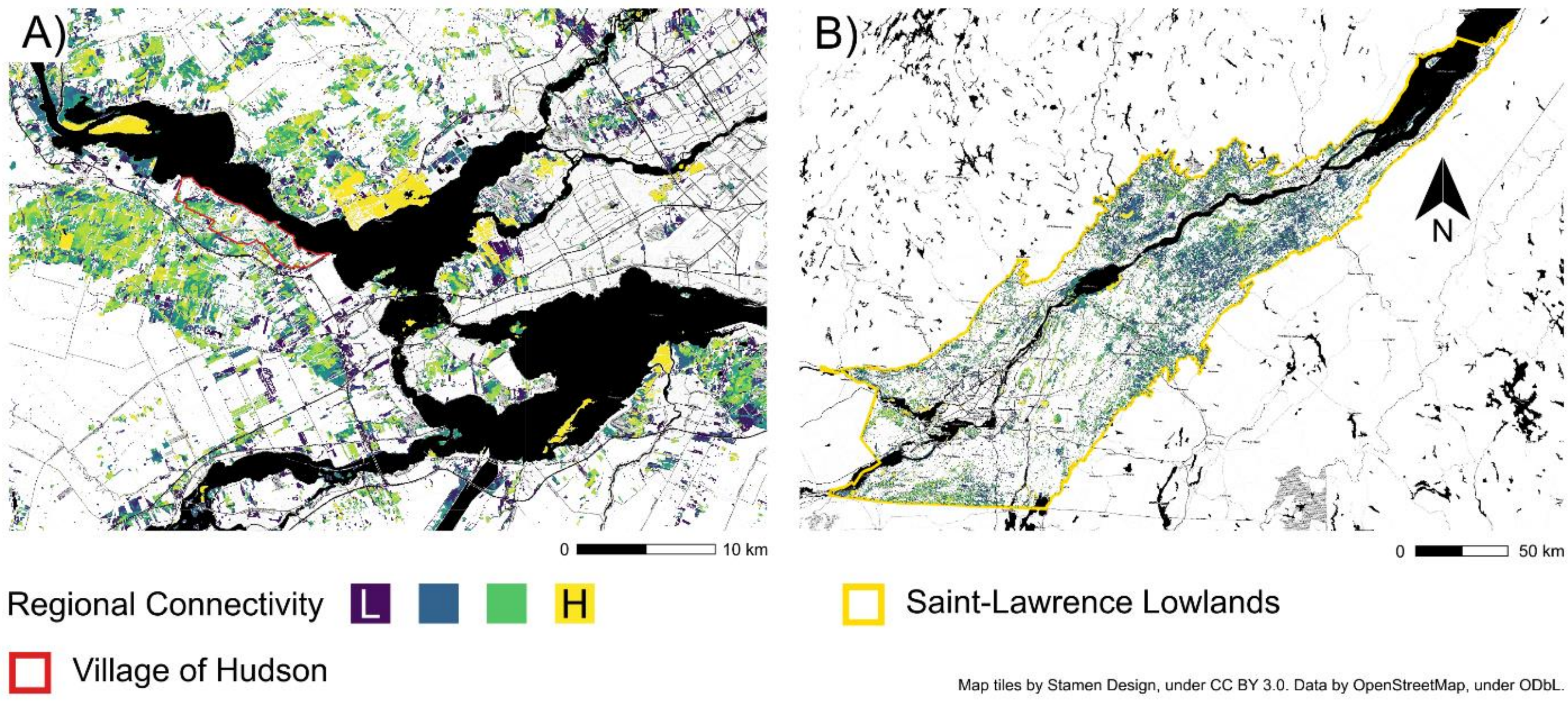

Figure 13. Ranking of natural areas according to their importance to regional connectivity. Panel A is set to the Vaudreuil Soulanges RCM and panel B the full study extent of the Saint-Lawrence Lowlands. Source data were taken from Rayfield et al. (2019).

3.3.2.2. Local connectivity

We conducted a fine-scale connectivity analysis of the natural areas in Hudson to better detect the structural and functional elements in the landscape that facilitate animal dispersal and migration. Results are summarized in Figure 14, which synthesizes the connectivity and habitat requirements for five umbrella species in our analysis using two indices (Figures 15-16). Many of the natural areas illustrated in Figure 14 are essential to regional connectivity as well. Most noteworthy, however, are the forested and wetland elements running the length of the Viviry River and Taylor Bradbury Trail, a corridor in western Hudson passing through West End forest and the forests east of Alstonvale road, as well as the Sandy Beach area (Figure 5, 14). Unlike the index quantifying regional connectivity, the conservation area associated with the Clark-Sydenham Conservation Area is of low to medium importance for local connectivity. This is due in part to conservation areas having been assigned a high connectivity value by default by Rayfield et al. (2019).

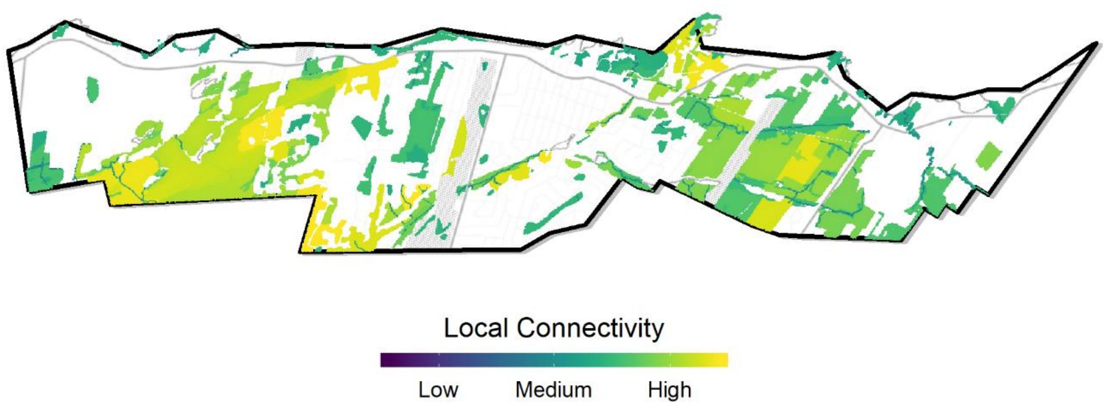

Figure 14. Ranking of natural areas according to their importance to local connectivity in Hudson.

The results in Figure 14 are a composite of those presented in Figures 15 and 16, which highlight landscape elements facilitating animal dispersal using the indices circuit connectivity and betweenness connectivity. Contiguous forested elements associated with West End forest and Como forest are most essential for landscape connectivity across species. Hudson's urban core prevents the flow of organisms between these two forested areas, save for natural areas along the Viviry River that act as a connecting bridge, as well as forest patches running along the Gary Cirko Trail. Forested elements east of Alstonvale road arise as essential for connectivity across species, as are forests and wetlands in the Davidson Park and Nature Area as well as the Sandy Beach area. Connectivity results are largely consistent across the five focal species except for the American pine marten, which exhibits low habitat connectivity overall. This is due to the absence of coniferous forests in Hudson, its preferred habitat. As such, the American pine marten and other similar species would have difficulty surviving in and around Hudson.

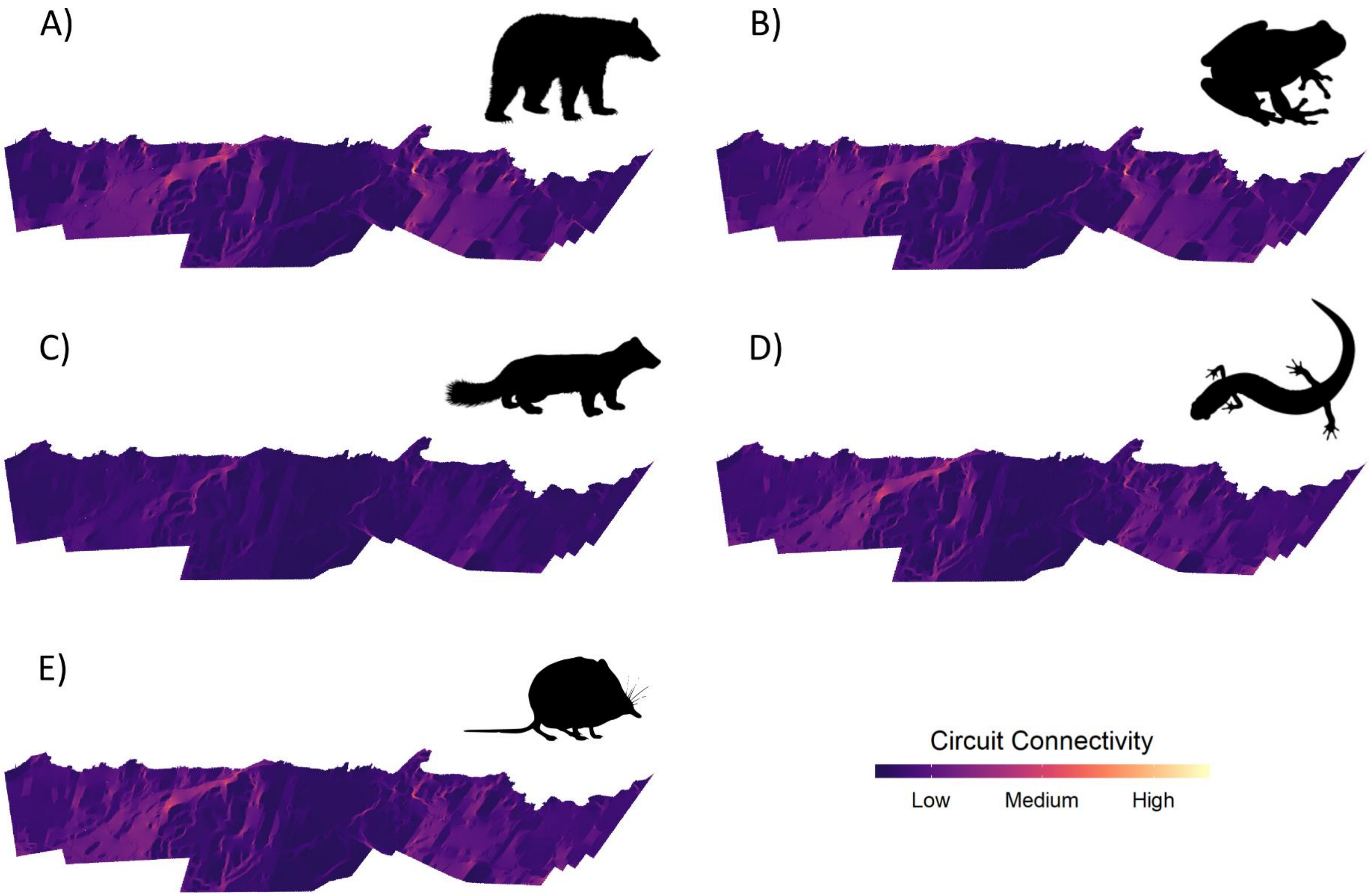

Figure 15. Circuit connectivity analysis results for five focal species, including a) black bear, b) wood frog, c) American pine marten, d) red-backed salamander, e) Northern short-tailed shrew.

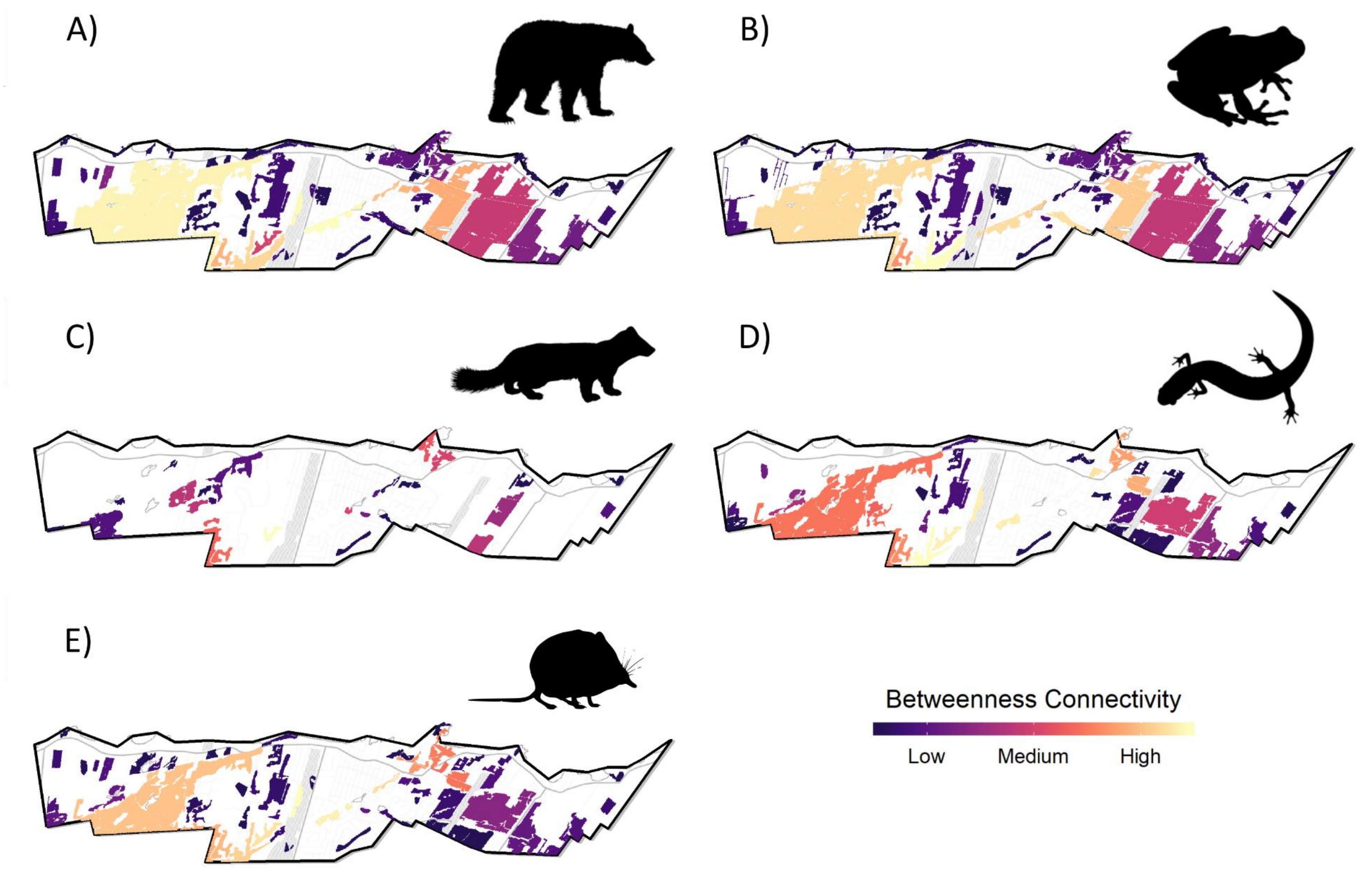

Figure 16. Betweenness connectivity analysis results for five focal species, including a) black bear, b) wood frog, c) American pine marten, d) red-backed salamander, e) Northern short-tailed shrew.

3.3.3. Forest integrity

3.3.3.1. Maturity

Forests in Hudson were classed as young, intermediate or mature using a combination of field-based observations (e.g. tree basal area, DBH) as well as geospatial data (Figure 17). Most of Hudson's forested areas are intermediate in age, whether for forested wetlands (94 ha, 13%) or upland forests (351 ha, 47%). Mature upland forests comprise a large component of the natural landscape (157 ha, 21%). Forested wetlands were seldom classed as mature, though this was in part due to limitations in our sampling protocol. Determining the age of trees in wetlands is challenging as they do not tend to reach the same age at maturity as in well-drained settings, being limited by waterlogging and anaerobic growing conditions.

Table 9. Age classes assigned to forests and forested wetlands. Percent values were calculated according to the total surface area of forested areas in Hudson (743 ha), excluding open wetlands.

	Forests		Forested Wetlands	
Age Group	No. Sites	Area (Ha)	No. Sites	Area (Ha)
Young (< 40 yr)	19	122 (17%)	9	19 (3%)
Intermediate (40-80 yr)	44	351 (47%)	33	94 (12%)
Mature (> 80 yr)	21	157 (21%)	2	1 (<1%)
Total	**84**	**629 (85%)**	**44**	**114 (15%)**

To validate the consistency and accuracy of our age classification, we cross-referenced estimates against DBH values measured at sites. In line with our expectations, larger maximum and average tree diameters tend to indicate greater forest maturity (Figure 18). This relationship is less clear in the case of mature wetlands due, in part, to the limited number of sampling sites for this age class-habitat type combination.

The largest tree found in sampled forested wetland sites had, on average, a diameter at breast height (DBH) of approximately 46 centimeters. The maximum DBH found in these sites was of 103 centimeters, while the smallest maximum DBH was of 15 centimeters (Figure 19). The species found to have the largest DBH at these sites was green ash (*Fraxinus pennsylvanica*). The average diameter across all forested wetland sites was of approximately 16 centimeters (Figure 19). Generally, average DBH was lower in forested wetlands than in forests, a phenomenon best explained by the more difficult growing conditions typical of wetlands.

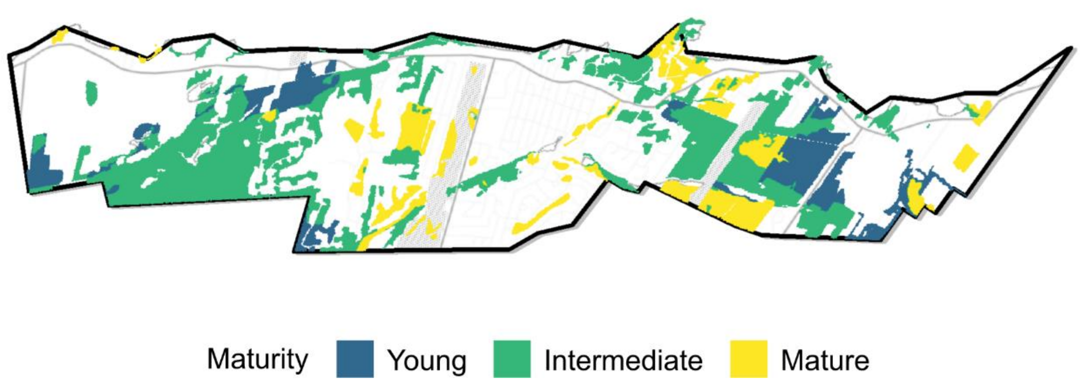

Figure 17. Distribution of forest maturity across the natural landscape in Hudson.

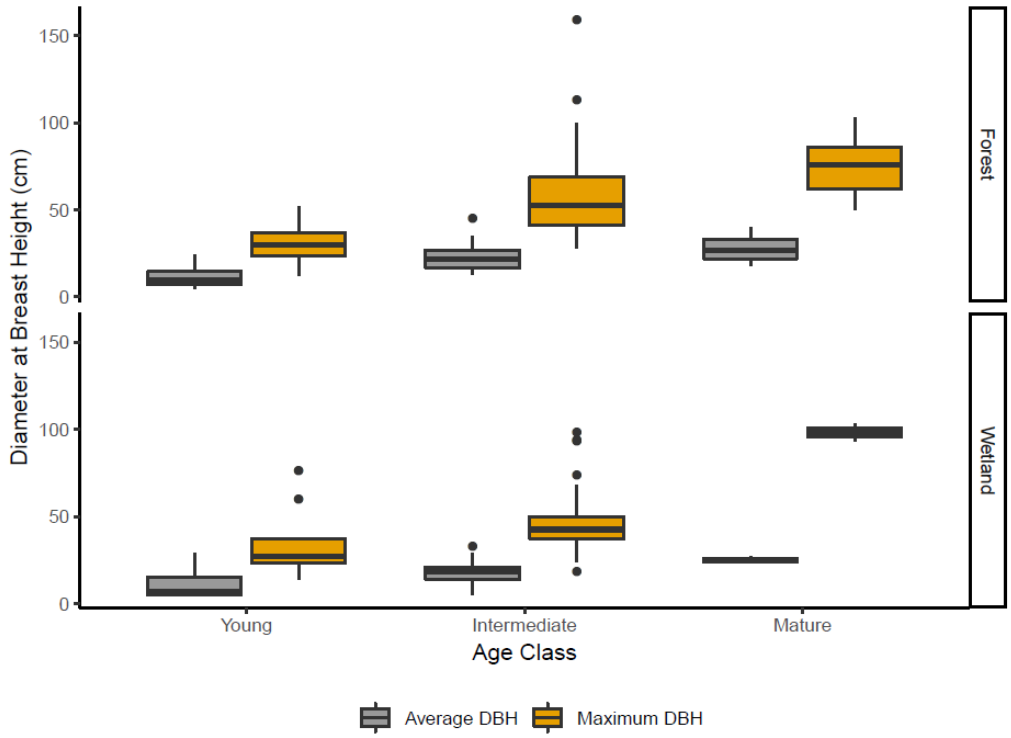

Figure 18. Relationship between diameter at breast height (DBH) and age class for upland forests (top) and forested wetlands (bottom).

