Atlas of Sites of Conservation Interest in the St. Lawrence Lowlands – Methodology Report version 2, including Outaouais region

June 2019

www.planstlaurent.qc.ca

This report presents the results of the Atlas of sites of conservation interest in the St. Lawrence Lowlands, including analysis results for the Outaouais region. It follows a first version of the Atlas that was made available in October 2018. Other results will be added in the coming months, including the analysis of aquatic ecological units in areas where LIDAR data is not currently available.

This document should be cited as follows:

Jobin, B., L. Gratton, M.-J. Côté, O. Pfister, D. Lachance, M. Mingelbier, D. Blais, A. Blais et D. Leclair. 2019. Atlas of Sites of Conservation Interest in the St. Lawrence Lowlands – Methodology Report version 2, including Outaouais region. Environment and Climate Change Canada, ministère de l'Environnement et de la Lutte contre les changements climatiques, ministère des Forêts, de la Faune et des Parcs, St. Lawrence Action Plan, Québec, 186 p.

Cover photos: © Thinkstockphotos

Published by Authority of the Minister of the Environment

Published by Authority of the Ministre de l'Environnement et de la Lutte contre les changements climatiques du Québec

Cat. No.: En154-124/2020E-PDF
ISBN: 978-0-660-36199-4

Aussi disponible en français sous le titre : Atlas des territoires d'intérêt pour la conservation dans les Basses-terres du Saint-Laurent – Rapport méthodologique version 2, incluant la région de l'Outaouais

Production team

Project coordination

Benoît Jobin[1]
Marie-Josée Côté[2]
Louise Gratton[3]

Planning committee

Name	Organization	Role	Expertise
Benoît Jobin	ECCC[1]	Project Coordinator	Open environments
Marie-Josée Côté	MELCC[2]	Member of the project team	Aquatic environments
Louise Gratton	Consultant[3]	Facilitator, member of the project team	Open standards, forested areas, flora
Daniel Lachance	MELCC[2]	Member of the project team	Wetlands
Olivier Pfister	MELCC[2]	Member of the project team	Forested areas, flora
Marc Mingelbier	MFFP[4]	Member of the project team	St. Lawrence Corridor
Line Couillard	MELCC[2]	Member of the project team	Flora

Mapping and Spatial Analyses

Matthieu Allard[1]
Denis Bellavance[2]
Daniel Blais[2]
Sophie Benoît[2]
Patrick Desautels[5]
David Leclair[7]
Danielle Leclerc[2]
Frédéric Poisson[2]
Martine Benoit[1]
Joany Suazo[2]

Collaborators

Andréanne Blais[6]
Martin Joly[2]
Annie Lebel[7]
Kateri Monticone[8]
Hubert Pelletier[8]
Normand Villeneuve[4]

---

[1] Environment and Climate Change Canada (ECCC)
[2] Ministère de l'Environnement et de la Lutte contre les changements climatiques (MELCC)
[3] Consultant
[4] Ministère des Forêts, de la Faune et des Parcs (MFFP)
[5] Néogis – Solutions géomatiques
[6] Conseil régional de l'environnement du Centre-du-Québec
[7] Bureau d'écologie appliquée
[8] Nature Conservancy of Canada Canada

Acknowledgments

We would like to thank all the people who contributed to this atlas by sharing knowledge, data or time, including Jean François Rail, Josée Tardif, Pierre Aquin, Bruno Drolet, Emmanuelle Fay, Sylvain Giguère, Karine Picard and Pierre André Bernier of the Canadian Wildlife Service of Environment and Climate Change Canada; Jacques Labrecque, Guy Jolicoeur, Vincent Piché and Tingxian Li of the Ministère de l'Environnement et de la Lutte contre les changements climatiques; Jocelyn Gosselin, Édith Cadieux, Jason Samson, Antoine Nappi, Nathalie Desrosiers, Claudine Laurendeau, Valérie Simard, Yohann Dubois, Marc Antoine Couillard, Yves Paradis, Aïssa Sebbane, Hughes Bernard and Marie Noëlle Blais of the Ministère des Forêts, de la Faune et des Parcs; Gino Lévesque of the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation; Stéphane Lamoureux and Simon Bédard of the Regroupement QuébecOiseaux; Stéphanie Côté of Nature-Action Québec; Frédéric Doyon of the Université du Québec en Outaouais; Pierre Drapeau of the Université du Québec à Montréal; Marc André Guertin and Philippe Lebel of the Université de Sherbrooke; Marc André Rhéaume of the Fédération des producteurs forestiers du Québec; Michèle Dupont Hébert of the Bureau d'écologie appliquée; Sylvio Demers and Thomas Buffin-Bélanger of the Université du Québec à Rimouski.

Abstract

One of the projects under the biodiversity conservation theme of the St. Lawrence Action Plan is the development of an integrated plan for conserving the St. Lawrence's natural environments and biodiversity. Identifying sites of interest for biodiversity conservation was the first step in this integrated planning process leading to the production of the Atlas of sites of conservation interest in the St. Lawrence Lowlands. Conservation targets (coarse filter) selected for this atlas are woodlands, wetlands, open habitats (old fields, perennial crops), and aquatic environments. This report presents the methods that led to the production of this atlas.

For each selected target, sites of conservation interest were determined up to a representativeness threshold of 20% for a given spatial reference unit (i.e., depositional contexts in the St. Lawrence Lowlands). To do so, sites with high conservation interest were first selected, those sites being located within or adjacent to protected areas or exceptional forested ecosystems, sites hosting species at risk and critical habitats, or those having unique ecological features. A prioritization analysis was then carried out on conservation targets using a multi-criteria analysis when the 20% representativeness threshold was not reached following the selection analysis. Other sites of interest not covered with the coarse filter targets and representing local sites with high conservation value were also determined (fine filter), such as rare aquatic environments of the St. Lawrence River (spawning sites), alvars, colonial bird nesting sites, other faunistic sites (e.g., nesting sites for Bank Swallow and Chimney Swift, etc.) and important floristic sites. Finally, a multitarget analysis was performed to determined regions with high concentration of sites of interest for multiple targets.