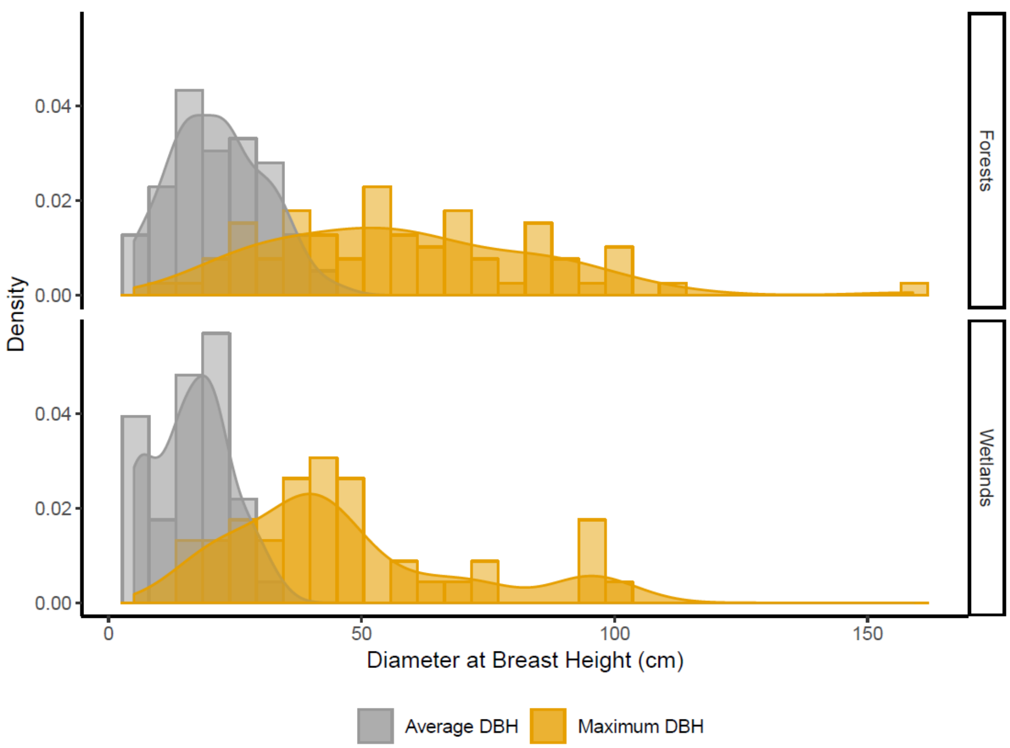

Figure 19. Distribution of average and maximum DBH across all sites in upland forests (top) and forested wetlands (bottom).

The most mature forests in Hudson are situated in areas that are either protected, highly valued for recreation, or difficult to access (Figure 17). These include forest stands associated with the Clark-Sydenham Conservation Area, the Viviry River, Como forest and forest fragments located at the far east end of town (Figure 17).

3.3.3.2. Anthropogenic disturbance

Most upland forests and forested wetlands did not show important signs of anthropogenic disturbance that undermined the ecological integrity of the site (Table 10; Figure 20). Sources of anthropogenic disturbance included the presence of pedestrian trails, electric wires, roads, train tracks, garbage and debris, as well as construction materials.

Table 10. Anthropogenic disturbance classes assigned to upland forests and forested wetlands.

	Forests		**Forested Wetlands**	
Disturbance Class	No. Sites	Area (Ha)	No. Sites	Area (Ha)
High	28	162 (22%)	15	35 (4%)
Low or None	56	468 (63%)	29	80 (11%)
Total	**84**	**629 (85%)**	**44**	**114 (15%)**

Very few sites showed signs of natural sources of disturbance that undermined the ecological integrity of sites, including insects, disease or windthrow. Beech bark scale was observed at one wetland site, as was butternut canker and dwarf mistletoes. Cherry black knot, on the other hand, was observed at two different wetland sites. In terms of upland forests, we observed signs of black knot, butternut canker, dwarf mistletoes and Eutypella canker of maple. Diseases and threats to tree health are further discussed in Section 3.3.4.2

Table 11. Natural disturbance classes assigned to forests and forested wetlands.

	Upland Forests		**Forested Wetlands**	
Disturbance Class	No. Sites	Area (Ha)	No. Sites	Area (Ha)
High	2	7 (<1%)	1	1 (<1%)
Low or None	82	623 (84%)	43	113 (15%)
Total	**84**	**629 (85%)**	**44**	**114 (15%)**

Our measure of forest integrity was calculated exclusively in terms of anthropogenic disturbance as opposed to natural sources of disturbance. As might be expected, anthropogenic disturbance was highest in easily accessible areas and those subject to high degrees of pedestrian traffic (Figure 20) via trails and roads. Areas with the lowest levels of anthropogenic disturbance included the Como and West End forests (Figure 20).

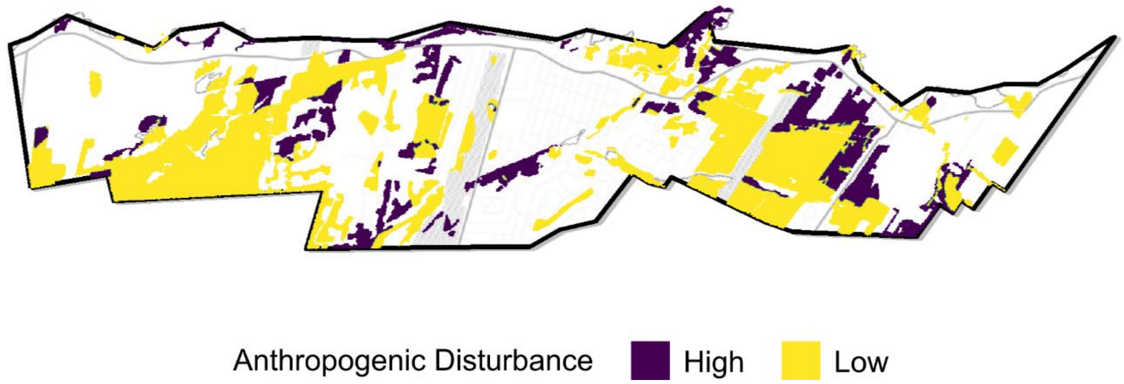

Figure 20. Distribution of the integrity of forests across the territory of Hudson.

3.3.3.3. Exotic species

Exotic species are a concern as they can outcompete native species and prevent the regeneration of the forest canopy as well as understory vegetation. Their dominance can have cascading effects on the forest ecosystem by limiting accessibility to habitat and valuable resources used by animal life. Most forest and forested wetland sites had low levels of exotic species or none (Table 12). However, 24% of the sites inventoried, comprising 14% of the surface area of forested areas in Hudson, were characterized by medium to high levels of disturbance from exotic species. Exotic species tended to coincide with anthropogenic sources of disturbances (e.g. trails, train tracks) and were most highly concentrated along the forest edge or openings in the forest canopy. The most abundant exotic species was buckthorn (*Rhamnus* spp.), present at 46% of sites inventoried and varying in coverage at each site from 5-80%. Additional problematic exotic species included: Tatarian honeysuckle (*Lonicera tatarica*; 5% of inventoried sites), Japanese barberry (*Berberis thunbergii*; 5%), Purple loosestrife (*Lythrum salicaria*; 4%), Common reed (*Phragmites australis; 3%*), Greater celandine (*Chelidonium majus;* 2%), Garlic mustard (*Alliaria petiolate;* 2%) and Japanese knotweed (*Fallopia japonica;* 1%). Purple loosestrife and Common reed tended to be found more often in forested wetland sites.

Table 12. Exotic species cover classes assigned to forests and forested wetlands.

Exotic Species Cover Class	Upland Forests		Forested Wetlands	
	No. Sites	Area (Ha)	No. Sites	Area (Ha)
Low or None (0-25%)	64	551 (74%)	34	86 (11%)
Medium (25-60%)	11	25 (4%)	6	13 (2%)
Medium-High (60-80%)	5	22 (3%)	3	8 (1%)
High (80-100%)	4	31 (4%)	1	6 (1%)
Total	**84**	**629 (85%)**	**44**	**114 (15%)**

As illustrated in Figure 21, the distribution of exotic species across the landscape is concentrated in specific areas and is largely associated with forest fragmentation resulting from walking trails, railways and major roads. Certain vegetation types also tend to be more prone to exotic species, including open habitats with sparse forest cover. Areas with high exotic species cover include forests and wetlands along the Taylor-Bradbury Trail and at the trail head of the Clark, stands along Rue Bellevue associated with Como forest as well forested areas on either side of the train tracks in Hudson West.

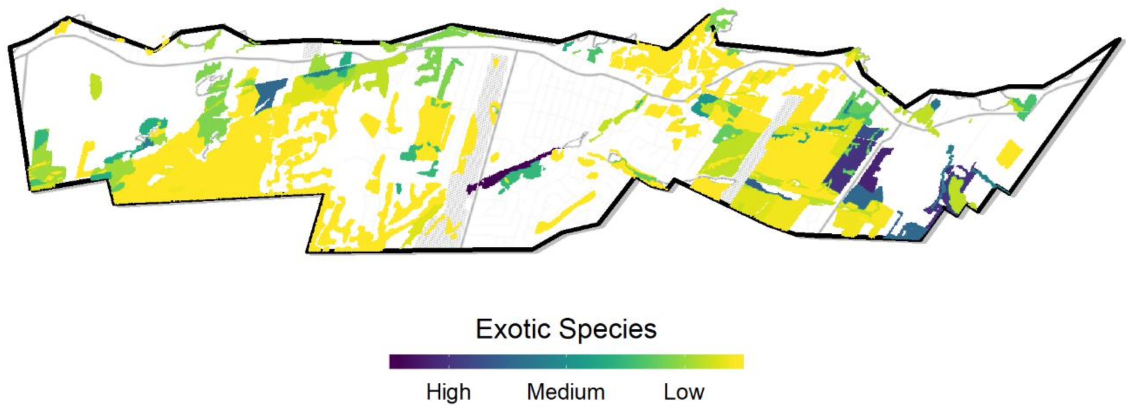

Figure 21. Distribution of exotic species across Hudson. Note that areas with darker colors have higher exotic species coverage.

3.3.4. Forest resilience

3.3.4.1. Tree functional diversity

Tree diversity is evaluated in terms of the relative abundance of multiple tree functional groups at each inventory site, with a total possible score of eight indicating that all possible functional groups are represented to the same degree. Most of Hudson's forested areas are characterized by low to medium tree functional diversity (Table 13). In other words, Hudson's forests are composed primarily of tree species that have similar functional traits. Functional diversity in forested wetlands tends to be lower on average than at upland forests, in part due to the harsher environmental conditions present.

Table 13.Tree functional diversity classes assigned to upland forests and forested wetlands. Classes are defined in terms of the weighted percentage of functional groups present at each site with a total possible score of eight (e.g. 1.5/8=19%).

Tree Functional Diversity Class	Upland Forests		Forested Wetlands	
	No. Sites	Area (Ha)	No. Sites	Area (Ha)
Low (1-29%)	45	334 (45%)	40	85 (11%)
Medium (29-45%)	30	208 (28%)	3	17 (2%)
Medium-High (45-62%)	7	69 (9%)	1	12 (2%)
High (62-80%)	2	18 (3%)	0	0 (0%)
Total	**84**	**629 (85%)**	**44**	**114 (15%)**

Across vegetation types, the forest canopy is dominated by Functional Group 2 (53%; Table 14) and, to a lesser degree, Functional Group 1 (18%) in coniferous and mixed forests. Remaining functional groups are represented to the same degree (5-7%) with the exception of Functional Group 7 (1%), which is underrepresented in the forest canopy overall and includes black cherry (*Prunus serotina*). A description of each functional group and associated traits is summarized in Table 5. Species in Functional Group 2 are shade tolerant with high waterlogging tolerance, high wood density and low leaf mass area. These species include certain maple species (*Acer saccharinum, Acer saccharum, Acer rubrum*), ash species (*Fraxinus americana, Fraxinus nigrea, Fraxinus pennsylvanica*), ironwood (*Ostrya virginiana*) and elm species (*Ulmus Americana*, *Ulmus rubra*). Mixed and coniferous forests are characterized by evergreen species in Functional Group 1 (*Abies balsamea, Larix laricina, Picea glauca, P. rubens, Pinus strobus, Tsuga canadensis*), distinct in having a high leaf mass area and shade tolerance but low wood density. Efforts to improve the resilience of the urban canopy in Hudson would aim to diversify its constituting tree species with Functional Groups 3-8, as listed in Table 5.

Table 14. Basal area percentage for each functional group and vegetation type.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Deciduous Forests	1.50%	24.47%	3.47%	4.24%	2.34%	3.55%	1.11%	0.17%
Mixed Forests	10.38%	5.83%	0.37%	2.66%	1.57%	0.90%	0.02%	1.11%
Coniferous Forests	4.79%	0.30%	0.05%	0.34%	0.16%	0.00%	0.05%	3.38%
Forested Wetlands	1.46%	22.07%	0.77%	0.10%	1.61%	0.60%	0.00%	0.63%
Total	**18.13%**	**52.67%**	**4.66%**	**7.34%**	**5.68%**	**5.05%**	**1.18%**	**5.29%**

Forest stands at northeast end of the Clark-Sydenham Conservation Area have high functional diversity (Figure 22), with tree basal area being evenly divided amongst at least five species and a total of eight tree species overall. A shade-intolerant and fast-growing tree (*Populus tremuloides*) is the dominant species at the site, while the two subdominant species (*Quercus rubra*, *Prunus serotina*) belong to distinct functional groups, as do the remainder of the species present.

Sites at the far west side of the municipality along Montée Lavigne are characterized by few species, or species belonging to similar functional groups with similar biological characteristics. Forest that are dominated by red ash and silver maple may be flood tolerant but are less resilient to additional environmental stressors (e.g. drought). Tree plantations in eastern Hudson are also characterized by low functional diversity, as are early-succession or disturbed sites along the railway dominated by ash (*Fraxinus* spp.) and buckthorn (*Rhamnus* spp.)

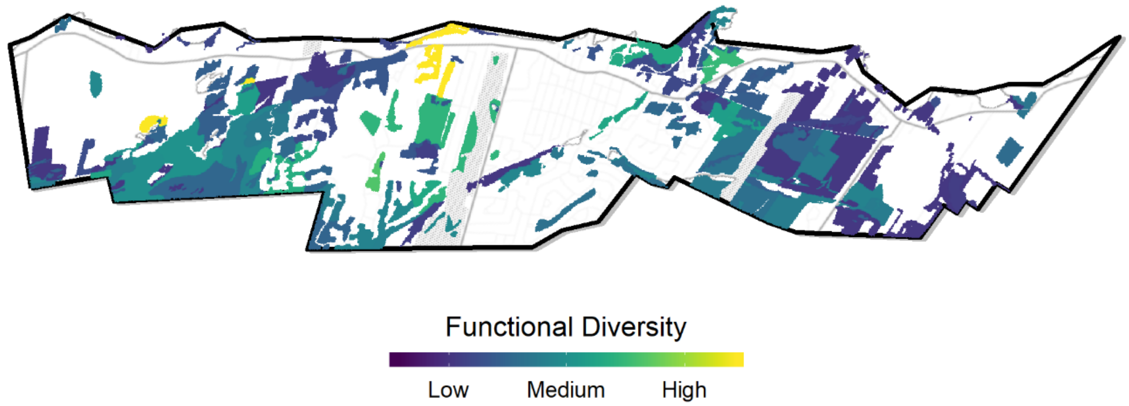

Figure 22. Distribution of tree functional diversity across Hudson's landscape.

3.3.4.2. Vulnerability to current and future biotic threats

Following a literature review and field inventories, we assessed that a total of nine biotic threats are currently established in Quebec. Four biotic threats have already been observed in Hudson including beech bark disease, butternut canker, Dutch elm disease and the emerald ash borer. Remaining threats in Table 15 are already established in Quebec and likely to threaten Hudson's forests. Vulnerable tree genera include fir (*Abies* spp.), beech (*Fagus* spp.), walnut (*Juglans* spp.), maple (*Acer* spp.), ash (*Fraxinus* spp.), spruce (*Picea* spp.) and elm (*Ulmus* spp.).

Eight additional pests and diseases have been identified as a possible threat to Hudson's forest canopy (Table 16). Apart from the Asian gypsy moth, these threats are already established in North America, and the vast majority are already present in eastern North America (Table 16). The Asian gypsy moth is considered a potential threat given the likelihood of its establishment via shipping used in global trade, and the widespread impact it could have on hundreds of species (Lovett et al. 2016). All listed pests and diseases are considered to have severe ecological and economic impacts should they become established (Lovett et al. 2016). The potential establishment of these biotic threats would have additional impacts on multiple tree genera, such as maple (*Acer* spp.), oak (*Quercus* spp.), elm (*Ulmus* spp.) and cherry (*Prunus* spp.).

Table 15. Summary of already-established biotic threats to the integrity of Hudson's forested areas. Information retrieved from Lovett et al. (2016) and the Ontario Invading Species Awareness Program.

	Common name	Latin name	Primary host
Established (QC)	Balsam woolly adelgid	*Adelges piceae*	True firs
	Beech bark disease	*Cryptococcus fagisuga & Nectria coccinea var. faginata*	All species of beech
	Butternut canker	*Sirococcus clavigignenti-juglandacearum*	Most species of walnut
	Chestnut blight	*Cryphonectria parasitica*	American chesnut
	Dutch elm disease	*Ophiostoma ulmi*	All species of elm
	Emerald ash borer	*Agrilus planipennis*	All species of ash
	European gypsy moth	*Lymantria dispar dispar*	Many, but favoring oak, maple, birch, alder and hawthorne
	European woodwasp	*Sirex noctilio*	Scot's pine
	Spruce budworm	*Choristoneura fumiferana*	Balsam fir, white spruce, red spruce

Table 16. Summary of not-yet established biotic threats to the integrity of Hudson's forested areas. Information retrieved from Lovett et al. (2016) and the Ontario Invading Species Awareness Program.

	Common name	Latin name	Primary host
Not yet established	Asian gypsy moth	*Lymantria dispar asiatica*	Many deciduous and coniferous species
	Asian longhorned beetle	*Anoplophora glabripennis*	Many species including maple, elm, willow
	Hemlock woolly adelgid	*Adelges tsugae*	Hemlock
	Oak wilt	*Ceratocystis fagacearum*	Oaks
	Phytophthora dieback	*Phytophthora cinnamomi*	Many, including American chestnut and oak
	Polyphagous shot hole borer*	*Euwallacea* sp. & *Fusarium euwallacea*	Many hosts including maple and oak
	Sudden oak death	*Phytophthora ramorum*	Most species of oak
	Winter moth	*Operophtera brumata*	Oak, cherry, maple

* Note that the Polyphagous shot hole borer is currently restricted to Western North America but has the potential to spread to the eastern part of the continent.

In terms of threats currently established in Hudson (beech bark scale, butternut canker, Dutch elm disease and the emerald ash borer), 17% of the forested area is vulnerable to further invasion (Table 17). Of this, emerald ash borer is of the greatest concern given its elevated mortality rate and its potential to affect approximately 11% of the municipal canopy. Biotic threats currently established in the province could affect up to 36% of forested areas (Table 17). Deciduous forest stands in Hudson are more vulnerable to current or potential biotic threats than other vegetation types (Table 17). Impacts on tree mortality vary depending on the type of threat and degree of infestation.

Among threats currently or potentially established in North America, the Asian gypsy moth is of greatest concern given its possible impact on 95% of the forested areas in Hudson (Table 17). Of more imminent concern is the Asian longhorned beetle, which could have very significant impacts on over 70% of the forest canopy (Table 17).

Table 17. Summary of the forested area affected by biotic threats for each vegetation type. Percentage values are expressed in terms of the total amount of forested areas in Hudson including forested wetlands. Threats currently observed in Hudson are in in bold.

Threat	Forested Area Affected by Biotic Threats (Ha)			
	Deciduous Forest	**Mixed Forest**	**Coniferous Forest**	**Forested Wetland**
Asian gypsy moth	438.98 (58.77%)	134.8 (18.05%)	23.98 (3.21%)	111.41 (14.91%)
Balsam woolly adelgid	4.22 (0.56%)	13.21 (1.77%)	0.01 (0%)	0.16 (0.02%)
Beech bark scale	**22.27 (2.98%)**	**4.02 (0.54%)**	**0 (0%)**	**0 (0%)**
Butternut canker	**0.33 (0.04%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**
Dutch elm disease	**14.95 (2%)**	**0.89 (0.12%)**	**0 (0%)**	**6.96 (0.93%)**
Emerald Ash Borer	**80.61 (10.79%)**	**3.8 (0.51%)**	**0 (0%)**	**39.32 (5.26%)**
European gypsy Moth	119.59 (16.01%)	24.62 (3.3%)	2.34 (0.31%)	13.44 (1.8%)
European woodwasp	13.1 (1.75%)	29.83 (3.99%)	14.59 (1.95%)	1.15 (0.15%)
Hemlock woolly adelgid	2.88 (0.39%)	11.6 (1.55%)	6.41 (0.86%)	0.53 (0.07%)
Oak wilt disease	63.18 (8.46%)	17.49 (2.34%)	0.88 (0.12%)	1.66 (0.22%)
Phytophthora dieback	0.12 (0.02%)	0 (0%)	0 (0%)	0 (0%)
Polyphagous shot hole borer	221.83 (29.7%)	55.37 (7.41%)	1.27 (0.17%)	42.69 (5.71%)
Asian longhorned beetle	370.12 (49.55%)	67.09 (8.98%)	2.73 (0.37%)	93.76 (12.55%)
Sudden oak death	63.18 (8.46%)	17.49 (2.34%)	0.88 (0.12%)	2.41 (0.32%)
Winter moth	231.4 (30.98%)	55.53 (7.43%)	1.27 (0.17%)	35.78 (4.79%)
Spruce budworm	4.48 (0.6%)	13.55 (1.81%)	11.63 (1.56%)	0.75 (0.1%)

Note: Chestnut blight is not included in this table given that no trees of the chestnut genus (*Castanea* spp.) were found in Hudson following through field-based inventories.

Most of Hudson's forested landscape has moderate to high vulnerability to future biotic threats. The most vulnerable sections of forest are in the West End forest and Como forest. Notably, two spruce plantations to the east of town along rue Main have low vulnerability despite having low tree diversity. Higher tree diversity generally increases the resilience of the forest canopy to potential threats. However, these sites are only affected by a single biotic threat amongst those studied (Tables 15-16), the spruce budworm, so the impact on the forest canopy was lower on average in our simulations when compared with forests vulnerable to multiple species. However, if the spruce budworm were to arrive, nearly 100% of the trees in these plantations would be at risk. Considering both tree diversity and our index of simulated vulnerability to future threats provides a more complete portrait of forest resilience in Hudson than either one alone.

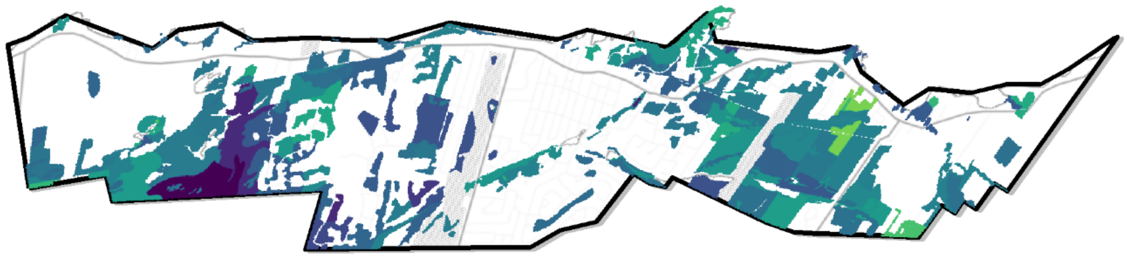

Figure 23.. Distribution of the forested landscape's simulated vulnerability to future biotic threats.

3.3.4.3. Waterlogging tolerance

In terms of tolerance to waterlogging, most of Hudson's upland forests rank from medium to low as per data obtained from Niinemets and Valladares (2016). Expectedly, all forested wetlands have either medium to high waterlogging tolerance.

Table 18.Waterlogging tolerance classes assigned to forests and forested wetlands. Classes are defined in terms of waterlogging tolerance on a scale from 0 to a maximum of 1 and evenly distributed among three tolerance classes (low, medium, high).

Waterlogging Tolerance	**Forests**		**Forested Wetlands**	
	No. Sites	Area (Ha)	No. Sites	Area (Ha)
Low	46	325 (44%)	0	0 (<1%)
Medium	29	241 (32%)	20	51 (7%)
High	9	64 (9%)	24	63 (8%)
Total	**84**	**629 (85%)**	**44**	**114 (15%)**

The areas which rank higher for this index tend to be dominated by species such as red ash or silver maple (Figure 24). Of concern would be forests along the waterfront susceptible to spring flooding and with low waterlogging tolerance, as is the case with parts of Parsons Point.

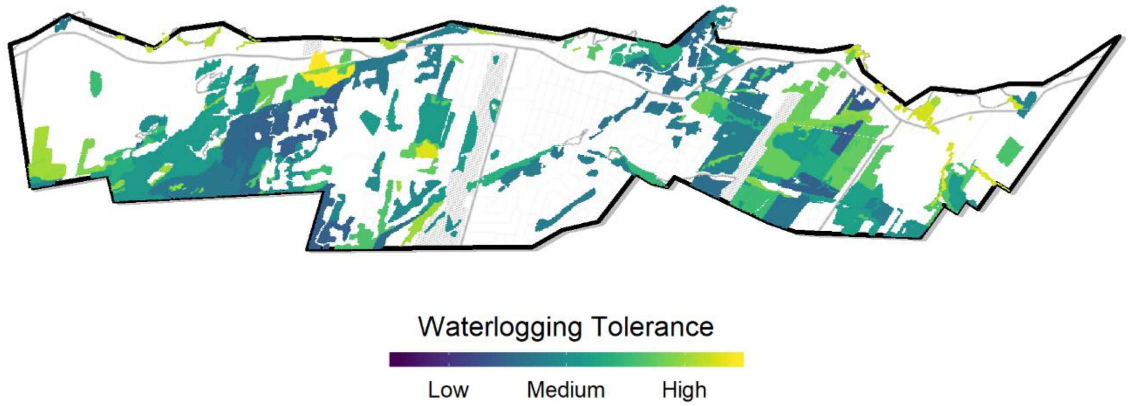

Figure 24.. Distribution of the forested landscape according to waterlogging tolerance.

3.3.4.4. Drought tolerance

Hudson's forests are generally more tolerant to drought than they are to waterlogging (Table 19, Figure 25). In fact, a total of 531 ha (64%) of the forested landscape is classified as having moderate levels of drought tolerance.

Table 19.Drought tolerance classes assigned to forests and forested wetlands. Classes are defined in terms of drought tolerance on a scale from 0 to a maximum of 1 and evenly distributed among three tolerance classes (low, medium, high).

Drought Tolerance	**Forests**		**Forested Wetlands**	
	No. Sites	Area (Ha)	No. Sites	Area (Ha)
Low	11	101 (14%)	5	4 (<1%)
Medium	59	450 (60%)	26	78 (11%)
High	14	79 (11%)	13	32 (4%)
Total	**84**	**629 (85%)**	**44**	**114 (15%)**

The forested stands with the highest drought tolerance tend to be dominated by red oak (*Quercus rubra*) and white pine (*Pinus strobus*)

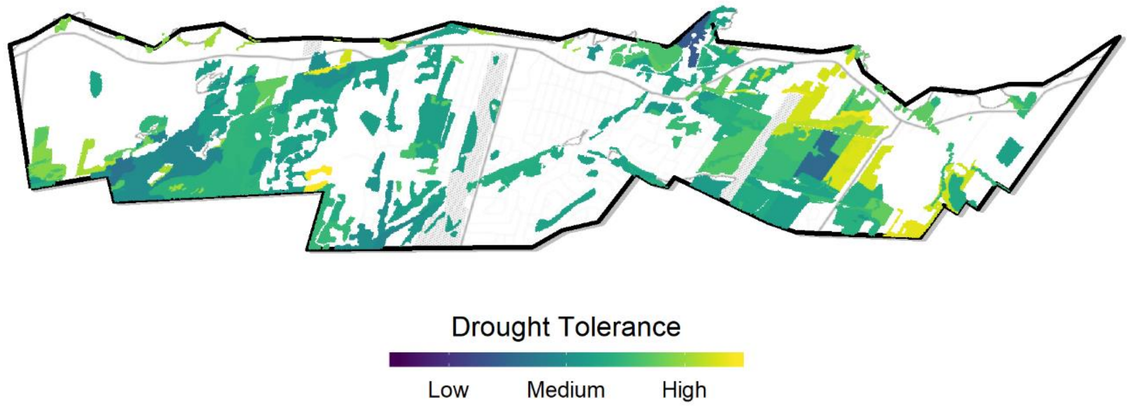

Figure 25. Distribution of Hudson's forested landscape according to drought tolerance.

3.3.4.5. Simulated Susceptibility to Development

Having run a set of land use simulations over a fifty-year time horizon for a total of 40 replicate runs of the model using a business-as-usual scenario, we identified forested areas in Hudson most susceptible to urbanization or agricultural intensification. Notably, simulations did not allow for the wetland loss, including forested and non-forested wetlands, as they are currently protected under Hudson's bylaws (bylaw No. 526) and according to provincial regulations (Bill 132; *Loi sur la Qualité de l'Environnement* L.R.Q., c.Q-2). Details on land use simulations, including the distribution and rate of urbanization and agricultural intensification, are found in Section 3.6. Across all our simulations, approximately 199 ha (27%) of the forested areas are at high risk of development. An additional 30 ha (4%) and 26 ha (4%) of upland forests are of intermediate to low risk, respectively, while 65% of upland forests are of very low risk. Low risk forests are either protected via municipal or provincial regulations or include those that are far from current urban infrastructure and agricultural land such that the probability of their loss is relatively low given the parameters defining land cover change in our models.

Results pertaining to simulated development pressures neither provide a prescription of where development ought to take place nor do they indicate where development will take place with absolute certainty. Rather, they should be interpreted as areas that are susceptible to urban development or agricultural intensification using the set of parameters in the land use models. Future work could include revised estimates based on new data or parameter estimates.

Table 20. Summary of the forested area susceptible to development. Percentage values are expressed in terms of the total amount of forested areas in Hudson including forested wetlands.

Simulated Development Probability	Area (Ha)
100%	199 (27%)
>=50%, <100%	30 (4%)
>0%, <50%	26 (4%)
0%	488 (65%)
Total	**743 (100%)**

In general, we observed very low variability across model iterations in terms of the spatial distribution of forest loss resulting from urbanization and agricultural intensification in our land use simulations. Forested areas susceptible to urbanization are associated with Hudson's urban core, including forest fragments associated with West End forest, the Gary Cirko trail, the Viviry River, Sandy Beach, Parsons Point and Como forest on either side of Rue Bellevue. Areas vulnerable to agricultural intensification include the margins of a set of forest fragments to the extreme east and west of the town.

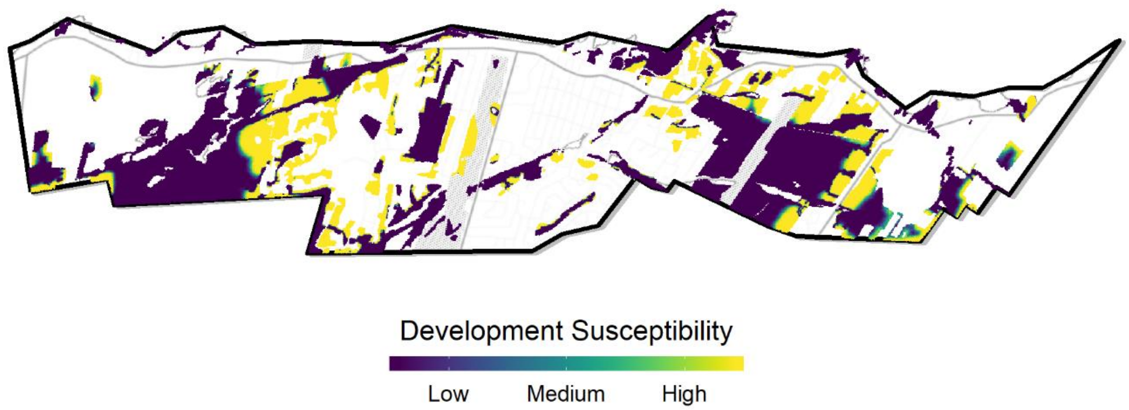

Figure 26. Distribution of forested areas most susceptible to urban and rural expansion.

3.3.5. Ecosystem services

3.3.5.1. Flood mitigation

We graded forests in terms of their spatial proximity to the flood zones defined by the *Ministre des Affaires municipales et Habitation* (MAMH) for the Special Intervention Zone (ZIS; Figure 27). Forests within the flood zone were ranked as contributing the most to the mitigation of spring flooding along the Ottawa River; flood mitigation services were said to decrease as a function of a forest's distance from the flood zone. Few of Hudson's forests are within the flood zone (49 ha, 7%). All other forests are evenly distributed across the remaining distance classes (Table 21). Many of the forests within the flood zone are in the Parsons Point area and natural areas along Main Road.

Table 21. Area distribution of forested areas, including forested wetlands, at increasing distances from the flood zone.

Proximity to Flood Zone	Forest Area (Ha)
In the flood zone	49 (7%)
1-500 m	191 (26%)
500-1000 m	230 (31%)
>1000 m	273 (37%)
Total	**743 (100%)**

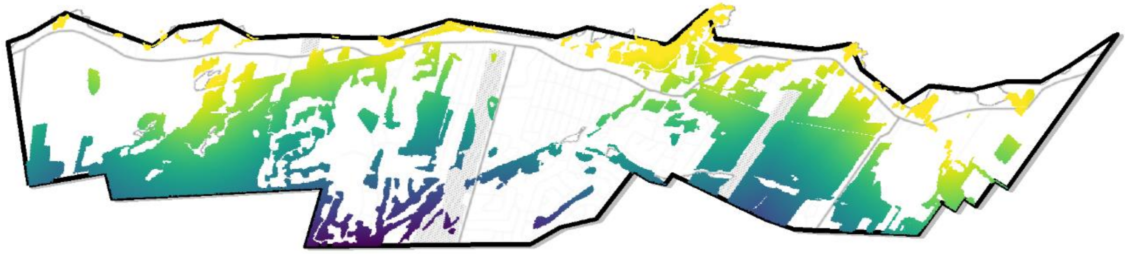

Figure 27. Distribution of Hudson's forested landscape according to its importance for flood mitigation.

3.3.5.2. Carbon storage

Aboveground stored carbon estimates varied across inventory sites between 72 – 670 t CO_2 /ha with a mean value of 330 t CO_2 /ha. The density of stored carbon tended to be highest in coniferous forests and lowest in deciduous forests (Table 22). This reflects both the age and species composition of trees in each forest stand.

Table 22. Mean density of carbon stored per vegetation type.

Carbon Class	Density of Carbon Stored (t CO_2/Ha)			
	Deciduous Forest	**Mixed Forest**	**Coniferous Forest**	**Forested Wetland**
Low	180.49	241.55	0.00	213.38
Medium	381.71	420.85	366.80	382.51
High	530.54	541.02	491.60	562.32
Mean	**364.25**	**401.14**	**429.20**	**386.07**

In total, Hudson's forests store over 268,776 tonnes of aboveground CO_2. Deciduous forests store the greatest reservoir of CO_2, largely due to the greater surface area that they occupy relative to other vegetation types.

Table 23. Total carbon stored per vegetation type.

Carbon Class	Total Aboveground Carbon Stored (t CO_2)			
	Deciduous Forest	Mixed Forest	Coniferous Forest	Forested Wetland
Low	104673.60	36826.27	14545.06	31981.46
Medium	30139.84	11422.96	0.00	0.00
High	30502.78	8683.64	0.00	0.00
Total	**165316.2**	**56932.87**	**14545.06**	**31981.46**

Areas critical for carbon storage in Hudson are adjacent to Falcon Golf Course near the Gary Cirko Trail, but the distribution of carbon density is relatively homogenous across the landscape. In general, mature forests that are either mixed or coniferous in species composition hold the greatest reservoir of stored carbon.

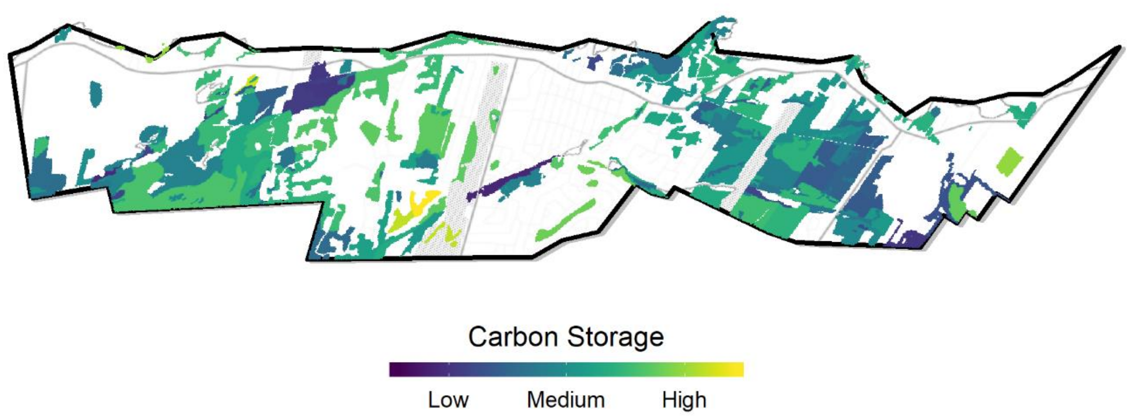

Figure 28. Distribution of Hudson's forested landscape in terms of its importance for carbon storage.

3.3.6. Recreation and history

3.3.6.1. Recreational importance

The areas having the highest importance for recreation, as identified by the participants at a workshop led by Eco2urb with Hudson's administration and municipal council (Section 3.4), covered approximately 315 ha or 42% of its forests. These are primarily associated with the town's trail network extending throughout the following areas: the length of the Viviry River and Taylor Bradbury Trail, the Gary Cirko trail, the Clark-Sydenham Conservation Area, Sandy Beach, Parsons Point, Davidson Park and Como forest (Figure 29).