Geospatial data of selected sites are publicly available. This will allow users to better visualize the geographical location of those sites of conservation interest and their associated conservation value. Users will also have the opportunity to adapt the determination of sites of high conservation value given their own spatial territory and conservation objectives.

Because the conservation of sites with high biodiversity value is a shared responsibility; this atlas will reach objectives of several conservation organizations and stakeholders having a strong interest in the conservation of natural sites in the St. Lawrence Lowlands; such as non-governmental organizations, municipalities, RCMs, governments and academic institutions. In addition, because this atlas is intended to be a tool in landscape and land-use planning, we believe that upcoming conservation strategies for natural sites can be oriented towards sites with high conservation value and where there exists urgent needs for conservation using the information provided by this atlas. For example, this atlas could guide the production of regional wetlands and bodies of water plans that will be produced in coming years following the recently adopted *Act respecting the conservation of wetlands and bodies of water*.

Résumé

L'un des projets indiqués sous le thème de la conservation de la biodiversité du Plan d'action Saint-Laurent est l'élaboration d'un plan intégré de conservation des milieux naturels et de la biodiversité du Saint-Laurent. Pour les Basses-terres du Saint-Laurent, il a été convenu dans un premier temps de produire un atlas des territoires d'intérêt pour la conservation afin de déterminer les sites où les besoins de conservation sont les plus criants. Les cibles de conservation (filtre grossier) retenues sont les milieux forestiers, les milieux humides, les milieux ouverts (friches, cultures pérennes) et les milieux aquatiques. Ce document méthodologique expose la démarche soutenant la production de cet atlas.

Pour chacun des éléments composant les cibles retenues, des sites à considérer pour la conservation ont été déterminés jusqu'à l'atteinte d'un seuil de 20 % de représentativité par unité spatiale de référence (p. ex., contextes de mise en place). Pour y parvenir, une sélection des milieux ayant une plus haute valeur de conservation a été réalisée, soit ceux qui hébergent des occurrences prioritaires et des habitats essentiels d'espèces en péril, des aires protégées, des écosystèmes forestiers exceptionnels et des sites irremplaçables. Des analyses de priorisation multicritère ont ensuite été effectuées si le seuil de 20 % de représentativité n'était pas atteint après l'analyse de sélection. De plus, s'ajoutent des éléments ponctuels d'importance pour la biodiversité (filtre fin), à savoir des habitats ou des occurrences reconnus scientifiquement qui ne sont pas considérés dans l'analyse des cibles de conservation. On parle ici de milieux aquatiques exceptionnels associés au couloir du Saint-Laurent (p. ex., des frayères), des alvars, des colonies d'oiseaux, des éléments fauniques (p. ex., des sites de nidification de l'hirondelle de rivage et du martinet ramoneur) et des occurrences floristiques d'importance. Enfin, une analyse multicible a été produite afin de déterminer des territoires où se concentrent des sites d'intérêt déterminés pour les cibles de conservation du filtre grossier.

Les données géospatiales associées aux sites d'intérêt déterminés dans le présent Atlas sont disponibles. Les utilisateurs pourront donc les consulter pour connaître de façon plus précise la répartition spatiale des sites d'intérêt et la valeur de conservation associée à chacun. Les utilisateurs pourront ainsi adapter l'analyse de ces données à leur réalité territoriale et en fonction d'objectifs particuliers.

La conservation des milieux naturels et des espèces en situation précaire étant une responsabilité partagée, le présent Atlas permettra de rejoindre les priorités des nombreuses organisations qui œuvrent dans le domaine de la conservation des milieux naturels dans les Basses-terres du Saint-Laurent, soit les organismes de conservation, les municipalités, les municipalités régionales de comté (MRC), les organisations gouvernementales et les institutions académiques. De plus, comme l'Atlas se veut un outil d'aide à l'aménagement du territoire, l'élaboration de stratégies de conservation des milieux naturels permettra d'orienter les actions concrètes aux endroits où les besoins sont les plus pressants. Il sera, entre autres, utile à la préparation des plans régionaux des milieux humides et hydriques qui devront être produits suivant l'entrée en vigueur de *la Loi concernant la conservation des milieux humides et hydriques*.

Table of Contents

List of tables

List of figures

List of appendices

1. Introduction

Since 1988, the governments of Canada and Quebec have been working together to conserve and enhance the St. Lawrence River through the St. Lawrence Action Plan (SLAP). With the aim of continuing this work while also adapting to emerging issues facing the St. Lawrence, the two governments made a commitment in 2011 to renew this partnership for a period of 15 years. This plan is also known as the Canada–Quebec Agreement on the St. Lawrence (SLAP, 2018a). Joint action projects are grouped within three main themes: conserving biodiversity, ensuring sustainable use of the St. Lawrence and improving water quality.

One of the projects aimed at biodiversity conservation involves the development of an integrated plan for conserving the St. Lawrence's natural environments and biodiversity. The State of the St. Lawrence Monitoring Program, launched in 2003, has demonstrated that the integrity and functionality of the natural environments of the river ecosystem are closely associated with pressure from human activities on land adjacent to the St. Lawrence, even in environments far beyond the river ecosystems themselves. It was agreed that the conservation plan should cover the entire Quebec portion of the St. Lawrence Lowlands (SLL), where natural environments are under heavy pressure from human activities such as urbanization and agriculture (Latendresse et al., 2008a) and where the concentrations of species at risk are the highest in Quebec (Tardif et al., 2005).

Identifying priority areas for biodiversity conservation was the first step in the integrated planning process. It led to the production of the *Atlas of Sites of Conservation Interest in the St. Lawrence Lowlands*. The second step in the process will be to develop strategies for land-use planning and for conserving natural environments, in order to focus concrete action on locations where the need is greatest. Together, these two stages of the project – the atlas and the conservation strategies – will constitute the plan for conserving natural environments in the St. Lawrence Lowlands.

1.1. Why produce an atlas of sites of conservation interest in the St. Lawrence Lowlands?

Conservation planning for natural environments of interest in the St. Lawrence Lowlands is not new. A review of the conservation plans carried out in the SLL between 2000 and 2016 revealed that many plans have been produced by various stakeholders (governments, municipalities, conservation organizations) and at various spatial scales (municipalities, RMCs, watersheds, etc.) (Lebel, 2013; Dupont-Hébert, 2017). A conservation plan covering the St. Lawrence Lowlands natural province was also produced by the Nature Conservancy of Canada 10 years ago (Gratton, 2010). With this in mind, it is reasonable to ask whether another conservation plan for the SLL is really needed. How will this atlas be different from previous planning exercises?

1) The analyses conducted for the atlas are based on the latest and most precise data on the distribution of natural environments in the SLL. Land use in this natural province was recently mapped in great detail (ECCC and MDDELCC, 2018).That mapping exercise

integrated data from the detailed mapping of wetlands produced by Ducks Unlimited Canada (DUC) and the Ministère de l'Environnement et de la Lutte contre les changements climatiques (MELCC), the 4th decadal Ministère des Forêts, de la Faune et des Parcs (MFFP) ecoforestry maps, data on agriculture from the Financière agricole du Québec (FADQ), and additional information (old fields, road network, hydrography, etc.). The boundaries of the polygons representing forest stands and human-modified environments identified in the ecoforestry maps were also updated for the entire SLL based on recent spatial data (satellite images, Google Earth, etc.) to ensure that the maps accurately reflect land use for the period 2014–2016.

2) Numerous conservation plans have been produced in southern Quebec (Lebel 2013; Dupont-Hébert, 2017). Past planning exercises have focused mainly on wetlands and forested areas. Yet other types of ecosystems in the SLL support plant and animal species that play significant roles in maintaining biodiversity there. One recommendation made by Gratton (2010) is to develop – and include in a future conservation plan – a method for analyzing and planning conservation of aquatic ecosystems. Recent advances in our knowledge of aquatic and fluvial habitats have thus enabled us to add several elements to the planning exercise for conservation of the St. Lawrence Lowlands: detailed mapping of the hydrographic network in southern Quebec; preparing an initial classification of the aquatic ecological units; and compiling a list of the important river ecosystems which can guide prioritization of aquatic and river ecosystems for conservation.

3) The St. Lawrence Lowlands are part of the Bird Conservation Region (BCR) 13, the Lower Great Lakes/St. Lawrence Plain (Environment Canada, 2013b). In addition to the issues related to conserving bird species at risk associated with natural habitats, this region is now the largest and most important grassland ecosystem in northeastern Canada, providing habitat for grassland species (Environment Canada, 2013b). For this reason, human-modified open areas have been integrated into conservation planning for the SLL. Innovative analyses have been developed to guide efforts to conserve old fields and agricultural matrices that provide favourable conditions for grassland birds and other species found in open habitats.

4) We also consulted numerous experts specializing in various taxonomic groups, so that the atlas will contain the most precise and up-to-date information about the distribution of Quebec plant and animal species at risk and about rare ecosystems such as alvars, exceptional forest ecosystems, bird colonies, important spawning grounds, and exceptional aquatic environments.

5) The existing conservation plans for the SLL were very useful in guiding conservation actions implemented at the local or regional scale by the organizations that produced them. However, most of these plans cover regions in southwestern Quebec, where pressures from human activities are the most severe (Montérégie, Centre-du-Québec). The Atlas of the St. Lawrence Lowlands will fill in the gaps in regions where conservation planning could provide much-needed support to organizations that have limited resources for carrying out

such analyses. It will also be a resource for updating existing plans or completing plans for ecosystems that, until now, have not been considered.

6) The spatial unit of reference used for biodiversity analyses makes it possible to consider regional ecological realities at the scale of the St. Lawrence Lowlands. It is derived from a classification of ecological districts from the MELCC's Cadre écologique de référence du Québec, which are grouped into regional depositional contexts. These different contexts are based on assemblages of major deposit types and associated landforms, and condition the organization of ecosystems and land use (see section 10.2).

1.2. Who is the Atlas of the St. Lawrence Lowlands intented for?

Integrating the conservation needs for the major ecosystem types of the SLL in a single atlas addresses the conservation priorities of many stakeholders involved in conservation in Quebec, primarily conservation organizations, municipalities, regional county municipalities (RCMs), government organizations, and academic institutions.

Since the responsibility for conservation of natural environments and species at risk is shared by several levels of government, the atlas will address the priorities of the government organizations, both federal and provincial, that are involved in the project. The identification of sites of conservation interest in the SLL will support the bird conservation strategy developed by Environment and Climate Change Canada (ECCC) (Environnement Canada, 2013b).

Figure 1. Action priorities for the primary conservation stakeholders in Quebec

Similarly, identifying important habitat for species at risk will support conservation action by ECCC, the MELCC and the MFFP and guide RCMs in developing regional plans for wetlands and water bodies by June 2022 as required under new Quebec legislation, *An Act respecting the conservation of wetlands and bodies of water* (Gouvernement du Québec, 2017). Bringing together the conservation priorities of the different levels of government (federal and provincial) in the same document will pave the way for making optimal use of resources while working toward common objectives, for example, to guide decisions about priorities for action under the federal and provincial funding programs.

Lastly, because the atlas will complement existing land use planning, the results of this project will be useful for organizations that want to know which sites are considered priorities for intervention in their respective areas, so that they can target their conservation actions accordingly. Public dissemination of the geospatial data and the analysis methods will enable regional stakeholders to adapt the analyses to the situation at their sites and their needs. Ultimately, the intent is that the sites identified as priorities in the analyses can be taken into consideration in reviews of RCMs' and municipalities' land use and development plans. Thus, the atlas is intended as a tool to assist with land-use planning that will complement the conservation planning exercises already carried out in a number of regions within the SLL.

1.3. Conceptual framework: Open Standards for the Practice of Conservation

The "Open Standards for the Practice of Conservation" approach (hereinafter, Open Standards) was used to create the conservation plan for the SLL. The Open Standards are a conceptual framework that is internationally recognized and used in planning projects for the conservation of species, ecosystems and protected areas, regardless of the scale, duration and scope of the conservation initiative. They were created by the *Conservation Measures Partnership*,[1] an international group of organizations dedicated to protecting nature by employing principles that have been tested in various areas of natural resources management. The standards include concepts, methods and a common terminology for planning, managing and implementing conservation projects.