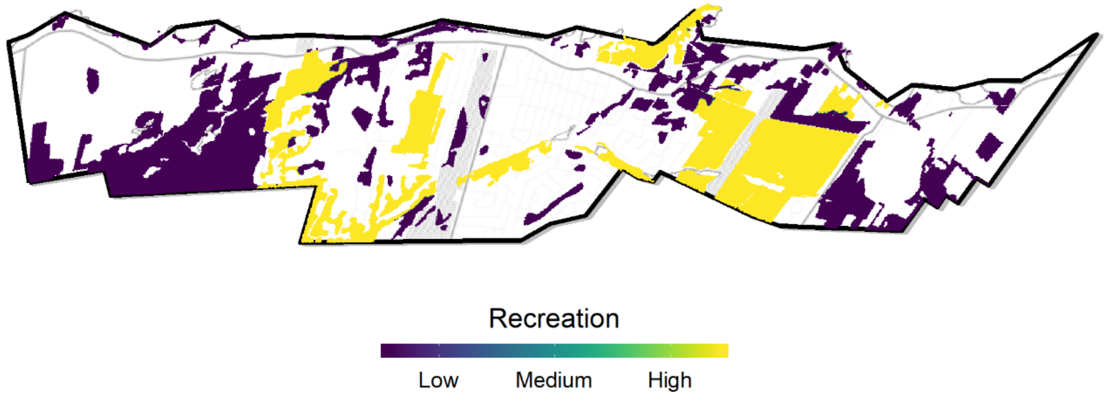

Figure 29. Distribution of Hudson's forested landscape in terms of its importance for recreation.

3.3.6.2. Historical importance

Natural areas with the greatest historical significance, as identified by the Hudson administration and town council, comprise a total of 240 Ha of forested area or approximately 32% of the forests in the town. As with areas of recreational importance, their distribution is associated with the Viviry River and Parsons Point, the Ottawa River, the Clark-Sydenham Conservation Area, Davidson Park and Como forest (Figure 30). Many of the historically important natural areas located along the Ottawa River have additional value as viewpoints or form part of the Hudson's heritage belt and scenic road (Town of Hudson 2009). Portions of the Como district, namely the Greenwood Center for Living History and nearby archaeological site, are also historically valuable (Figure 30; Town of Hudson 2009). Additional information on the historical significance of these areas is provided in Section 3.4.

Figure 30. Distribution of Hudson's forested landscape in terms of its historical importance as prescribed by the Hudson administration and town council.

3.4. Workshops

We conducted two workshops to 1) gather information on municipal (Section 3.4.1) and citizen (Section 3.4.2) conservation priorities, 2) identify natural areas of historical and recreational importance, and 3) develop land use change scenarios corresponding to anticipated land use change trajectories for the municipality over the next 50 years.

3.4.1. Workshop with Town's council and administration

3.4.1.1. Attendance

The ten attendees present at the workshop for the Town's council and administration consisted of members of Hudson's executive council as well as employees of the Urban Planning and Public Services departments. Workshop participants were divided into two groups, each one led by an Eco2urb employee through a series of exercises (Sections 3.4.1.2- 3.4.1.4).

3.4.1.2. Areas of historical importance

Areas of historical importance were defined by each of the two groups, after which results were discussed and consolidated. Participants identified multiple sites as being historically significant (Figure 30), but only those located within or adjacent to natural areas were included in the conservation plan:

- **Sandy Beach**: Historical train station site and beach area that was once heavily used by tourists and local vendors. It was the site of a glass factory of some notoriety, as well as one of Hudson's local ice companies (J. Nicholls, pers. comm. 2019).
- **Greenwood Center for Living History**: A heritage site in Hudson founded in 1732.
- **Parsons Point**: Used as a trading point for First Nations' peoples, also referred to as the "*Point du grand détroit"* (J. Nicholls, pers. comm. 2019).
- **Railroad**: The entirety of the railroad running through Hudson east to west was identified as being of historical importance given that six train stations were once established along it.
- **Côte-Saint-Charles**: During the 1800s, Jean Condon owned land on either side of this road. Lots were then divided and flipped to two settlers: Forbes, a timber baron, and Mathison, who founded Westwood High School. Tensions arose between the two families during the rebellions of 1837, one owner being a Loyalist and the other a Patriot (J. Nicholls, pers. comm. 2019).

Natural areas were graded as being of historical significance to the degree that they coincided with the areas identified during the workshop by participants. Results are presented in Section 3.3.6.2.

3.4.1.3. Areas of recreational importance

As with the previous activity, each of the two groups identified important recreational areas separately and then discussed them together before arriving at a consensus. Participants identified the entirety of Hudson's trail network, located on both public and private properties, as being recreationally important. Additional recreational areas included Sandy Beach, forests and wetlands along the Viviry River and Davidson Park.

3.4.1.4. Forecasted development pressures

Each group envisioned their own scenario detailing how the landscape of Hudson might evolve over the course of the next 50 years, focusing on two drivers of land use change: agricultural intensification and urban development. Following some discussion, participants decided to keep the two scenarios distinct rather than drawing on elements of each in reaching a consensus. Scenarios differed both in terms of the distribution and extent of anticipated land use change. It was understood throughout the exercise that participants were being asked how the landscape might evolve and not to provide prescriptions for how forest loss, urban development or agricultural intensification should proceed in the future. The nature of the activity was to explore a range of different land use change alternatives to ascertain expected impacts on the ecological integrity of the landscape. Described further in Section 3.6.2, the two scenarios were as follows:

Scenario 1 - Transit-oriented development:

Urban development would proceed at multiple points along Hudson's main transport axes, including the railway and route Harwood. Development pressure emanating from Vaudreuil-Dorion would cause most development to take place in eastern Hudson and at its extremities following an "outside-in" pattern. Some agricultural expansion would be expected at the southern edge of the Whitlock Golf and Country Club but would otherwise be minimal. Agricultural land would be lost in part to urban developments in areas previously zoned white. Hudson's golf courses would also be flipped into urban developments resulting in the erasure of Golf Falcon, the Whitlock Golf and Country Club as well as the Como Golf Club.

Scenario 2 - Service-oriented development:

Development would follow an "inside-out" spatial pattern, expanding from the urban core towards Hudson's extremities using available infrastructure (e.g. sewage connections). Existing fallow land adjacent to urban areas would be prioritized for urban development, as well as Golf Falcon, the Como Golf Club and the segment of the Whitlock Golf and Country Club north of Chemin du Golf. More agricultural expansion into fallow fields would take place than in the Transit-oriented development scenario, concentrated foremost in western Hudson adjacent to existing agricultural fields. Forest loss would be concentrated in eastern Hudson resulting in the complete erasure of forested areas on all sides of the Como Golf Club.

3.4.1.5. Conservation priorities

The final exercise provided information on which weights to assign ecological characteristics used in prioritizing Hudson's natural areas for conservation. The approach adopted by each of the two groups in assigning weights varied such that arriving at a consensus was difficult. To remedy any discrepancies between groups, it was agreed that Eco2urb would adopt the average of the two sets of ranks developed during the workshop (Table 24). Results of the landscape prioritization are further described in Section 3.5.1.

Table 24. Summary of ranks assigned to ecological characteristics by members of Hudson's administration and council. The consensus column represents the average between the two ranks and was ultimately used in the analysis (Section 3.5.1).

Variables	Group 1	Group 2	Consensus
Carbon	4	3	4
Connectivity	5	1	3
Ecological integrity	8	3	6
Faunal Biodiversity	3	1	2
Flood mitigation	6	2	4
Maturity	2	1	2
Recreation	1	4	3
Resilience	7	5	6
Tree Biodiversity	1	1	1

3.4.2. Workshop with Town residents

3.4.2.1. Attendance

Approximately 26 participants attended the workshop held for Hudson's residents, five of which were present at the previous workshop for the Town's council and administration (Section 3.4.1). Workshop participants were divided into sub-group of approximately eight individuals, each group facilitated by an Eco2urb employee or volunteer and guided through a set of exercises.

3.4.2.2. Conservation priorities

During the workshop and ensuing discussions, concerns were raised by participants regarding the mandate of the conservation plan detailed in the current report. For instance, some voiced disapproval towards the idea of prioritizing natural areas for conservation. They argued that all of Hudson's natural areas should be conserved as they represent a fraction of its historical forest cover. Similarly, when asked to prioritize ecological characteristics in terms of their perceived importance for conservation, many of the participants did not see the value in the exercise. They chose not to rank the ecological characteristics provided and opted to assign them an equivalent level of importance.

The consensus in terms of prioritizing either natural areas or ecological characteristics for conservation was in fact not to rank them at all. Many of the participants expressed a concern that all remaining natural areas in Hudson should be conserved, and that all ecological characteristics described were of equal importance. That said, biodiversity emerged consistently across participant subgroups as being critical to conservation. Participants emphasized that many ecological characteristics either directly or indirectly depend on biodiversity. The general conclusion was to assign equal weights to ecological characteristics in model development, as contrasted with the weights developed by the Hudson town council and administration. Refer to Section 3.5.1.2 for results of the landscape prioritization using weights assigned by the sample of citizens at the workshop.

3.5. Synthesizing conservation priorities

Taking into consideration 17 metrics quantifying the importance of natural areas to biodiversity, landscape connectivity, forest integrity, forest resilience, ecosystem services, as well as recreation and history, we identified priority areas for conservation in Hudson. Rankings are weighted by the perceived significance of each metric by the town council and administration as well as a sample of Hudson's citizens. They reflect municipal and provincial regulations stipulating natural elements of the landscape with de facto conservation status, while maximizing the spatial contiguity of priority forested and wetland features.

The approach taken was to use conservation metrics to rank forested elements according to municipal (Section 3.5.1.1) and citizen (Section 3.5.1.2) priorities separately, as established through a set of workshops held with each (Sections 3.4.1 and 3.4.2). We conducted two additional runs of the analysis in which areas with de facto conservation status were assigned the highest values by default, and all other areas were scored in terms of their spatial contiguity with these areas as well as their respective conservation index scores. The average of these two results was taken as a final consensus map, and thereafter used in the development of landscape models (Section 3.5.1.3).

3.5.1. Conservation priority scenarios

3.5.1.1. Municipal ranking

Conservation indices were weighted according to ranks established with the town council and administration and pertain only to forested areas incorporated in our analysis, excluding open wetlands but including forested wetlands. Results identify a set of key forested landscape features for conservation in Hudson, including those along the shoreline (e.g. Sandy Beach, Parsons Point) and those associated with the Viviry River, Davidson Park, Como forest, the Clark-Sydenham Conservation Area, Como forest and the Gary Cirko Trail (Figure 31).

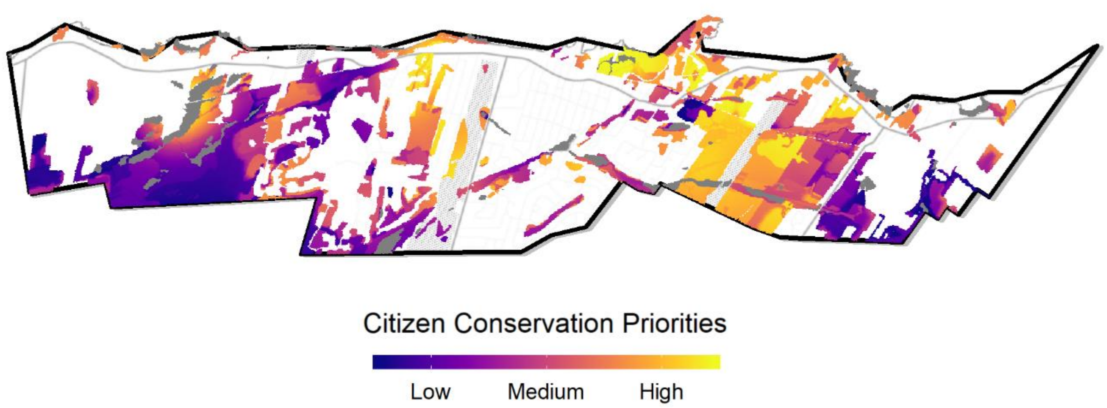

Figure 31. Ranking of Hudson's natural areas in terms of their priority for conservation as determined by the town's administration.

3.5.1.2. Citizen ranking

Conservation indices were weighted according to ranks established during a workshop with Hudson's citizens and pertain only to forested areas, excluding open wetlands but including forested wetlands. In this case, equal ranks are assigned to all conservation indices. Results (Figure 32) are ostensibly similar to those generated using the municipal rankings (Section 3.5.1.1). As multiple conservation indices were in fact given the same weight in the conservation scenario developed by the municipality (e.g. faunal biodiversity and maturity, recreation and connectivity, flood mitigation and carbon, ecological resilience and integrity), variability amongst indices was low and comparable to assigning all variables the same weight as in the scenario developed by citizens. The overall pattern of resulting conservation priorities in Figures 31 and 32 is the same, but the relative ranking of any given forest varies to a small degree between scenarios.

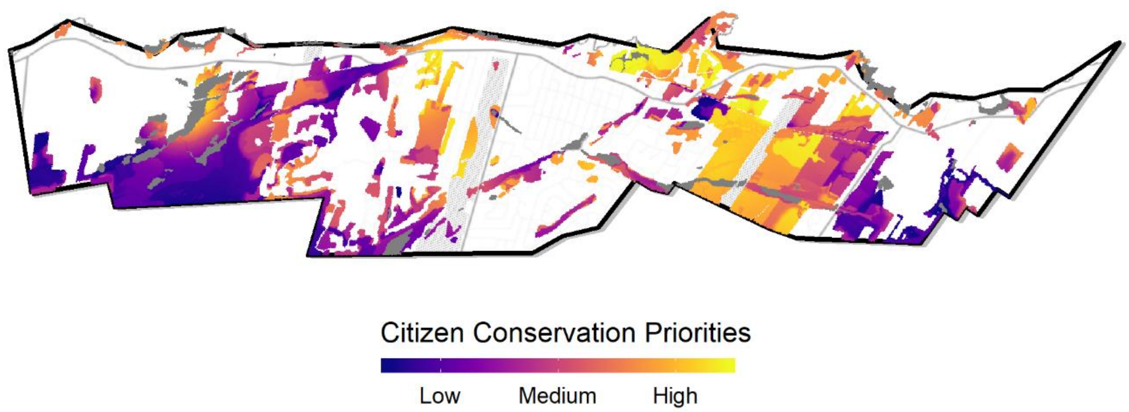

Figure 32. Ranking of Hudson's natural areas in terms of their priority for conservation as determined by the town's citizens.

3.5.1.3. Consensus ranking

We calculated the average conservation priorities for all forests as established through the municipal and citizen ranking scenarios and graded areas with de facto conservation status the highest values by default in building a final consensus map (Figure 33). The spatial distribution of priority natural areas is consistent with Figures 31 and 32, with the addition of all wetland areas (open and forested), as well as steep slopes, riparian buffers and conservation areas coinciding with natural areas (Section 2.7).

We used consensus results in designing a set of landscape modelling scenarios (Section 3.6). Specifically, we identified the highest priority natural areas in the landscape comprising 20, 25, and 30% of the landscape (Figure 35) and estimated the impact of their protection over a 50-year time horizon given anticipated rates of urban and agricultural expansion.

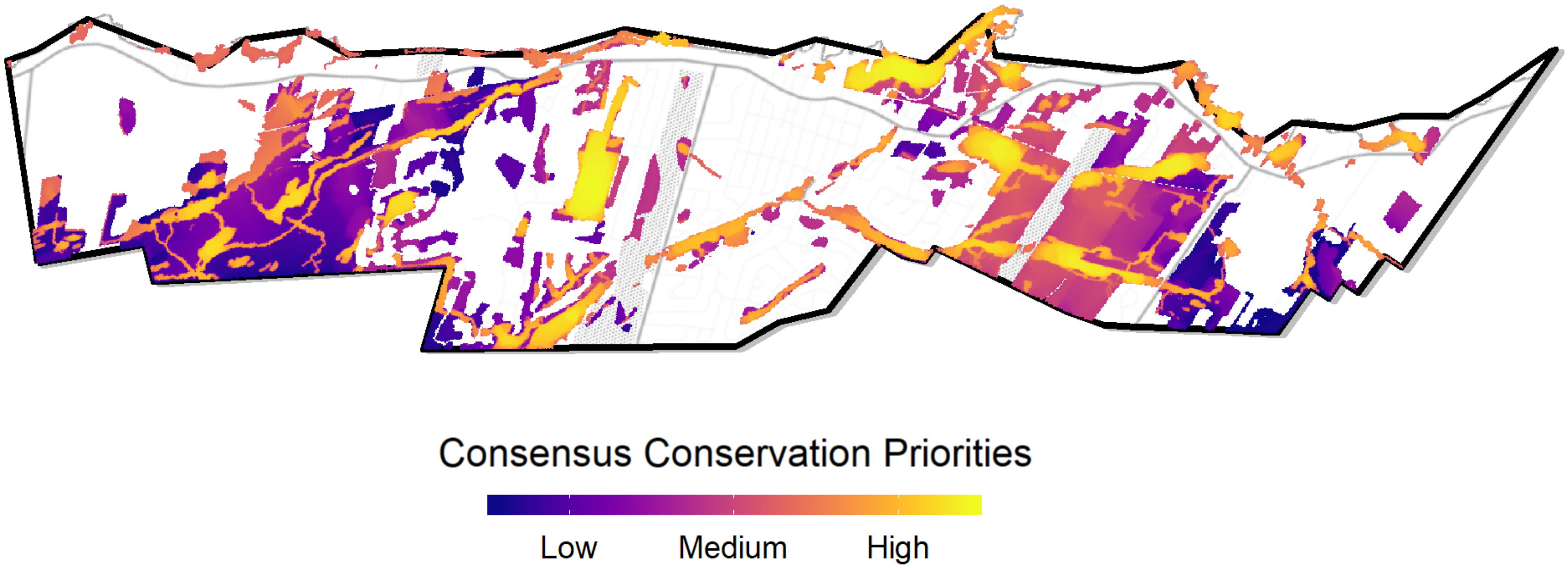

Figure 33. Consensus prioritization of Hudson's natural areas for conservation as per municipal and citizen rankings.

3.6. Landscape Modelling

3.6.1. Historical development and population trends

Extensive urban development first started in Hudson at the beginning of the 1900s and continued steadily throughout the century that followed (Figure 34). Using cadastral data, we established that between 1990 and 2018, the average urbanization[1] rate in areas zoned white for development was approximately 5.77 hectares per year. Urbanization rates in areas zoned green for agriculture, obtained by examining AAFC (2015) land use data, were substantially lower during this time period (0.80-1.43 ha/year), likely due to regulations protecting agricultural land in Quebec , such as the *Loi sur la protection du territoire et des activités agricoles*. Additional land use transition rates implemented in our models are detailed in Table 25.

Table 25. Land use transition rates in Hudson.

Transition Type	Average Transition Rates (Ha/year)			Data Source	Reference Period
	Green Zoning	White Zoning	Protected		
Agriculture-Fallow	2.37	0	0	Contemporary	1990-2018
Agriculture-Urban	0.80	0.74	0	AAFC (2015), Cadastral	
Fallow-Forest	1.18	0.39	0.24	Contemporary	
Natural Area-Agriculture	0.54	0.14	0	AAFC (2015)	1990-2010
Natural Area-Urban	1.43	5.77	0	AAFC (2015), Cadastral	1990-2018

Notably, transition rates pertaining to fallow land were inferred based on their contemporary distribution and coverage in Hudson (see Section 2.8 for more details). All rates were calculated by comparing the most recent geospatial and cadastral data (ca. 2010-2018) with those available for the recent past (ca. 1990). We cross-referenced rates against aerial images of Hudson when necessary.

We compared observed and projected urbanization rates generated using our land use transition models to validate the accuracy of our analyses (Figure 34). Land use models consistently projected urbanization rates in line with observed historical trends obtained through the cadastral dataset despite imposing considerable restrictions on the extent of natural areas that could be lost (Section 2.7). The two model scenarios generated through the workshop with the town's council and administration (Section 3.6.2.1.), namely Service and Transit Oriented Development, slightly overestimated development rates when compared with the past and a Business-as-usual scenario. We observed a discrepancy between the amount of land classed as urban in 2018 using cadastral data and the amount classed as such in 2020 using land cover data. This is due to inherent differences between land use and land cover classifications in the geospatial datasets consulted, such that portions of cadastral lots classed as urban may in fact comprise areas with distinct cover types (e.g. agriculture, forest).

[1] Urbanization is defined as the increase in urban surface area resulting from the addition or subdivision of new cadastral lots less than five hectares in size and used as residential lodging.

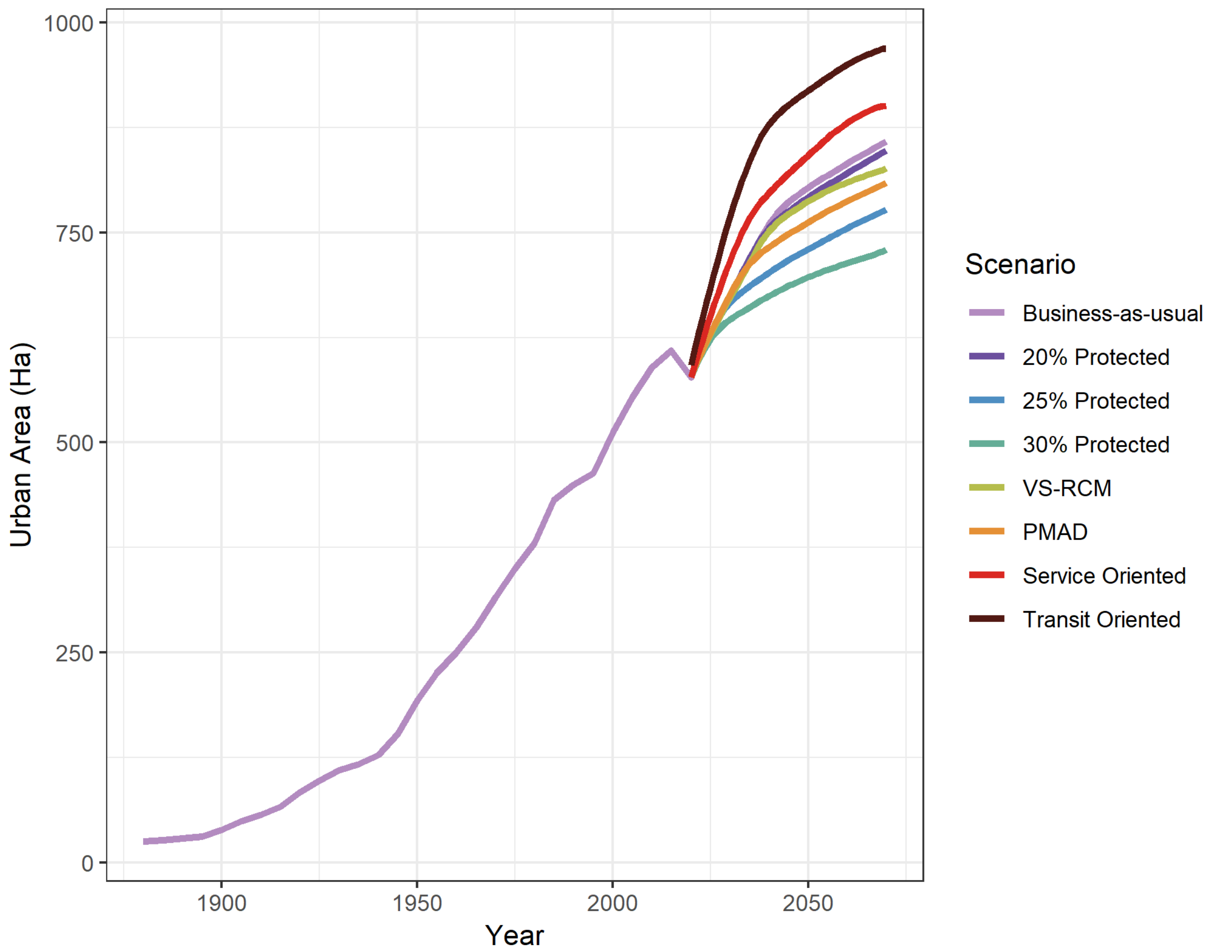

Figure 34.Historical and projected urban development area from 1880 to 2070.

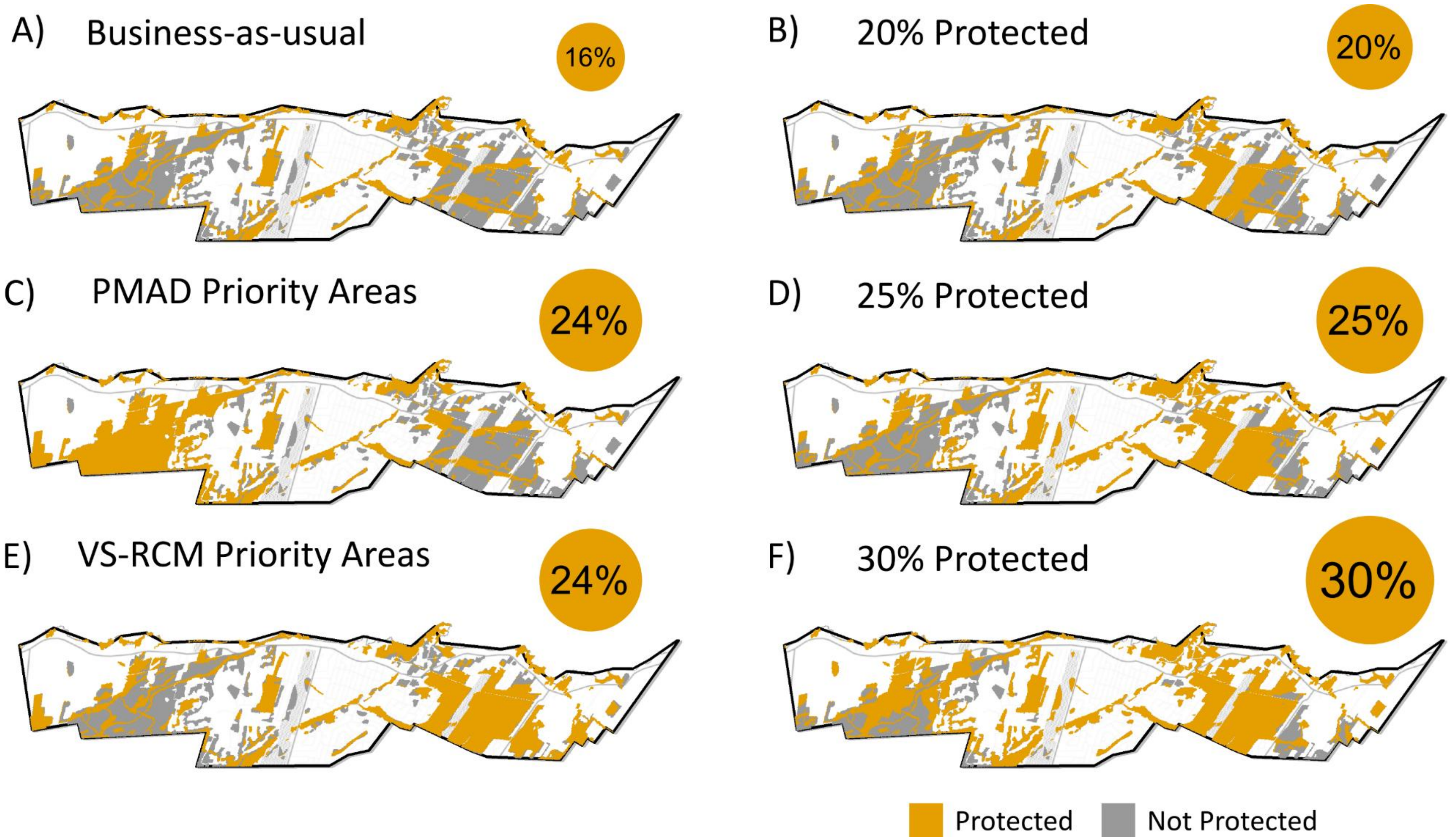

Figure 35. Natural areas protected under each land use scenario are highlighted in orange. The percentage of the total surface area of the landscape protected is given to the right of each subfigure.

3.6.2. Landscape scenarios

We developed a set of eight land use-land cover (LULC) scenarios to assess the potential changes in in Hudson's landscape from 2020 - 2070. Scenario outcomes reflect the parameterization of our LULC models, informed by historical trends in agricultural and urban development in Hudson (Section 3.6.1). They are sensitive to contemporary residential and agricultural zoning and differ in terms of the extent and distribution of protected land (Section 3.6.1, Figure 35). Scenarios are not prescriptive in terms of optimal future urban or agricultural development strategies and can not be used to validate any current or potential development projects in the municipality. Results present an exploration of possible urban planning trajectories and quantify their potential impact on the towns' natural areas.

3.6.2.1. Workshop Scenarios

Scenarios developed over the course of a workshop with the Hudson town council and administration, namely Service and Transit Oriented Development, are unique to the extent that they are not directly based on historical LULC transition rates. They also prescribed the urbanization of certain land cover types, principally golf courses and wetlands, that were not incorporated into other models either due to the absence of a historical baseline or restrictions imposed by municipal and provincial regulations. That being said, the 50-55% increase in urban surface area for both workshop models is higher than would be expected from historical data alone (Figures 36-37). Significantly more golf course area was lost in the Transit Oriented than in the Service Oriented scenario. The Service Oriented development scenario is unique in projecting an increase in agricultural land resulting in a substantial decrease in fallow land. Deforestation rates for Service Oriented Development and Business-as-usual scenarios are comparable and greater than for Transit Oriented Development.

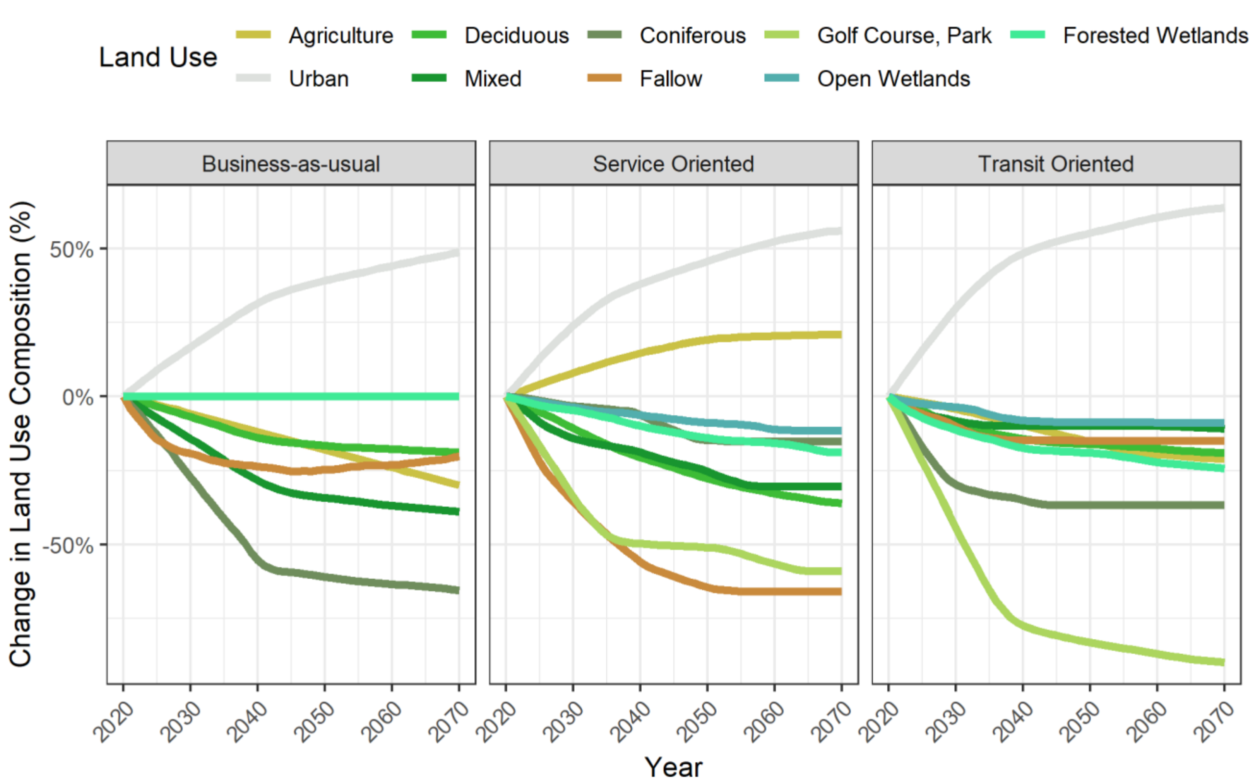

Figure 36.Projected land use composition following Business-as-usual and two workshop scenarios.

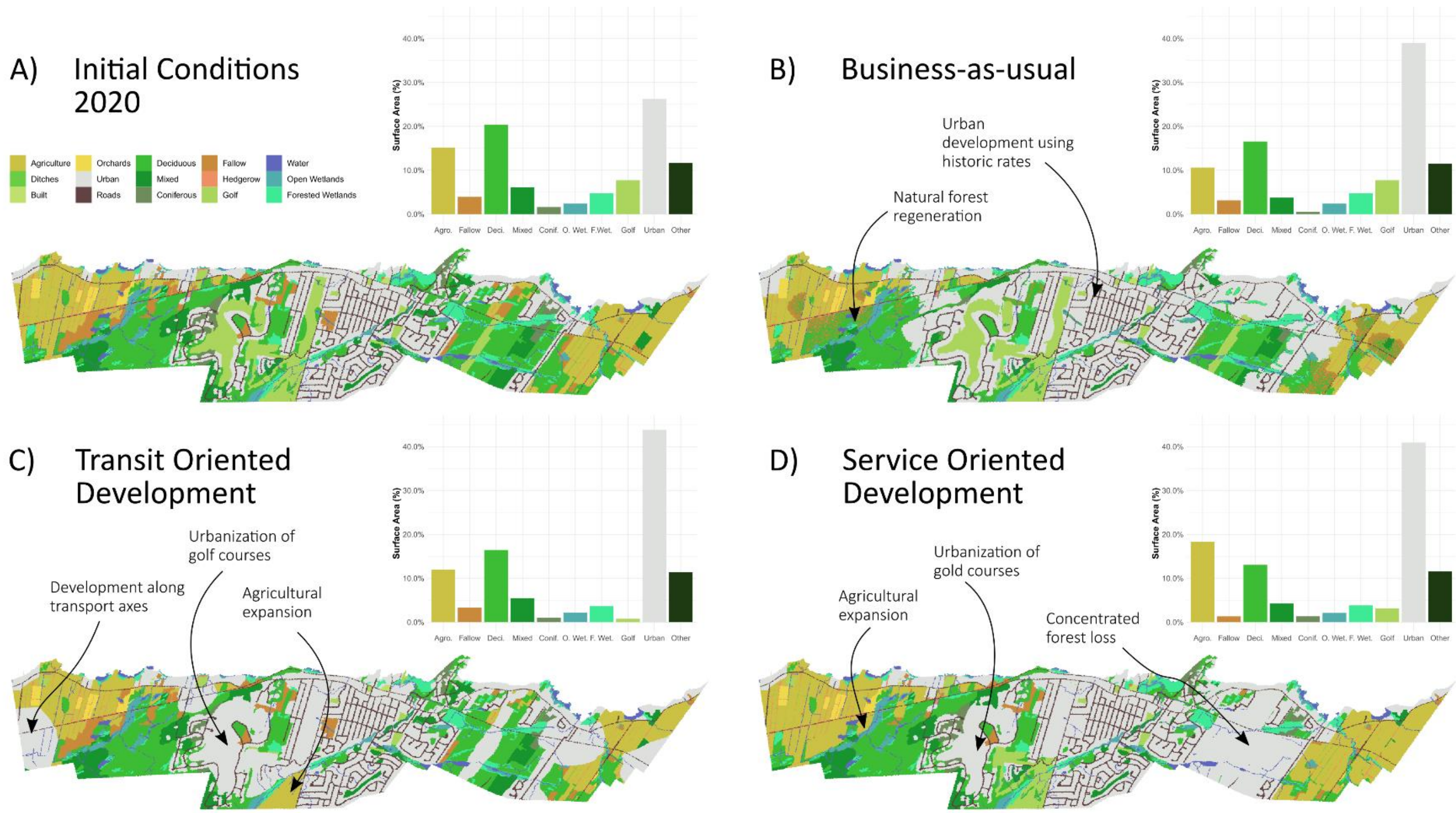

Figure 37. Summary of changes in land use for scenarios a) initial conditions in 2020, b) business-as-usual, c) transit oriented and d) service oriented development.

3.6.2.2. Regional Planning Scenarios

The two regional planning scenarios are distinct in that they target the protection of priority natural areas as designated by either the Vaudreuil-Soulanges RCM or the MMC under PMAD. Results from both VS-RCM and MMC scenarios can be compared with those generated through 25% Protected as the total percentage of natural areas protected is the same across them, roughly 25% of the municipality's total surface area (Figure 35). However, the spatial distribution of protected land is distinct across these three scenarios: VS-RCM focusing on forests in eastern Hudson, PMAD those in the west and 25% Protected on forests across the landscape. See Appendix 7 for a tabular summary of the land use change statistics.

Total forest surface area is lower and urban surface area higher after 50 years in both VS-RCM and PMAD scenarios than in 25% Protected (Figures 38-39). Coniferous and mixed forests undergo disproportionately more loss relative to deciduous forests across scenarios. Forest loss begins to plateau after 10 – 20 years as the amount of eligible forests to urban or agricultural development is expended. Moreover, some forest regeneration is expected if fallow fields in western Hudson remain uncultivated, resulting in a net stabilizing effect on forest loss. Urbanization proceeds after 2030 largely through the displacement of agricultural land, which continues to decrease steadily throughout the time series. Significant fallow land is lost initially in areas zoned for residential development but recuperates through the abandonment of agricultural fields thereafter.

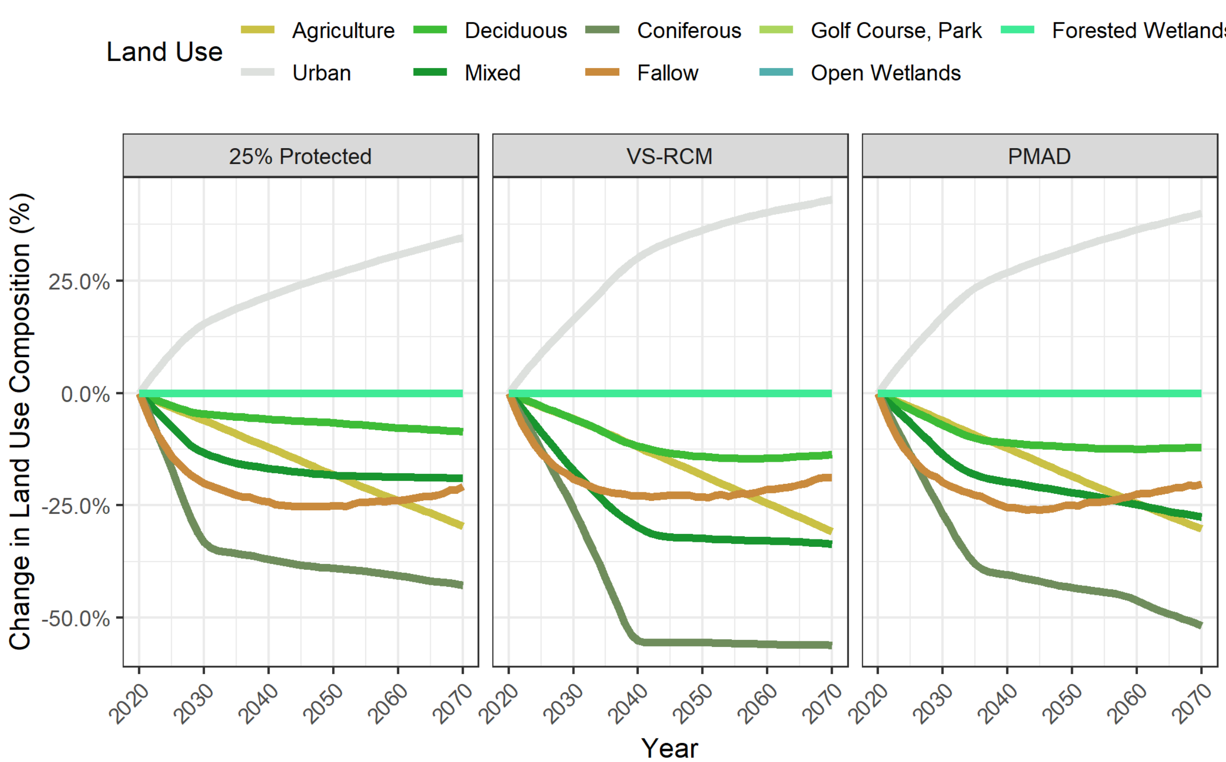

Figure 38. Projected changes in landscape composition for each land use change scenario.