The Open Standards set out an adaptive management cycle that helps identify conservation targets, develop strategies, design conservation activities, measure their effects and focus on those that are most effective (figure 2). They also served as a framework for designing the adaptive management software program Miradi[2]. This software guides managers through the different stages involved in using the standards (CMP, 2013).

[1] http://www.conservationmeasures.org/

[2] www.Miradi.org

Figure 2. Adaptive management cycle for a project according to the Open Standards

The production of an atlas of sites of conservation interest in the St. Lawrence Lowlands falls within the first stage: conceptualization. This stage consists of

- Determining the goal of the planning process;
- Deciding who will be part of the project team;
- Define the project's thematic and/or geographic scope;
- Define the vision to be achieved;
- Determine conservation targets;
- Evaluate threats that affect conservation targets.

It also involves presenting an analysis of the situation by identifying, in advance, the enabling conditions and the stakeholders that will play a key role in planning the measures and monitoring the implementation of actions as part of the action plan (CMP, 2013).

2. Goal of the planning process

The biodiversity of the St. Lawrence provides many ecosystem services that benefit communities. Although rich and diversified, it is subject to numerous pressures and, in many ways, remains fragile. Habitat loss and alteration caused by human activity and the introduction of invasive alien species are the main threats to the biological diversity of the St. Lawrence. The governments of Canada and Quebec agreed to make biodiversity conservation one of the priority issues of the St. Lawrence Action Plan. Since the resources available for carrying out conservation projects are limited, it was agreed that it was essential to increase the effectiveness of actions taken and to develop common planning tools for identifying sites of interest and implementing actions for maintaining biodiversity in the St. Lawrence Lowlands (SLAP, 2018a).

The goals to be achieved through the preparation of the conservation plan for the SLL are as follows:

1) First, produce an atlas of sites of conservation interest in the St. Lawrence Lowlands by identifying sites to be prioritized for conservation in order to maintain biodiversity. Specifically, the objectives are as follows:

    a) Maintain the remarkable elements of the biodiversity of the St. Lawrence Lowlands such as rare ecosystems, species assemblages, and habitat of rare or unique species;

    b) Ensure that, taken together, the sites are representative of each type of environment making up the ecosystems found in the SLL, attaining the objective of 20% representativeness for each spatial reference unit.

2) Second, produce action plans to support organizations in developing and implementing conservation strategies and actions in order to reach these objectives.

3. Project team

Although the governments of Canada and Quebec lead the completion of the Atlas of sites of conservation interest in the St. Lawrence Lowlands, the Open Standards specify that the initial project team must include key personnel from the organizations and the external partners, whose roles and responsibilities have been clearly defined. The team for implementation of the conservation plan for the St. Lawrence Lowlands is made up of professionals from ECCC, MELCC, and MFFP, as well as a consultant who specializes in the Open Standards. The composition of the team may change during the management cycle.

In order to make optimal use of existing skills and identify the best knowledge available for carrying out the project, the project team has several analysts and advisors to whom the team can turn for input and advice, including a few stakeholders in the implementation of the conservation plan. A list of individuals who contributed to the project can be found in the introductory pages of this report (see: Project team and Acknowledgments).

4. Vision

The vision statement is a general summary of the desired or ultimate condition of the study area that is being sought and agreed upon by the project team members (CMP, 2013). The vision statement for the St. Lawrence Lowlands Conservation Plan is as follows:

> *The St. Lawrence Lowlands are recognized for their remarkable biodiversity, consisting of functional and representative ecosystems, many of which support viable populations of species at risk. By 2050, habitats necessary for the survival of terrestrial and aquatic fauna and flora (marshes, swamps, bogs, old fields, forests, perennial crops, etc.) are conserved within an ecological network that is resilient to anticipated changes. The preservation of this natural heritage is possible through the concerted action of different levels of government (federal, provincial and municipal), conservation groups, regional consultation committees, businesses and citizens that manage natural resources in a sustainable manner.*

5. Scope of project

The scope of the Atlas of sites of conservation interest in the St. Lawrence Lowlands is geographic, i.e., it targets a defined territory for which strategies and actions will be implemented to achieve specific conservation objectives (CMP, 2013). Thus, the area covered by the Atlas corresponds roughly to the southernmost natural province[3] of Quebec, the St. Lawrence Lowlands (Li et al., 2014) (Figure 3). However, it differs from it by including at its eastern limit the L'Isle-aux-Grues archipelago, which, according to the ecological framework, is part of the natural province of the estuary and Gulf of St. Lawrence, and the aquatic domain of the middle estuary extending downstream to Cap-aux-Oies on the north shore and Rivière-Ouelle on the south shore of the river (Île aux Coudres is excluded from the study area). Also included in the study area is the Covey Hill area located in the foothills of the Adirondack Mountains in the Montérégie region, to take into account the wildlife communities unique to this region.

[3] First level of perception of Quebec's Ecological Reference Framework developed by the MELCC (Li et al., 2014)