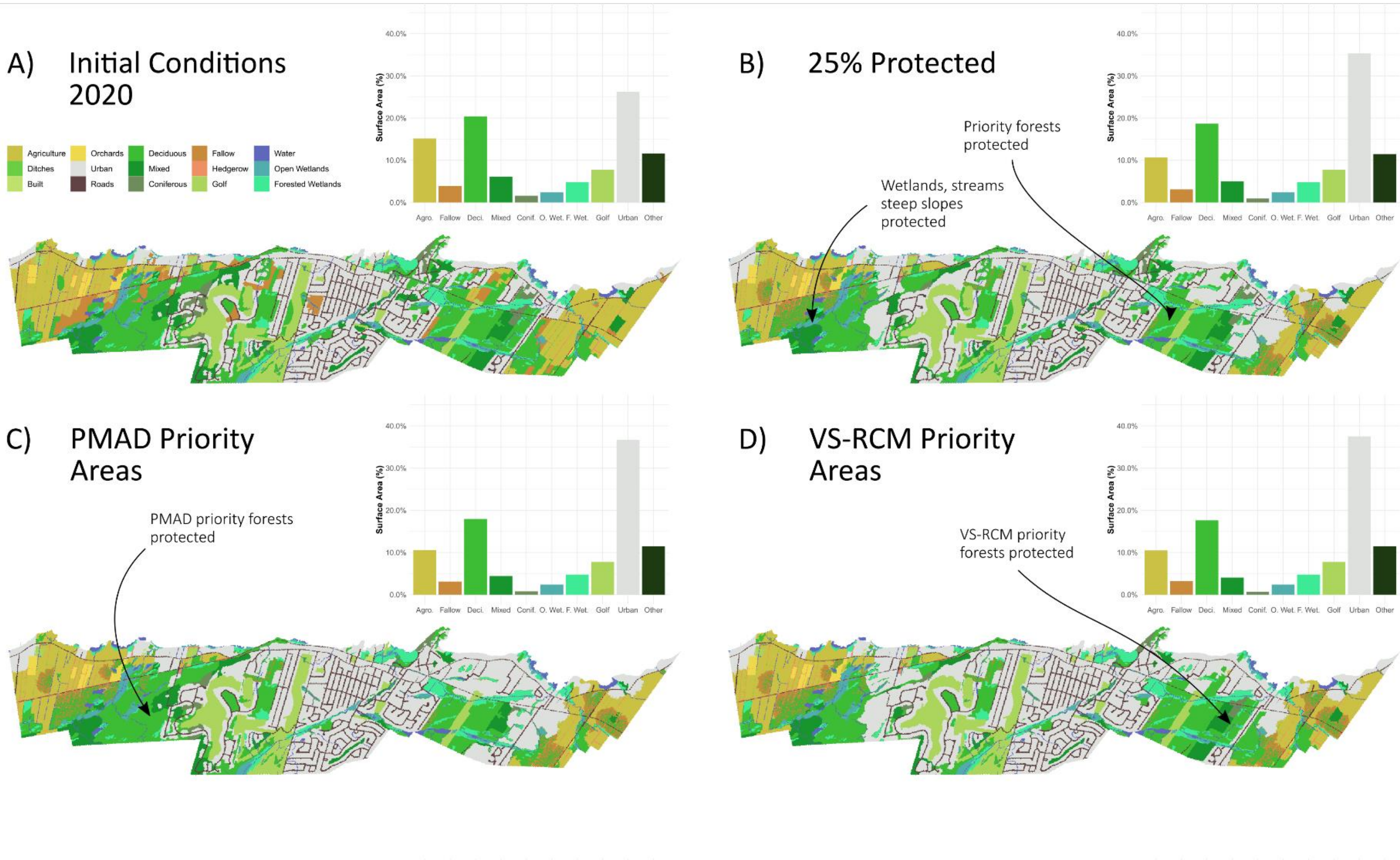

Figure 39. Summary of changes in land use for Eco2Urb scenarios, including a) initial conditions in 2020, b) 25% protected, c) PMAD priority areas, d) VS-RMC priority areas

3.6.2.3. Conservation Planning Scenarios

The conservation planning scenarios developed by Eco2urb are distinct in terms of the distribution and quantity of natural areas that are protected. Scenarios are designed to maximize the protection of important natural areas in the landscape, as well as the temporal retention of ecosystem services, biodiversity and connectivity. The percentage of Hudson's landscape protected varies from 20 – 30% depending on the scenario considered to capture a range of conservation outcomes over the time series (Figure 35).

Expectedly, the 20% protected scenario undergoes the greatest increase in urban surface area and the greatest forest loss (Figures 40-41). In fact, its results do not differ appreciatively from those of the Business-as-usual scenario, which models the protection of approximately 16% of the landscape via provincial and municipal regulations alone (Figure 35). The overall pattern of land use change across these three scenarios is consistent, namely the loss of agricultural fields, forests and fallow land to urban expansion. As previously described (Section3.6.2.2), rates of forest loss would be expected to plateau after 10-20 years as those eligible for urban expansion would be expended. Moreover, natural forest regeneration would take place in western Hudson. Agricultural land in our models decreases throughout the time series at a constant rate. In general, protecting a greater proportion of natural areas in the landscape (e.g. the 30% protected scenario) mitigates and stabilizes forest loss through time.

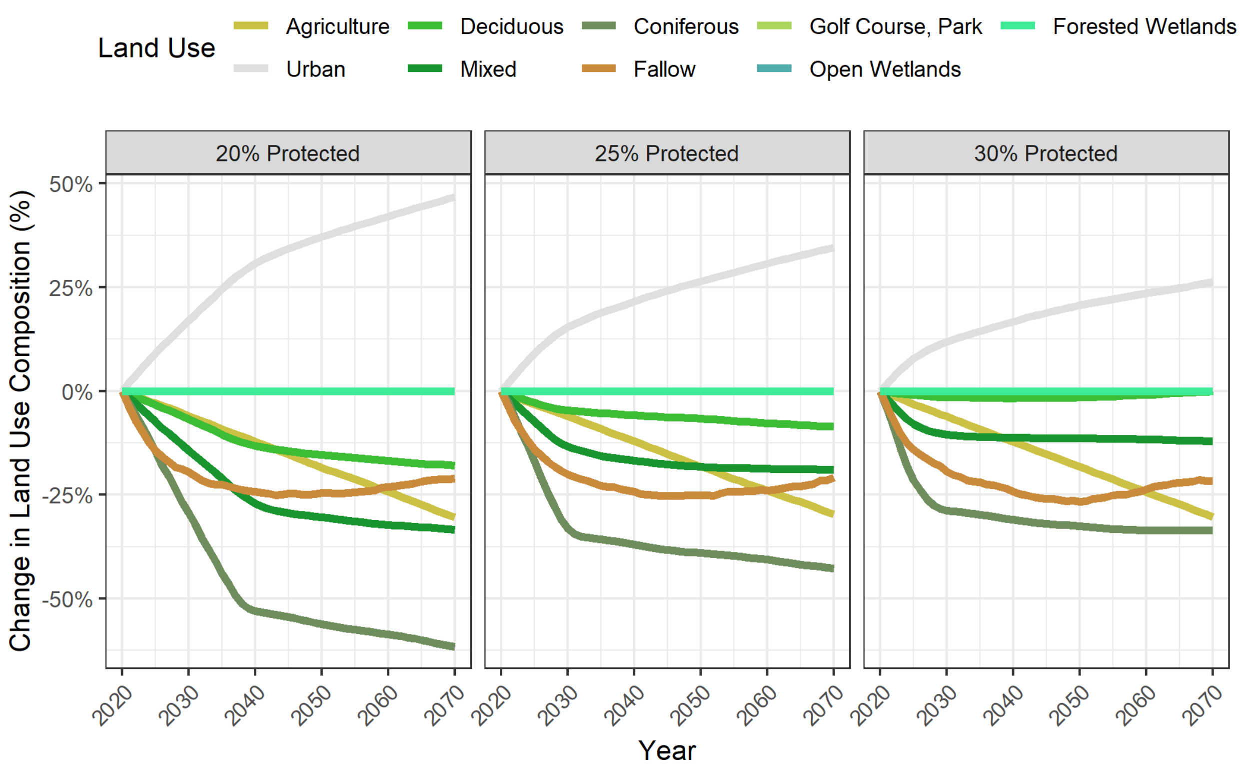

Figure 40. Projected changes in landscape composition for each land use change scenario.

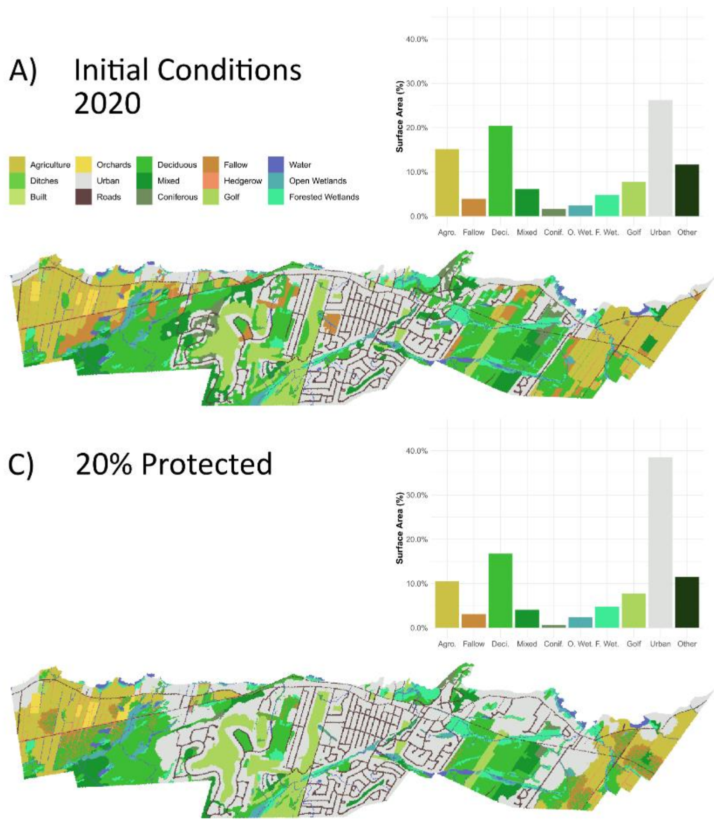

Figure 41. Summary of changes in land use for Eco2Urb scenarios, including a) initial conditions in 2020, b) 25% protected, c) 20% protected, d) 30% protected.

3.7. Forecasting changes in future connectivity and ecosystem services

For each timestep in our land use simulations (Section 3.6), we calculated the impact of changes in landscape composition and configuration on Hudson's ecosystem connectivity, biodiversity and ecosystem services.

3.7.1. Changes in local connectivity according to development scenarios

Across all scenarios, our measures of local landscape connectivity decrease with time on average by 10 – 40% with the loss of important habitat patches for the five focal umbrella species. The greatest losses were observed for the scenarios Service Oriented, Business-as-usual and the 20% scenario.

Decreases for connectivity indices are not linear as they consider the multiple multiplicative effects of habitat gains and losses for each scenario. For instance, the Transit Oriented scenario retains high betweenness connectivity by inadvertently avoiding the development of important habitat corridors, but scores low for cumulative current. Cumulative current grades the potential flow of organisms across the landscape, which is impeded by the high degree of urban development in rural areas and golf courses simulated in this scenario.

The scenarios 30% protected and PMAD retain the highest connectivity scores through time. Although they differ in terms of the total amount of natural land protected (Figure 35), they both simulate the conservation of forested areas along the Gary Cirko Trail in the West End district as well as those east of rue Alstonvale. Protecting these forested elements appears to help secure habitat connectivity over the 50-year time horizon, despite differential decreases in habitat availability and forest cover.

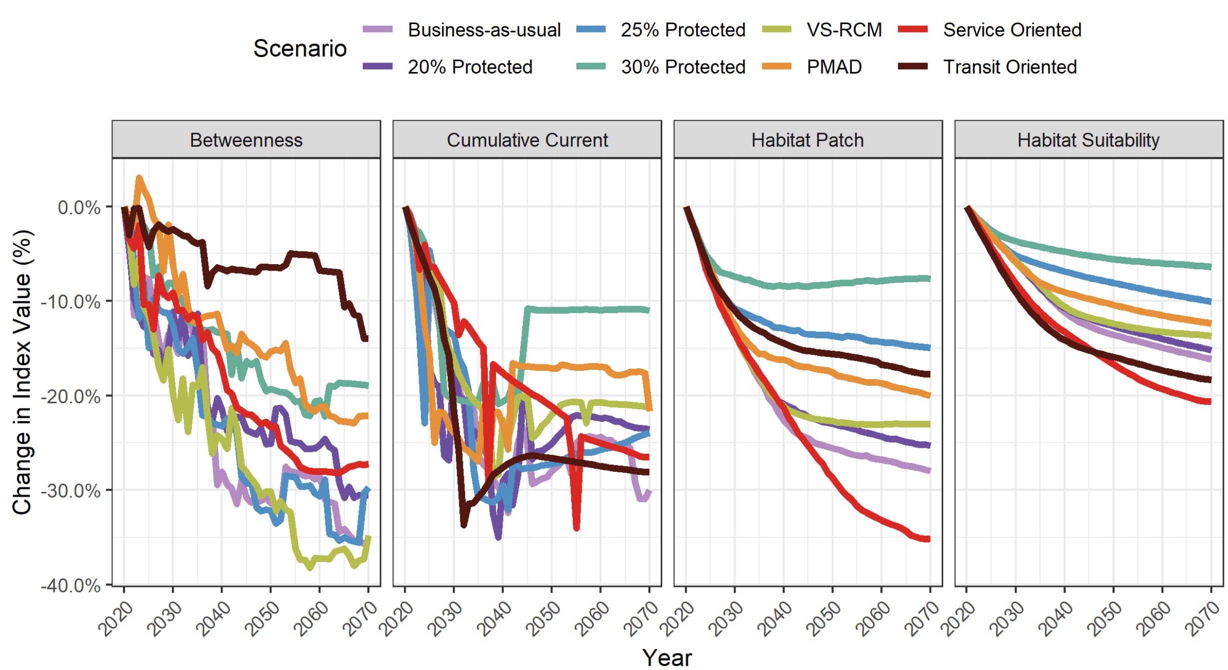

Figure 42. Summary of the different land use change scenarios and their impacts on two connectivity (betweenness, cumulative current) and two habitat availability (habitat patch, suitability) metrics.

3.7.2. Changes in ecosystem services and biodiversity according to development scenarios

3.7.2.1. Mean changes across all variables for each scenario

Simulated forest loss resulted in a net decrease in ecosystem service and biodiversity metrics on average, varying in degree by 10-35% (Figure 43). Scenarios incurring the greatest losses were Service Oriented, Business-as-usual and 20% Protected, while those that performed best through time included 30% Protected, 25% Protected and Transit Oriented.

The index with the greatest observed decrease in value across models was Simulated Development Susceptibility, not surprisingly as it grades the potential of forest loss under a Business-as-usual scenario. The degree to which mean conservation index values decrease in time scales proportionately with the extent to which susceptible forests are lost. This is true of all models except for Transit Oriented and Service Oriented Development, which simulated distinct land use transition rates and pathways specified over the course of a workshop with the Town's administration and council (Section 3.6.2.1). Notably, the Service Oriented Development scenario resulted in significant losses (25-65%) in the indices rare species, herpetological observation hotspots, recreation and maturity, due to its simulated erasure of all major natural areas in Como forest and Davidson Park.

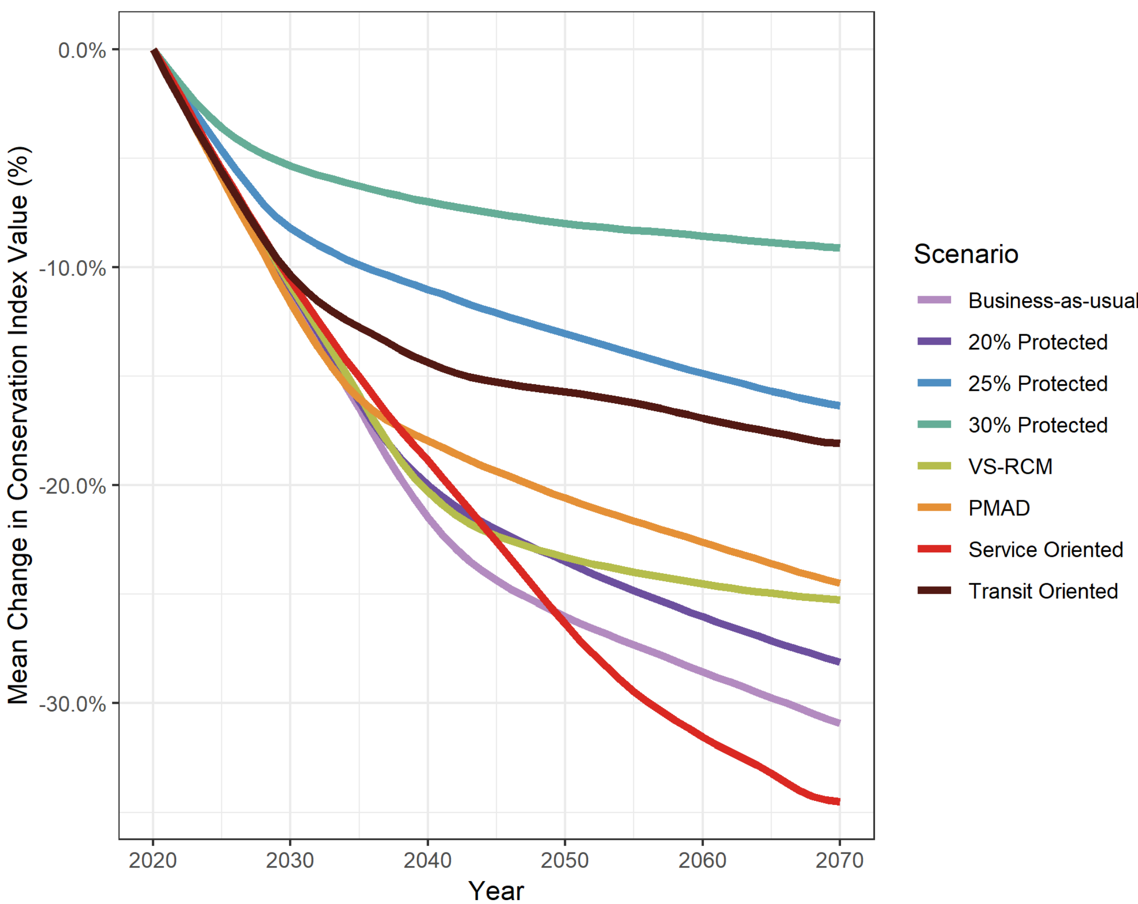

Figure 43. Average loss for all the measured variables for each of the different land use change scenarios.

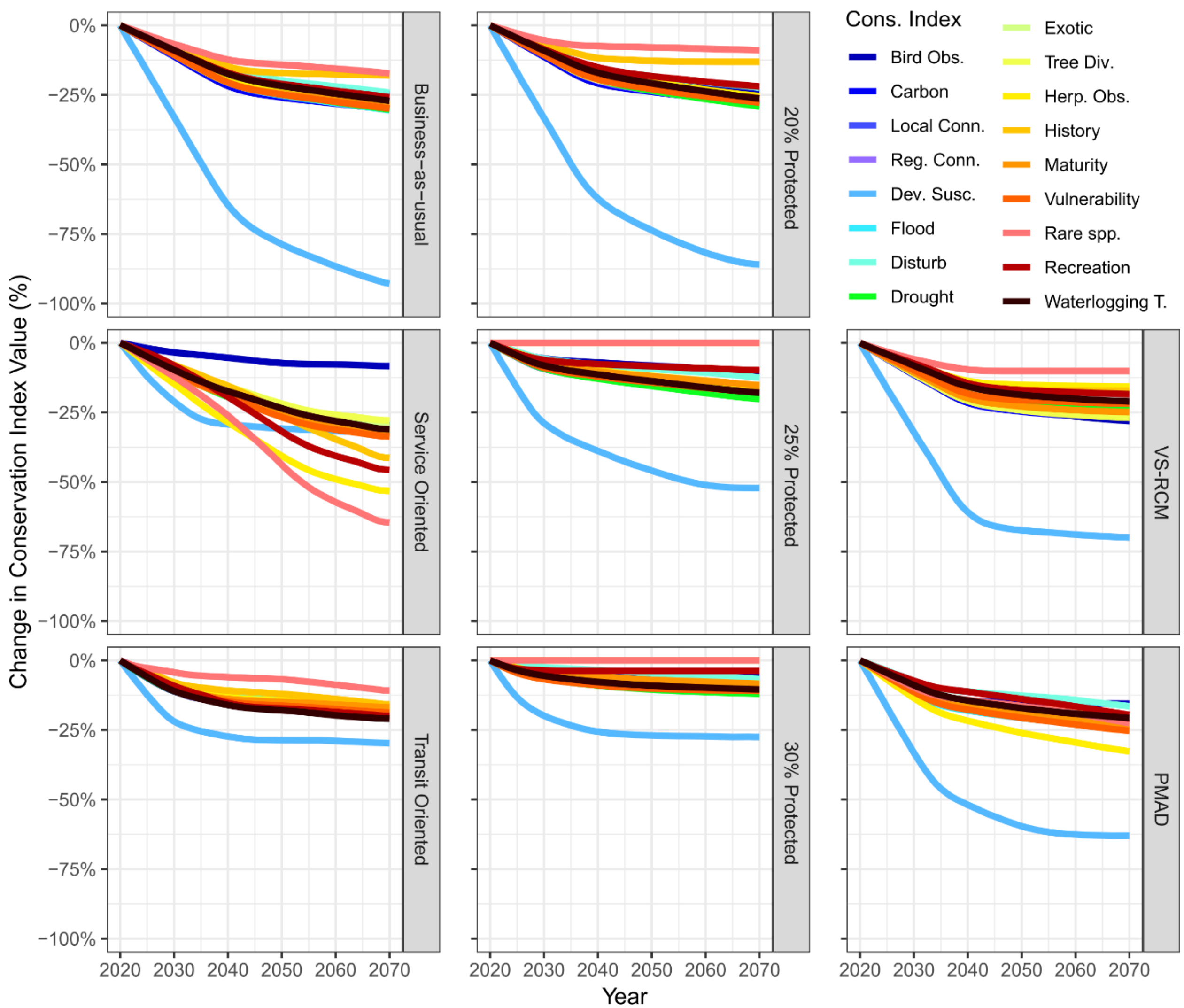

Figure 44. Average loss for all the measured variables for each of the different land use change scenarios.

3.8. Synthesizing results

Hudson's landscape is rich and dynamic, remarkable for its waterfront, high forest cover and extensive network of wetlands. Divergent strategies to conservation planning will have long-lasting effects on the retention of biodiversity, ecosystem services and habitat connectivity through time.

To synthesize results established through our analyses, workshops with the town administration and council, as well as our review of municipal and regional planning documents, we have divided natural areas in Hudson according to five tiers ranking their priority for conservation. Conservation tiers are nested within each other, such that Tier 1 natural areas are necessarily nested within Tier 2, and so forth. The area defined by each tier excludes the tier nested within it, where applicable.

Tier 1: Core Conservation Areas

Natural areas with de facto conservation status as per municipal and provincial legislation. These include wetlands (treed and open), riparian buffers, steep slopes and natural areas within the flood zone along the Ottawa River. The area corridors of high ecological value.

Tier 2: Top 25% Conservation Priorities

The top 25% of the landscape with the highest conservation value as established through the consensus ranking of conservation indices using municipal and citizen priorities.

Tier 3: Top 30% Conservation Priorities

Results from the same conservation ranking as in Tier 2, but with the addition of natural areas encompassing a total of 30% of the landscape.

Tier 4: PMAD and MRC Vaudreuil-Soulanges Conservation Priorities

Natural areas defined as high priority for conservation as per PMAD and the Vaudreuil-Soulanges RCM that are not already encompassed under Tiers 1-3.

Tier 5: Remaining natural areas

All remaining natural areas not included in Tiers 1-4.

Tiers 2 and 3 were given priority over Tier 4 as conservation scenarios established through our analyses generally outperformed those defined through PMAD (CMM 2012) and the *Politique de l'arbre et des boisés* (MRC Vaudreuil-Soulanges 2008) throughout our model simulations (Section 3.6.2). They retained high average values for the conservation indices considered (Section 3.7.2.1), as well as the connectivity of important habitats (Section 3.7.1). Tier 4 conservation priorities are nonetheless essential to regional planning efforts aiming to protect natural areas in the Vaudreuil-Soulanges RCM and the MMC, more broadly speaking.

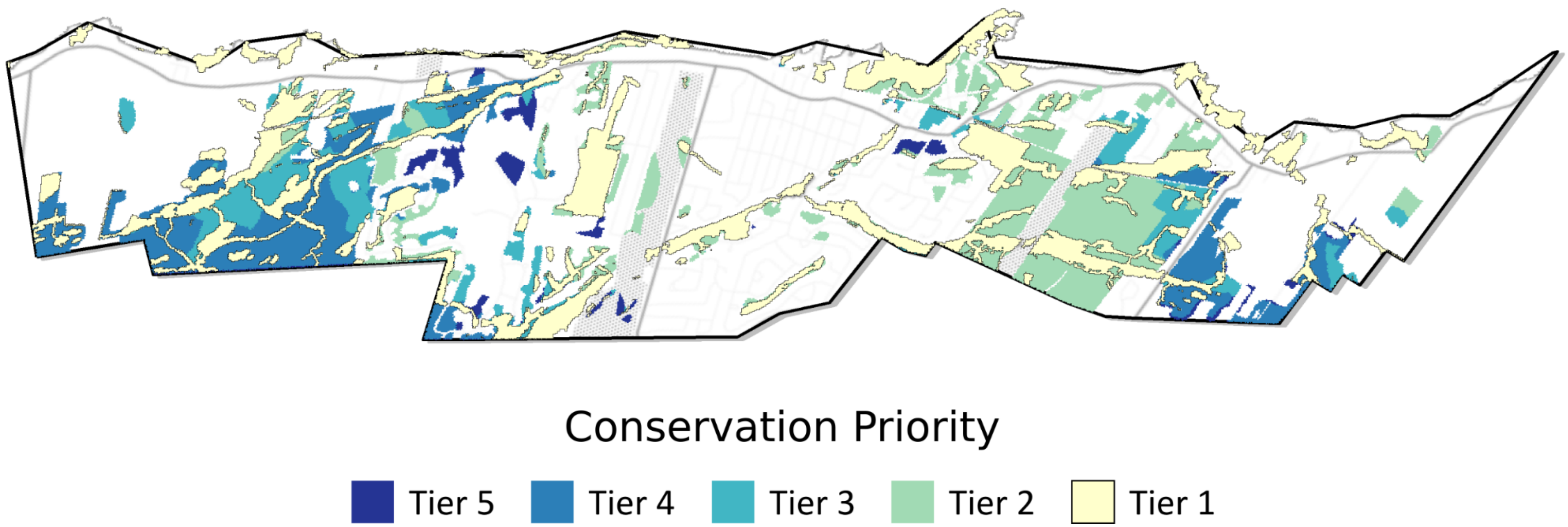

Figure 45. Synthesized conservation priority tiers as established through the analysis. Tier 1 areas have the highest priority

4. Discussion and recommendations

A resilience-based approach to conservation planning anticipates and prepares for future environmental stressors before they occur. Our landscape models identified that Hudson could lose up to 26% of its forests over the next 50 years presume historical land use change transition rate. Our projections are in line with past trends in land use management for the municipality as well as the erosion of forested and rural areas at the regional (Albert et al. 2017; Sokpoh 2010) and provincial scales (Pellerin and Poulin 2013). At least 95% of the urban canopy is vulnerable to at least one biotic threat that is either likely to invade or already impacting tree health. A total of 14% of forests are invaded by exotic species that crowd out native flora. Expansive forested areas in West End and Como districts are disconnected but for a selection of fragments lining the Viviry River and Gary Cirko Trail. Given limited resources and increasing socioeconomic pressures, the challenge is to prioritize natural areas today that retain high biodiversity, ecosystem services and connectivity into the future.

We identified elements of Hudson's green infrastructure that are most vulnerable to environmental and socioeconomic pressures. Following exhaustive field inventories and geospatial data processing, we ranked natural areas in terms of their contribution to 17 conservation indices. We conducted multi-criteria analyses to identify priority green and blue corridors adapted to municipal, regional and provincial legislation. We went one step further in testing our landscape management proposal against eight landscape scenarios to study the temporal-spatial stability of ecosystem services, biodiversity and connectivity. Our results highlight the value of strategically protecting 16-30% of forested and wetland elements in the municipality. Our quantitative assessment identifies priority areas most at risk and of greatest ecological value to include in a future conservation plan. This report does not offer practical recommendations for implementing a conservation plan.

4.1. Synthesis and recommendations

4.1.1. Biodiversity

Hudson's natural areas act as habitat for a diverse fauna, including over 230 bird species and 22 species of reptile and amphibian. These animals are supported by multiple habitats extending from the waterfront to the headwaters of the Viviry, with key concentrations of animal life identified through our analysis of biodiversity observation hotspots. Species at risk have also been observed in the town, though records are sparse. Butternut (*Julgans cinerea*) stands dot the landscape, a tree designated as endangered federally and likely to be designated as threatened or vulnerable provincially. Similarly, the northern map turtle is listed as vulnerable provincially and has been inventoried in marshes and swamps between Parsons Point and Willow Inn, as well as in Como forest. Hudson sustains high levels of biodiversity for an exurban municipality in a metropolitan context. The continued monitoring of animal and plant populations, as well as species at-risk in forests and wetlands is a key recommendation for any future conservation plan (Marsh and Trenham 2008).

Text box 2. List of recommendations for biodiversity.

Recommendations:

- Conduct thorough inventories of at-risk species and monitor populations.
- Promote habitat diversity at the landscape scale, including forests, open fields and wetlands.
- Favor diverse forest stands of varying maturity levels.
- Restore open fields by optimizing the functional diversity of tree species.
- Implement forestry practices that favor biodiversity in and around agricultural fields.

Species and habitat diversity often go hand-in-hand, satisfying the multiple life history (e.g. foraging, mating, migration, dispersal) requirements of animal and plant life (Katayama et al. 2014; Fahrig et al. 2011). Hudson features forest types of varying tree composition and maturity suitable for a host of specialist and generalist birds (Carrara et al. 2015; Katayama et al. 2014). Our analysis granted greater weight to the presence of old and mature forests in our conservation prioritization because of their rarity in southern Québec (Crête and Marzell 2006) and the substantial time required to achieve maturity in the region (greater than 80 years; MFFP 2015). However, the contribution of immature forests and edge habitat to biodiversity should not be discarded. In fact, certain bird populations (e.g. bobolink) are in decline across North America due to the loss of open field habitats necessary for their nesting and foraging (COSEWIC 2010; Valiela and Martinetto 2007).

Beyond their value to bird biodiversity, open field habitats play a significant role in sustaining bee populations. Martins et al. (2017) found that semi-natural meadows provide nectar, pollen and nesting resources for high levels (>100 species) of bee diversity in southern Quebec. Furthermore, residential gardens can act as refugia from agricultural pesticides and offset the inadequate floral and nesting resources of agricultural landscapes. Taken together, the level of urbanization and rich gardening culture observed in Hudson is compatible with bee conservation, as is the expansive set of open field habitats in West End along the now-abandoned train tracks. In fact, bees originating from these fields likely provide pollination services to nearby orchards, which, incidentally, are within the flight range (400 m) of apple-pollinating specialists (e.g. Andrena sp.; Martins et al. 2015). Furthermore, the complement of forest, garden, open field and orchard flowering resources likely support bee populations through the spring and summer (Martins et al. 2018). KM observed a yellow-banded bumble bee (*Bombus terricola*) at the tailhead of Davidson Park, a rare bee species listed as 'Special Concern' according to the Species at Risk Act (COSEWIC 2015). Given declines in pollinator populations across North America, further research will help elucidate the contribution of Hudson's natural areas to pollinator conservation efforts and management strategies to support bee populations.

Under suitable conditions and given enough time, agricultural set-aside will invariably transition to young, intermediate and then mature forest. The progression is initiated with the colonization of open fields from the surrounding landscape by fast-growing, sun-loving tree species. Slow-growing, shade-tolerant species eventually take their place as the forest grows taller and the canopy closes. Our landscape simulations indicate that open fields in West End can potentially mature into forest stands within a 50-year time horizon The reestablishment of forests in open field through natural regeneration can even offset and stabilize observed forest loss resulting from urbanization, provided adequate levels of forest conservation (Tiers 1-3).

To facilitate reforestation in West End old fields, we recommend investing in tree planting initiatives that favor the functional diversity of the canopy. Tree functional diversity is low in Hudson overall, making its forests susceptible to a range of diseases, pests and environmental stressors (e.g. drought, flooding). Planting many different tree species in old fields presents itself as a unique opportunity for bolstering tree diversity and improving the resilience of the canopy. Doing so would require planting species from a variety of tree functional groups, especially groups 3 – 8 (Section 2.6.4). As an extension of the No Net Loss principle applied to Quebec's wetlands through Bill 132, compensating forest loss through tree planting can sustain biodiversity, ecosystem services and connectivity at the landscape scale.

4.1.2. Connectivity

Our assessment of forest conservation priorities in Hudson captures the habitat and connectivity requirements of a host of vertebrate species. Forest and wetland patches along the Viviry River and Gary Cirko trail connect forests in West End and Como forests, while natural areas in the Sandy Beach and Alstonvale areas ensure waterfront accessibility. Forests form part of a broader regional network extending through Rigaud, Saint-Lazare, Vaudreuil-Dorion and the Saint-Lawrence Lowlands (Rayfield et al. 2018). Ensuring the protection of pinch points to animal migration will facilitate the flow of organisms across the landscape, such that they can better meet their life-history requirements. Disconnected forest patches surrounded by agricultural fields or residential housing also play a role in connecting the landscape as intermediate steppingstones between point A and point B (Herrera et al. 2017). Linkages between various vegetation types, such as wetlands, forests and open fields, ensure the spatio-temporal complementarity in resource provisioning through the spring, summer and fall (Martins et al. 2018).

Text box 3. List of recommendations for connectivity.

Recommendations:

- Restore blue-green corridors between fragmented habitat patches.
- Conserve fragments of quality habitat that can serve as steppingstones.
- Protect ecological corridors essential to biodiversity.

We recommend the implementation of multi-function blue-green corridors to enable the dispersal of fauna and plants across the landscape (see also Section 4.2.1). Corridors are a design solution that use rivers and adjacent natural areas to build interconnected passageways between habitats. They facilitate the natural movement of wildlife, provide green space for hiking and secure ecosystem services in suburban contexts. For instance, plant roots along the riverbank help filter water, control erosion and prevent flooding (Zuazo and Pleguezelo 2008).

Hudson is well-suited to blue-green corridors, as it already has a set of trails that follow its principal river axis (Taylor Bradbury Trail), and bylaws that promote riparian vegetation (Town of Hudson 2009b). Possible avenues for further work would be to create treed linkages between disparate forest patches along the Viviry River and gaps in its trail systems. Plans favoring landscape connectivity would put in place one continuous network of forest and wetlands following the Viviry River profile, from the Gary Cirko Trail through the Taylor Bradbury Trail and extending through to the Sandy Beach area. Building forested linkages between the headwaters of the Viviry and Clark-Sydenham Conservation area will also help promote the resilience of the network to forces that threaten further fragmentation of the landscape.

Central to conservation planning that optimizes landscape connectivity is the protection of contiguous forest patches that already facilitate animal movement and plant dispersal. Future development projects should avoid breaking apart functional linkages identified through our analysis. Further development in West End should retain the forest corridor following the Alstonvale talus as a key component of the landscape. The same applies to pathways for forest connectivity between Como forest, Sandy Beach and Parsons Point.

4.1.3. Integrity

We ranked forest integrity in terms of observed levels of anthropogenic disturbance as well as exotic species cover. Forests in Hudson generally exhibit low levels of anthropogenic disturbance. Most signs of human impact are confined to easily accessible areas. Exotic plant species, however, are common and coincide with forest fragmentation and edge effects (Yates et al. 2004). They invade via openings in the forest canopy and have negative impacts on native biodiversity (Blair et al. 2011; Huebner and Tobin 2006). Certain exotic ornamental plants in residential gardens can also prove invasive, such as Tatarian honeysuckle (*Lonicera tatarica*) and Japanese barberry (*Berberis thunbergii*).

Text box 4. List of recommendations for forest integrity.

Recommendations:

- Limit forest fragmentation through strategic urban and agricultural development.
- Sensitize residents regarding garden-safe plants through awareness campaigns.
- Organize volunteer initiatives to restore forests invaded by exotic species to limit their spread.
- Develop a control plan for buckthorn as per best management practices defined in Anderson (2012).
- Target mature forests for conservation.

Exotic species are released from the environmental and biotic constraints that usually limit their growth in their native range, allowing them to spread easily (Keane and Crawley 2002). Purple loosestrife (*Lythrum salicaria*) and common reed (*Phragmites australis*), for instance, are relatively harmless in their native European range but threaten wetland integrity by out-crowding native species in North America (Munger 2002; Gucker 2008). They also impact agriculture by blocking water flow in irrigation ditches (Munger 2002), and the extent of these economic impacts are difficult to quantify (Warne 2016). Invasive barberry not only forms dense thickets inhibiting tree regeneration, but also serves as the secondary host to black stem rust (*Puccinia graminis f. sp. tritici*) with severe impacts on agricultural crops (Saunders et al. 2019). No exotic species poses as significant a threat to forests in Hudson, however, as buckthorn.

Buckthorn species, namely common buckthorn (*Rhamnus cathartica*) and glossy buckthorn (*Rhamnus frangula*), are known to be aggressive invaders in North American forests and originate from Europe and Asia (Klionsky et al. 2011). Invasion by buckthorn has significant impacts on forests by producing dense shade, modifying soil conditions and inhibiting the survival and growth of native plants (Klionsky et al. 2011). Common buckthorn poses a significant threat in agricultural areas, such as in forest edges along agricultural fields in Hudson, because it is a secondary host for oat crown rust (*Puccinia coronata*) and a main host for the soybean aphid (*Aphis glycines;* Kurtz et al. 2018), which are pathogens with potentially severe economic impacts on oat and soybean crops.