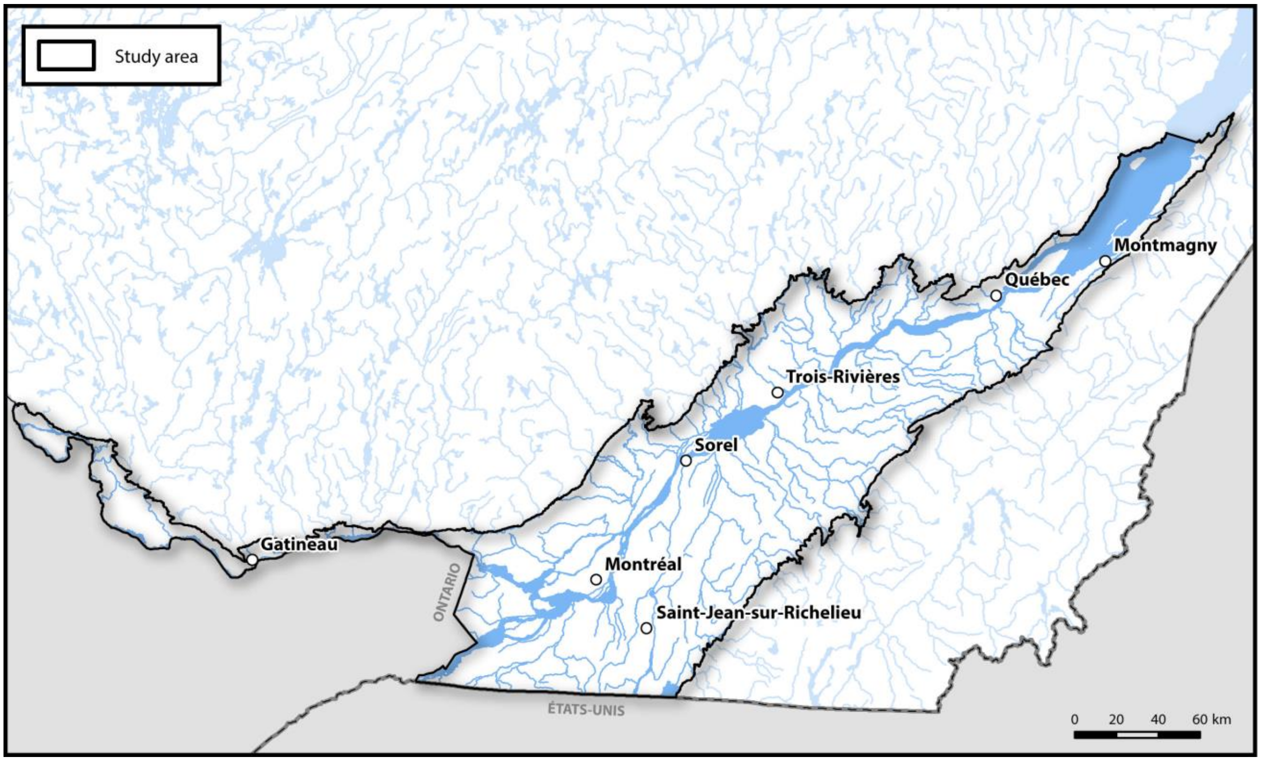


Figure 3. Study area covered by the Atlas of Sites of Conservation interest in the St. Lawrence Lowlands

The territory analysed occupies a total area of 32,350 km^2, including the open water areas of the St. Lawrence River. The St. Lawrence Lowlands are divided in two by the St. Lawrence River and the landscape is essentially that of a vast plain surrounding this imposing watercourse. To the south, the boundary of this territory follows the first prominent features of the Appalachian relief and the American border. To the north, the territory includes the lowlands of the Ottawa Valley and borders the Canadian Shield at times abrupt contact. It includes the agricultural plain of the Ottawa region and is interrupted by the Ontario border.

6. Ecological context

6.1. Geology and topography

The undeformed Paleozoic sedimentary rocks of the St. Lawrence Platform geological province and the somewhat deformed sedimentary rocks of the foreland of the Appalachian Orogeny underlie the vast plain of the St. Lawrence Lowlands. They are composed of sandstones, dolomites, limestones, shales, slates and shales (Li et al., 2014). The altitude is generally less than 150 m. This lowland relief is only interrupted by rare hills, the highest of which barely reach 400 m. The most noteworthy are the Monteregian hills, of intrusive origin, established in the

Cretaceous, namely the Royal, Saint-Bruno, Saint-Hilaire, Saint-Grégoire, Rougemont and Yamaska mountains[4] (Landry and Mercier, 1992).

In Upper Wisconsinan, as little as 22 ka (thousands of years ago), most of Quebec was covered by the Laurentide Ice Sheet, a glacier up to 3,200 m thick. It was at least 1500 m thick over the St. Lawrence Valley (Occhietti et al., 2011). Because of its topography and low elevation, the bedrock was completely covered with Quaternary age mineral sediments. The glacier left thick deposits of carbonate till rich in clay and silt derived from the bedrock over which it was advancing (Landry et al., 2013).

At the end of this period, a global warming begins that will be felt throughout the northern hemisphere. This warming begins towards the end of the Upper Wisconsinan (18 to 16 ka) and initiates the melting of the ice sheet. As the continent collapses under the weight of the glacier and the glacial fronts retreat, a long arm of sea from the Atlantic slowly invades the St. Lawrence Lowlands to give birth to the Champlain Sea. Between 12 and 10 ka, this post-glacial sea occupied the entire St. Lawrence Valley and has left numerous traces of its presence (Landry et al., 2013). In deep water, the sea became a sedimentation basin where the fine clay and silt particles that dominate the southwestern part of the natural province accumulated. It is not uncommon for these fine marine sediments to reach 20 to 50 m in thickness. This abundant sedimentation helped to mask the glacial pattern and to build a calm relief broken by deltas made up of stratified sand and gravel and perched at different altitudes corresponding to the different stages of continental emergence. These coastal marine deposits have been remodeled, in places, by the wind to form parabolic dunes that are now stabilized by vegetation (Filion, 1987). The former shores of the Champlain Sea are now just over 200 m above sea level in the north and between 150 and 190 m in the south due to differential isostatic rebound on either side of the St. Lawrence River (Elson, 1969). At about 6.7 ka, the St. Lawrence Lowlands had about their present configuration (Landry and Mercier, 1992). The further one moves away from the St. Lawrence River, the greater the importance of glacial deposits reworked by the waters of the Champlain Sea (Landry and Mercier, 1992). On the plain, rock outcrops are found only along the river and rivers where fluviomarine erosion has been active for a long time or is still active (Payette and Rochefort, 2001). Elsewhere, poorly drained depressions in marine clays and fluviomarine outwashes formed by the invasion and retreat of the Champlain Sea have favoured the paludification processes that created the peatlands (Payette and Rochefort, 2001).

6.2. Hydrography

The St. Lawrence River dominates the St. Lawrence Lowlands. It is part of the St. Lawrence-Great Lakes hydrographic system that drains more than 25% of the world's freshwater reserves and influences environmental processes on the North American continent. With a drainage basin of

[4] Six of the nine Monteregian Hills emerge in the St. Lawrence Lowlands, while the other three, Shefford, Bromont and Megantic Mountains, straddle the Appalachian Natural Province. Three other intrusions of the same origin are completely or almost completely buried in marine sediments, namely those of Saint-André and Oka (according to sources, sometimes recognized as the tenth Monteregian Hill), west of Montréal, and the Iberville intrusion, near Mont Saint-Grégoire.