Young, disturbed forests are the most vulnerable to exotic species, being characterized by open canopies and well-lit understories (Blair et al. 2011). In this regard, we prioritized mature forests in our analysis for conservation as closed canopies may help slow the spread of most invasive plants by limiting light accessibility (Valladares et al. 2016, Blair et al. 2011). They are also less frequently observed in Southern Quebec and support ecosystem specialists, such as the brown creeper (*Certhia americana*) and the southern flying squirrel (*Glaucomys Volans*; COSEWIC 2006, D'Astous and Villard 2012). Mature forests, representing one fifth of the total forested area in Hudson, must be prioritized for conservation given the time required to achieve such a level of maturity (greater than 80 years) and the vast quantities of carbon stored in woody tissue.

Using data on forest integrity, Hudson is well positioned to combat the spread of exotic species and minimize anthropogenic disturbance. Maps assembled through our analysis highlight priority areas requiring restoration. Replacing buckthorn stands with diverse assemblages of native trees can help boost forest integrity and functional diversity – a doubly effective restoration strategy. Initiatives targeting the eradication of problematic invasive species, including buckthorn, are being spearheaded by Nature Action Quebec. Enlisting their services or organizing citizen-run volunteer conservation efforts can help improve ecosystem health while building community engagement. Action begins with informing citizens of the presence of exotic species as well as their impact on the environment. Workshops focusing on identifying exotic species and gardening with plants unlikely to spread to adjacent forests and wetlands are essential first steps. The "In the Zone" program developed by the World Wildlife Fund can serve as a useful template for promoting the selection of native plants in gardens.

4.1.4. Forest resilience

Hudson's forests are moderately to inadequately resilient to future sources of environmental risk, such as prolonged and severe flooding events, drought, windstorms, the arrival of biotic pests and disease, as well as urban and agricultural expansion. Stands with the highest levels of functional diversity (e.g. the Clark-Sydenham Conservation Area) tolerate a wide range of drought and flooding conditions and are resilient to impacts from pests and diseases. Tree diversity should be promoted across the urban canopy at large as it reduces the odds that these areas will be decimated by any one source of environmental disturbance. Results from our report can be used to target stand-specific weak points to forest resilience.

Of special concern are the expected impacts of biotic threats either currently affecting Hudson's forests or likely to do so in the near future. Among these is the emerald ash borer, which has already been reported in Hudson and risks causing high tree mortality for 17% of its forests. Though the Asian longhorned beetle has yet to reach Quebec, it has been sighted in Toronto and government efforts are being taken to prevent its spread in the country. It is like the emerald ash borer but for maple trees, with potential and serious repercussions for 73% of Hudson's forests and maple syrup production.

In the next 50-years, Hudson will not only be subjected to the arrival of new forest pest and disease species but a changing climate as well, resulting in extreme weather events. Besides forested wetlands, many of

Hudson's forests are unable to cope with worsening floods. Of concern are those along the shoreline comprising tree species with relatively low tolerance to waterlogging. Monitoring tree survival rates in this area will help determine if forest health is at risk, as well as the erosion of the shoreline. Establishing more flood tolerant tree species by planting is another possible strategy to bolster resilience to flooding.

Although integrated and low-impact development is possible, our landscape simulations indicated that comparable amounts of forest cover could be lost in coming years to urban development and agricultural transformation as aforementioned biotic threats. Results help identify which forests are most susceptible to future development and have high conservation value according to other criteria. This tactic can help shed light on potential trade-offs amongst conservation indices to help inform urban planning. Forests associated with Parsons Point and the Gary Cirko Trail are both susceptible to development according to our land use models. The former help mitigate spring flooding and the latter ensure ecological connectivity. Given the choice between the two, where should development efforts be concentrated? The analytical tools applied by Eco2urb and described in the current report can support decision making aimed at minimizing future loss of biodiversity, ecosystem services and connectivity.

Text box 5. List of recommendations for forest resilience.

Recommendations:

- Conserve wetlands to improve overall tolerance to waterlogging, especially in the flood zone along the Ottawa River.
- Promote tree functional group diversity to improve forest resilience.
- Plant flood tolerant tree species to improve resilience to flooding.
- Favor a range of forest management practices (planting, selective harvests) that contribute to stand- and landscape- level habitat diversity.
- Focus conservation efforts on forests with higher levels of functional diversity.
- Focus restoration efforts on forests with poor resilience.
- Sensitize residents as to vectors of invasion for exotic pests and diseases (e.g. firewood), and on how to identify main biotic threats.

4.1.5. Ecosystem services

Our analyses quantified the contribution of forested areas to flood mitigation and carbon storage, two ecosystem services of local, regional and global relevance. Extensive floods in 2017 and 2019 resulted in the ministerial moratorium of 2019 on the development and repair of buildings in affected areas (ZIS). Forests and especially wetlands within the flood zone of the Ottawa River help reduce the impacts of flooding on homes and surrounding natural areas while absorbing excess water (Watson et al. 2016). Co-benefits associated with the protection of these areas includes erosion control, naturalizing the shoreline and improved ecological connectivity.

Climate change is increasing the incidence of flooding along the Ottawa River, highlighting the importance of not only implementing flood but also carbon mitigation in conservation planning. Trees in Hudson, especially those in mature forests with high basal area, store thousands of tonnes of carbon in their woody tissue. Coniferous stands in the town have the highest density of stored carbon given their size and species compositions, including those adjacent to the Gary Cirko trail.

Although our analysis was focused on stored carbon, carbon sequestration (uptake by growing trees) is an additional important ecosystem service. Mature forests have already accumulated vast quantities of carbon in woody tissue, but sequestration and growth rates tend to decline with tree age (Gray 2015). Younger forests sequester more carbon than older ones (Gray 2015), such that promoting the equitable distribution of tree ages and forest composition will help maintain carbon in tree trunks and out of the atmosphere. Favoring diversity in forest composition and structure is also compatible with biodiversity (Storch et al. 2018) and resilience to anticipated biotic threats (Thompson et al. 2009). Finally, it should be underscored that we assessed carbon stored in aboveground woody tissue as opposed to tree roots or in the soil. Wetlands might be sparser in tree cover but still play an important role in mitigating climate change: bogs store a significant portion of the world's carbon (Harenda et al. 2017). Further research will help quantify soil and peat carbon sinks in Hudson, as well as the possibility of incentivising conservation through carbon credit programs.

Text box 6. List of recommendations for ecosystem services.

Recommendations:

- Protect wetlands and forests with high flood mitigation potential.
- Consider forests with high maturity and basal area for conservation efforts aimed at preserving stored carbon.
- Favor carbon sequestration by protecting young forests and planting trees.
- Implement conservation measures targeting bogs.

4.1.6. Recreation and history

Natural areas highly frequented for recreation tended to also hold historical value. Areas such as Sandy Beach or Parsons point are some such examples and considered to have high social and cultural importance. Recreational values were heavily linked to the town's trail network and were concentrated towards the center of the town, where the bulk of the population resides. Historical sites identified were considered important particularly due to landscape features that hearkened back to the town's pre-colonial and early colonial history.

Text box 7. List of recommendations for recreation and history.

Recommendations:

- Collaborate with the Hudson Historical Society to determine and popularize key natural areas.
- Conserve natural areas heavily used for recreation that are concentrated towards the center of the town.

4.2. Conservation Tiers

We divided natural areas into five conservation tiers to facilitate conservation planning. To retain key biodiversity, ecosystem services and connectivity metrics through time, we recommend protecting Tiers 1 through 3, amounting to 30% of Hudson's surface area. This is in line with prescriptions for protecting between 30-50% of natural areas per watershed area to sustain biodiversity and ecosystem services (Environment Canada 2013).

Conservation tiers follow a nested structure, in that Tier 1 conservation areas are surrounded by forested elements of depreciating albeit important ecological ranking. This reflects the approach to conservation proposed by CIMA+ (2017) and the UNESCO World Network of Biosphere Reserves. Biosphere reserves promote solutions to reconcile the protection of biodiversity with its sustainable use. They are articulated around core conservation areas that have the highest form of protection, favouring biodiversity and the maintenance of ecosystem services (e.g. stabilizing the supply of drinking water, carbon sequestration). Certain activities can be developed in core areas providing they have little to no environmental impact, such as education and research (UNESCO n.d.). Buffer zones surround core areas and host activities compatible with the environment, such as recreation. They buffer core zones from human activities and can be used as natural corridors connecting the landscape.

Our landscape models show that protecting core (Tier 1) and buffering (Tiers 2-3) natural areas ensures the greatest retention of biodiversity, ecosystem services and landscape connectivity through time presuming historical development rates. Below we break down characteristics associated with each conservation tier as well as associated management recommendations.

4.2.1. Tier 1: Core conservation areas

Conservation Tier 1 applies provincial regulations and Hudson's bylaws to natural areas with de facto conservation status. This includes the municipality's extensive network of waterways and wetlands, which taken together are a scaffold, a conservation structure around which additional priority areas can be grafted (Tiers 2-5). Wetlands are essential to controlling flooding and shoreline erosion by absorbing excess water (Watson et al. 2016). The conservation of Hudson's wetlands will stabilize spatial hydroconnectivity, enabling linkages between blue and green corridors at the landscape scale while combating the significant losses observed for this vital vegetation type provincially (UNESCO n.d.).

Tier 1 areas include additional measures to mitigate flooding and erosion by prioritizing natural areas within the flood zone of the Ottawa River, and those associated with steep slopes in excess of 20% grade. Natural areas along Hudson's shoreline act as a physical barrier against spring floods (Watson et al. 2016) already impacting the town's waterfront as seen through the floods of 2017 and 2019. At the same time, tree roots prevent the continued erosion of the shoreline and decrease the susceptibility of landslides further inland (Sandercock et al. 2017; Zuazo and Pleguezelo 2008).

A prominent topological feature included in Tier 1 due to the steepness of its slopes is the Alstonvale talus, a transition area between the Choisy Plain and the Hudson Heights Plateau extending through Como forest. This belt of rugged terrain inadvertently serves as a vegetated corridor connecting forests in Rigaud to the Ottawa River. As relief heterogeneity typically gives rise to a diversity of microhabitats and associated flora, ensuring the conservation of this area not only favours landscape connectivity but potentially biodiversity as well.

As previously stated, perhaps most essential to ensuring the connectivity of terrestrial and aquatic habitats in Hudson is the conservation of natural areas associated with the Viviry River bisecting the town. This applies equally to the main tributary of the Viviry, Black Creek, extending through Como forest until reaching the Ottawa River. A series of wetlands punctuating the Viviry River profile support a rich community of reptiles and amphibians, with an observation hotspot located along the shoreline adjacent to the Willow Inn. Protecting natural areas the length of this green-blue corridor stabilizes meta-population dynamics of the town's herpetofauna populations and ensures that they are better able to meet their various life history requirements. Moreover, such a corridor links the waterfront to Como and West End forests, triangulating the conservation requirements for a host of fauna and flora.

A water quality assessment of the Viviry conducted by KM in 2016 in partnership with COBAVER-VS and the Liber Ero Chair in Conservation Biology, held by Martin J. Lechowicz at the time, highlighted the critical role that green spaces play along the river in mitigating water pollution (Martins et al. 2016b). Although a measure of river health, the Index of Bacterial and Physiochemical Quality (IBPQ), was highest at the Viviry's headwaters, it decreased substantially as water flowed through the town's residential areas. This was linked to phosphorous and suspended solids building up in the water column sourced from urban runoff. Water quality increased, however, further downstream at the mouth of the Viviry after having passed through the marshes and swamps in the Sandy Beach area. Without these wetlands, water quality would likely continue to decline as it moves downstream and empties out unfiltered into the Ottawa River. Waterfront wetlands provide multiple ecosystem services to Hudson, acting as a buffer against flooding and municipal runoff on either side of the shore, further underscoring their importance for conservation. Caution should be executed with all development projects proposed along the river's profile, including the headwaters in neighboring municipalities, lest they have cascading effects on the environmental integrity further downstream.

Tier 1 priority areas along the Viviry River facilitate the dispersal of animals across the landscape, encompassing a network of trails also used recreationally by residents. We are in no way advocating for the removal or disuse of trails in Tier 1 areas. Quite the contrary, they help leverage the community's support for wetland and forest conservation given their value for various activities (e.g. dog-walking, hiking). As previously stated, we recommend the restoration of natural areas in parks, such as the removal of exotic species (e.g. buckthorn, common reed, purple loosestrife) and sources of anthropogenic disturbance (e.g. residential waste).

Taken together, Tier 1 priority areas should form the basis of Hudson's conservation plan but are not sufficient in themselves to sustain ecosystem services, connectivity and biodiversity through time. Although comprising 16% of the landscape, conservation indices decreased by 30% on average when protecting Tier 1 areas alone in our landscape simulations. The conservation of Tier 2 and 3 areas is necessary for sustaining ecological integrity more broadly.

4.2.2. Tier 2-3: Buffer forest areas

Following our prioritization of natural areas, landscape scenarios in which 25% and 30% of the landscape was protected retained the greatest proportion of biodiversity, ecosystem services and connectivity through time. As such, they were used to designate natural areas in Tiers 2 and 3, respectively. These conservation tiers comprise upland forests exclusively as all open and forested wetlands are already included in Tier 1.

Forested stands were those that ranked highest across environmental factors examined and reflect the consensus conservation priorities of participants present at a set of workshops held for Hudson's town council, administration and citizens. Forest habitats in Hudson are critical in supporting the town's biodiversity and ecosystem services, storing thousands of tons of carbon in tree biomass, supporting rich avifauna, herpetofauna and species at risk, while offering recreational opportunities for citizens. They are also part of the town's natural heritage, the setting for a historical narrative continuously unfolding since Hudson's inception.

Natural areas identified in Tier 2 represent roughly the same proportion of the landscape as forests protected through either PMAD and VS-RCM plans but were substantially better at ensuring the retention of biodiversity and ecosystem services through time in our landscape models. This was because PMAD and RCM-VS scenarios concentrated conservation efforts in either the Como or West End districts to the east or west of town, respectively. Results from our landscape prioritization performed best in our analysis as they favoured a more equitable distribution of protected areas across the landscape.

Tier 2 and 3 areas are strategic in design as they favor the protection of priority forests with high conservation index scores that are most susceptible to projected development pressures. This ensures the long-term sustainability of services delivered over the 50-year time series. However, Tier 2 conservation priority forests representing 25% of the landscape were not adequate alone in sustaining landscape connectivity. Tier 3 area, that encompass only an additional 5% of the landscape, proved most effective at maintaining ecological connectivity. Tier 3 forests cover critical pinch points to animal dispersal not included in Tiers 1 and 2, such as forests associated with the Gary Cirko Trail and those east of Alstonvale road.

Landscape connectivity is one of the primary measures defining ecosystem integrity (Haddad et al. 2015). By explicitly incorporating connectivity into our prioritisation, our management recommendations are adapted to habitat and movement requirements for a host of vertebrate species emblematic of the Saint-Lawrence Lowlands. Protecting natural areas in Tiers 1-3 form the basis of an ecologically sound conservation plan designed to anticipate known current and future environmental pressures. Based on our assessment of historical land use patterns in Hudson, assigning conservation status to 30% of the landscape would result in projected development rates consistent with past urbanization trends going back to the 1950s. Although beyond the scope of the current mandate, strategic urban planning can ensure that protecting natural areas will not have a significant negative impact on the housing requirements of Hudson's population (Heymans et al. 2019). On the contrary, academic research shows that green space accessibility can serve to increase quality of life in suburban and urban areas (Dadvand and Nieuwenhuijsen 2019).

4.2.3. Tier 4: Regional planning priorities

As mandated by PMAD (CMM 2012), municipalities are required to ensure the concordance of their environmental plans with those of the MMC and their respective RCM. As such, we integrated conservation priorities identified by the MMC and VS-RCM in our ranking of conservation tiers. Tier 4 natural areas include forested elements designated as priority by either PMAD or the VS-RCM that are not otherwise already covered by Tiers 1-3. They were assigned quaternary ranking following Tiers 1-3 as conservation plans conceived by the MMC and the VS-RCM resulted in greater declines in biodiversity, ecosystem services and connectivity through time in our analysis. The conservation of Tier 4 areas is nonetheless recommended to the extent possible given regional conservation efforts conducted at the RCM and MMC levels.

4.2.4. Tier 5: Remaining forests

Tier 5 conservation areas include all those not already covered in Tiers 1-4. They represent only 1% of the landscape and are sparsely distributed in rural and urban sectors. Notably, their exclusion from Tier 4 is likely the result of the precision of our landscape analysis and field inventories. We delimited forested areas not otherwise included in conservation plans conducted at the CMM or VS-RCM scale. The low ranking of these areas should therefore not be confused with a lack of ecological value, but rather the result of having been omitted from previous studies. Moreover, low ecological value does not validate the erasure of natural areas through urbanization or agricultural expansion. All proposed development projects affecting the integrity of natural areas in Hudson should be subject to a formal environmental impact assessment by a trained biologist and approval by the Ministry of the Environment, where applicable.

4.3. Funding conservation planning

Though critical to the maintenance of integral ecosystems and the services they provide, the implementation of conservation measures can sometimes be a costly or resource intensive undertaking. To alleviate pressures on municipalities and private owners and to incentivize conservation efforts, certain funding programs are made available to interested parties. The *Fondation de la Faune du Québec* (FFQ) offers various sources of funding to support conservation efforts throughout the province. Some of their programs include:

- *Faune en Danger*

  This program targets projects focused on the protection and the restoration of vertebrate species that are considered in Quebec's *Loi sur les espèces menacées ou vulnérables*. Municipalities can apply to this source of funding, and projects must involve planning for the conservation of these species, conducting research on their habitat needs, or sensitizing the public as to their status and requirements.

- *Protéger les habitats fauniques*

  This program supports projects aiming to protect habitats with high value for fauna through the conclusion of agreements with private landowners. Municipalities can apply for this source of funding.

- *Programme pour la lutte contre les plantes envahissantes*

  This source of funding supports projects that seek to reduce the threats and impacts of exotic invasive plants on the biodiversity and the integrity of Quebec's natural areas. Projects aim to restore invaded habitats important to fauna and flora and to limit the introduction and spread of exotic species. Municipalities can apply to this source of funding.

- *Programme Hydro-Québec pour la mise en valeur des milieux naturels*

This program aims to ensure the development of green infrastructure, the protection of natural areas, biodiversity conservation and public education on environmental issues. Municipalities can apply to this program.

Furthermore, the Government of Canada offers funding through their Habitat Stewardship for Species at Risk, which supports habitat projects benefiting currently at-risk species or potentially designated species while engaging local communities and furthering research on the use of stewardship for conservation. Municipalities, private landowners and many other types of entities are eligible for this funding source.

Other programs that may be of interest include bequeathing land for conservation to organizations such as the Nature Conservancy of Canada, which can benefit donors through tax cuts. Moreover, as per recommendations provided by CIMA+ (2017), the implementation of a green fund or turning towards legal options such as conservation easements and planned habitat designations for conservation could also provide promising avenues for implementation.

5. Conclusion

We recommend a conservation plan based on a connected protected area network for Hudson. This conservation network is designed to account for known risks stemming from climate change and ecological change, such as emerging pests and diseases and the impacts of extreme weather events currently experienced and forecasted for the region. The conservation plan should promote the resilience of natural areas but management of the network must be adaptive and take into account new risks as they arise.

Our analysis supports the need for conservation action to ensure the protection and sustainable management of Hudson's remaining natural areas. The present study combines a wealth of objective analyses and scenario-based projections to identify areas of greatest ecological value and under greatest threat. Our results should guide further reflections and decisions aimed at creating and implementing Hudson's conservation plan. The report goes beyond a simple assessment of Hudson's natural areas and provides the information and data needed to support the Town of Hudson in its mission to manage its landscape and mitigate the expected impacts of environmental change on the built and natural spaces present within its territory.

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