1.6 million square kilometres and an average annual flow of 12,600 m^3/s (cubic metres per second), the St. Lawrence ranks among the 20 largest rivers in the world (State of the St. Lawrence River Monitoring Working Group, 2014).

The St. Lawrence system, which extends from the Great Lakes to the Atlantic Ocean some 1,600 km, is complex (Centre Saint-Laurent, 1996). It is made up of fluvial lakes and narrow stretches whose physiographic and hydrological characteristics vary greatly in space and time. This natural heterogeneity greatly influences aquatic habitats and organisms, particularly through the highly contrasting water flow patterns between the calm and fast water sectors. In addition, a large number of tributaries and effluents, originating in the Appalachian Mountains or the Canadian Shield, flow into the St. Lawrence River and greatly increase its hydrological variability (particularly the Ottawa River) as far as the tidal estuary (Morin and Bouchard, 2000; Boyer et al., 2010). These tributaries bring waters whose natural physicochemical characteristics are very distinct and sometimes very degraded compared to those of the river. In fact, for much of its course, the river resembles a juxtaposition of several rivers flowing side by side, each bearing a different signature identifiable over more than 100 km in the fluvial portion (referred to as "bodies of water"). In addition, the river is artificially divided in two by a navigation channel that limits exchanges between the north and south banks, channelling the flow of water in its centre. It is mainly because of this natural physical heterogeneity, coupled with the many small and large-scale anthropogenic disturbances, that so many contrasts can be observed in fish communities from one sector of the river to another (La Violette et al., 2003; Mingelbier et al., 2008).

Within the St. Lawrence Lowlands, the St. Lawrence hydrographic system comprises three major distinct portions (State of the St. Lawrence River Monitoring Working Group, 2014):

1) A fluvial section, starting upstream at the Ontario border and ending near Trois-Rivières, consisting of fresh water and free of tidal influence. This section includes three river lakes (Saint-François, Saint-Louis and Saint-Pierre) alternating with narrow sections, major rapids resulting from elevation changes of more than 20 m (Les Cèdres and Lachine) and numerous islands sometimes grouped together in archipelagos (Îles-de-la-Paix, Boucherville, Contrecœur, Sorel);
2) A fluvial estuary between Trois-Rivières and the eastern tip of Île d'Orléans, consisting of fresh water subject to a tide whose amplitude gradually increases downstream and reaches 7 m at Quebec City. The tidal range also results in a current reversal at rising tide, which occurs from Lake Saint-Pierre, but with a greater impact on ecosystems from Grondines downstream;
3) A middle estuary, also known as a brackish water estuary, part of which is included in the St. Lawrence Lowlands region. The middle estuary begins at the eastern tip of Île d'Orléans and ends, on the north shore, at the mouth of the Saguenay River and, to the south, at the western tip of Île Verte. Downstream of the eastern tip of Île d'Orléans, turbidity suddenly reaches maximum values, which then gradually decrease as far as the maritime estuary, while water salinity gradually increases from 0 to about 15 to 20 ‰ (Morissette et al., 2016).

The course of the St. Lawrence system continues downstream of the St. Lawrence Lowlands boundary with the maritime estuary consisting of salt water (from Tadoussac to Pointe-des-Monts) and the gulf flowing into the Atlantic Ocean.

Apart from the three major fluvial lakes of the St. Lawrence River (Saint-François, Saint-Louis and Saint-Pierre) and the Ottawa River (des Chats and Deux-Montagnes), there are very few other lakes in this natural province and most of them are small in size. The most notable is Lake Champlain, which belongs to the Richelieu River watershed and of which only the northernmost portion, Missisquoi Bay, is in Quebec. Although the boundaries of the Lowlands are relatively close to the mouths of the major tributaries of the St. Lawrence River, their watersheds extend far upstream. Because they are located north and south of the St. Lawrence River, they present significant climatic contrasts that have impacts on the St. Lawrence system that are greater than the influences of the Lowlands in the strict sense (e.g., flood and low-flow periods, water volume, temperature) (Boyer et al., 2010).

6.3. Climate

The natural province enjoys some of the mildest weather conditions in Quebec. It has a moderate subhumid continental climate characterized by relatively warm summers and cool winters influenced by the presence of the St. Lawrence system and Lake Champlain. The average annual temperature ranges from 4.2 to 5.8° C and the average temperature for the three warmest months varies from 17.7 to 19.2° C. The growing season[5] lasts 199 to 214 days. Precipitation is abundant and totals nearly one metre annually (Mc Kenney, 1998, in Li and Ducruc, 1999), about a quarter of which falls as snow (Wilson, 1971).

6.4. Natural environments and biodiversity of interest

As in all temperate regions of the world, centuries of agriculture, logging and urbanization have profoundly altered the landscape and fragmented natural environments into isolated islands. New landscapes have been created, creating large tracts of farmland on the fertile clays of the Champlain Sea, while forests and wetlands occupy soils less suitable for agriculture because of excess water or excessive stoniness. Agricultural land now occupies 40% of the territory (ECCC and MDDELCC, 2018). The remaining forest cover (24%) is represented by a predominantly deciduous mixed forest that is, overall, highly degraded (Li and Ducruc, 1999). Many of the forest patches or fragments are now associated with farm woodlots, floodplains, urban forests or existing protected areas. However, larger areas of forest, with varying degrees of fragmentation, still occur in the Ottawa River Lowlands, the Monteregian Hills, the Adirondack and Appalachian foothills, and the Quebec Plain. Mature forests currently occupy a very small area compared to young forests of anthropogenic or natural origin. These landscapes of cultivated plains and forests often give the impression that the pre-colonial fabric was primarily forest. However, some areas of the St. Lawrence Lowlands did not support forests, but rather peat bogs or marshes (Payette and

[5] Number of days when the temperature exceeds 5° C

Rochefort, 2001). Analysis of soil maps also suggests that this natural province was once covered by vast expanses of forest interspersed with significant wetlands.

Physical characteristics have indeed favoured wetlands. On the one hand, the hydrographic network of high-flow rivers such as the St. Lawrence, Ottawa and Richelieu rivers, which are associated with significant spring flooding resulting from snowmelt and summer low water levels, have been conducive to the formation of swamps, marshes and aquatic grass beds (Bérard and Côté, 1996). On the other hand, the flat topography and the nature of surface deposits in the Lowlands have been conducive to the establishment and expansion of peat bogs (Payette and Rochefort, 2001). Today, wetlands cover 10% of the St. Lawrence Lowlands; swamps and marshes spared from agriculture and urbanization are concentrated mainly in the riparian zones of the lentic portions of the St. Lawrence, Ottawa and Richelieu rivers, as well as in the intertidal zone of the St. Lawrence Estuary. Favoured by the size of the floodplain, the most remarkable expanses of marshes and swamps are those of the Lake Saint-Pierre basin, which, with a little over 16,000 ha, account for more than 55% of these types of wetlands found in the Quebec portion of the St. Lawrence system (Jean and Létourneau, 2011).

Although many of them are degraded, the peatland distribution pattern has remained relatively intact in the eastern part of the St. Lawrence Lowlands. In the west, only cultivated blacklands sometimes remain as evidence of their presence. The peatlands that remain are generally those of very large areas. Although they have often been amputated or drained at their periphery, the numerous peat bogs of the Joly-Manseau Plain, as well as those of Lake Champlain, Lac à la Tortue, Lanoraie, and the Small Tea Field and Large Tea Field of the Upper St. Lawrence, have retained their characteristics (Gratton, 2010).

The St. Lawrence Lowlands occupy barely 1.8% of Quebec (Li et al., 2014), but this area is very important for the conservation of its biological diversity. More than two thirds of Quebec's vascular plants are represented here. In total, 198 of the 240 bird species that frequent the St. Lawrence Lowlands regularly nest there (Environment Canada, 2013b). Almost all species of terrestrial and semi-aquatic mammals characteristic of the hardwood forest still live there. Thirty-two of Quebec's 33 species of amphibians and reptiles have already been inventoried there (Jobin et al., 2002). Globally, more than 100 species of freshwater and diadromous fish are distributed throughout the river, depending on physical conditions and habitat preferences. This diversity is the result of the river's wide geographic extent, its position between the Great Lakes and the Atlantic, its connections with southern river systems, such as the Mississippi River via Lake Michigan and the Hudson River via Lake Champlain, and the diversity of available aquatic habitats (Mingelbier et al., 2008).

As of January 2016 for plant species and February 2016 for wildlife species, the study area had 86 terrestrial and aquatic species at risk (excluding saltwater fish and marine mammals), of which 16 are designated endangered and 22 threatened in Canada and listed in Schedule 1 of the *Species at Risk Act* (S.C. 2002, c. 29), and of which 45 are designated threatened and 22 vulnerable in Quebec under the *Act respecting threatened and vulnerable species* (S.Q., C.E 12.01) (see Appendix A). In addition to these species are dozens of plant and animal species likely to be designated threatened or vulnerable in Quebec or of special concern in Canada, such as the sedge wren (*Cistothorus platensis*) and the northern ringneck snake (*Diadophis punctatus*), as well as calcicultural plants observed in alvars, such as the Virginia juniper (*Juniperus virginiana* var. *virginiana*) and the false pennyroyal (*Trichostema brachiatum*).

6.5. Protected areas

According to the Government of Quebec's Registre des aires protégées au Québec, protected areas in the St. Lawrence Lowlands covered 4.5% of the natural province in 2009 (MDDEP, 2010). The protected areas belong to the following categories:

- Federal Protected Areas - National Parks, National Wildlife Areas and Migratory Bird Sanctuaries;
- Provincial protected areas - Quebec national parks, ecological reserves, wildlife refuges, salmon rivers, biodiversity reserves, legally designated wildlife habitats on public land, designated plant habitats, natural environments protected by the Fondation de la Faune du Québec;
- Municipal Protected Areas - Recreation, Tourism and Conservation Parks and Urban Regional Parks;
- Areas protected by a private organization charter including the property of conservation organizations by institutions or by owners under the status of a recognized nature reserve on private land.

Excluding the wildlife habitats designated in this register (waterfowl concentration area, white-tailed deer winter sites, muskrat habitat, bird colony, heronry), and adding the areas of dozens of other sites subject to conservation measures, the majority of which are located on private land, (see the Répertoire des sites de conservation volontaire du Québec; RMN, 2020; as of september 2017), this proportion now represents only 1.4% of the area of the St.Lawrence Lowlands. The list of sites listed in the Registre des aires protégées au Québec, excluding designated wildlife habitats, appears in Appendix B.

The effective protection of biodiversity varies depending on whether the protected areas belong to one or the other of the categories of the International Union for Conservation of Nature (IUCN) (Dudley, 2008). Finally, although these are not IUCN-recognized conservation statuses, many areas enjoy international recognition, including the Lac-Saint-Pierre and Mont-Saint-Hilaire World Biosphere Reserves and RAMSAR sites targeting wetlands of international interest such as those of Lac Saint-Pierre, Lac Saint-François and Cap Tourmente. Twenty-nine Important Bird Areas (IBAs) have also been recognized, making the St. Lawrence Lowlands, and primarily the St. Lawrence system, a key migratory corridor for birds (Nature Québec, 2018).

7. Threats

As in the past, forest, wetland, aquatic and open environments continue to be altered and their quality compromised. Many species living in these environments are now in a precarious situation. Several human activities (e.g., port development, mining, hydroelectric and wind power development, industrial development, hunting, fishing and harvesting) can have serious local consequences. Presented according to the IUCN classification of threats (IUCN-CMP, 2006), the direct threats described here are those which, in the more or less short term, are likely to have the greatest impact on ecosystems.

7.1. Residential and commercial development

Linked to strong population growth on the outskirts of major cities (ISQ, 2017), urban sprawl is largely responsible for anthropogenic pressures on natural environments that, until now, had been spared by agriculture. In the 1950s, there was virtually no sprawl in the Montréal and Québec City regions. Urban expansion in these two regions increased exponentially between 1951 and 2011 and shows no sign of slowing down, unlike what has been observed in several European cities (Nazarnia et al., 2016).

In the Montreal metropolitan community, urban sprawl led to an increase of more than 60% in the amount of built space on the territory, while the population grew by only 27% during the same period (Perreault and Porlier, 2005). Residential development does not come alone; the migration of populations to the suburbs and the peri-urban area inevitably leads to a significant increase in the need for goods and services. The centralization of businesses is creating an increasing dependence on the automobile and, consequently, the development of the road transportation network. To meet the recreational activities of the growing population, the increase in recreational and tourist infrastructures is manifested by the multiplication of golf courses, marinas and resorts. In natural areas, whether or not they have protected status, the increase in traffic and the intensification of recreational activities are causing pressure.

The destruction or alteration of habitat results in reduced wildlife populations, reduced capacity to provide ecological goods and services, and generally lower ecological integrity (Environment Canada, 2013a). There is also growing evidence that the matrix can have a profound effect on habitat use by individual species, particularly in fragmented landscapes, by altering the dynamics within the natural habitat patch itself and affecting the ability of species to move between patches (Ewers and Didham, 2006 in Environment Canada, 2013a). Fragmentation, which is defined as the gradual division of a landscape into a series of distinct and more or less isolated fragments of habitat in a matrix of anthropogenic environments, would be one of the main causes of population extinction; the resulting insularization and degradation of isolated ecosystems would therefore be the greatest threat to maintaining biodiversity in the St. Lawrence Lowlands (Gratton, 2010).

By modifying the spatial organization of natural environments and limiting the exchanges that can occur between them, fragmentation can alter the structure of plant and animal communities, causing a loss of richness and diversity (Saunders et al., 1991; Kareiva and Wennergen, 1995).

According to Rioux et al. (2009), the small areas and high level of fragmentation of forest habitats in intensive agricultural landscapes are responsible for the decline and precarious situation of several bird species and other taxonomic groups. The phenomenon of fragmentation is not exclusive to forest and wetland habitats. Declines in area and the fragmentation of agricultural habitats particularly affect avian species that require large areas to nest, such as the upland sandpiper (*Bartramia longicauda*) (Bélanger et al., 1999).

The loss of connectivity between different habitats particularly affects species with reduced mobility or limited dispersal patterns. Indeed, the ability of a species to colonize a habitat depends, to some extent, on the distance separating it from other areas of comparable natural environments, be it other fragments or unfragmented habitat. This ability is necessarily related to the mode of dispersal and the size of the species (Saunders et al., 1991).

7.2. Agriculture

The forests and wetlands of the St. Lawrence Lowlands have disappeared due to their conversion to cultivated areas or urban development (industrial, commercial or residential). As a result, forested areas now account for only 24% of land use (ECCC and MDDELCC, 2018). Géomont (2018) estimates that between 2000 and 2017, forest cover declined by 6% in the Montérégie region alone. In addition, some 40 to 80% of the area of wetlands in agricultural and urban areas disappeared, with this proportion reaching over 85% in the Greater Montreal area (Joly et al., 2008; Gratton, 2010). The various studies listed by Pellerin and Poulin (2013) indicate that the areas disturbed can be significant in the St. Lawrence Lowlands, but can reach, depending on the period and location, up to more than 60% over a 50-year period. The regions where fertile Champlain Sea clays are found are those that have undergone the most intensive deforestation and drainage in Quebec (Gratton, 2010).

As a result of the accelerated conversion of natural landscapes over the last century, the agricultural sector now covers 40% of the St. Lawrence Lowlands (ECCC and MDDELCC, 2018). Successional habitats in rural landscapes can serve as critical habitats for a large number of species, including forest species (Environment Canada, 2013a). However, the diversity and quality of human-originated habitats tend to decline. When not encroached upon by suburban development, land in the southwestern part of the province is subject to intensive production. Field crops, such as corn and soybeans, occupy large areas and have destroyed many habitats such as windbreaks, riparian strips, woodlots and wetlands, leaving less and less room for, among other things, the diversity of birds it used to support (Jobin et al., 2003; Gauthier et al., 2004; Quesnel et al., 2006).

The replacement of grasslands and pastures has led to habitat degradation, loss of nesting cover or alteration of feeding areas, which has resulted in the decline of several species of birds characteristic of rural environments, such as sparrows and swallows, eastern loggerhead shrike (*Lanius ludovicianus migrans*), grasshopper sparrow (*Ammodramus savannarum*), bobolink (*Dolichonyx oryzivorous*) and eastern meadowlark (*Sturnella magna*) (Desgranges et al., 1994; Jobin et al., 1996; Jobin et al., 1998). Rioux et al. (2009) also found, in studying the habitat dynamics in the St. Lawrence Lowlands between 1950 and 1997, that perennial crops had been replaced by annual crops in landscapes dominated by agriculture. In contrast, in landscapes dominated by forest habitats, old fields have been replaced by forests.

Between 1950 and 1965, agricultural intensification was largely responsible (34%) for the significant impacts on wetlands (Environment Canada, 1986, in Pellerin and Poulin, 2013). In order to take advantage of as much land as possible and to facilitate the movement of farm equipment, low or wet areas were drained and reshaped, watercourses were straightened over hundreds of kilometres and riparian vegetation was eliminated. To bring some of the land flooded by the spring freshet into cultivation more quickly, dykes were erected. These substantial alterations to hydrographic systems in the St. Lawrence Lowlands have reduced the carrying capacity for waterfowl and limited access to spawning grounds and rearing sites for several fish species (Environment Canada, 2007). Between 2004 and 2011, 19% of the total area of wetlands in the St. Lawrence Lowlands was disturbed; agricultural activities were the main sources of disturbance, affecting 44% of the wetlands (Pellerin and Poulin, 2013). The vast peat bogs in the eastern regions have not yet been converted to agriculture and are increasingly being sought after for cranberry production. Avard et al. (2013) showed, using an analysis of aerial photographs and field work, that between 1966 and 2010, 5,433 ha of peatlands (24% of the peatland area present in 1966) were irreversibly disturbed, mainly due to cranberry cultivation.

7.3. Changes in natural systems

Dams built on the St. Lawrence River and its main tributaries are responsible for the most significant modification of a natural system in the St. Lawrence Lowlands. These flow regulation and control structures are used primarily to stem spring flooding, as well as to facilitate commercial navigation and hydroelectric power generation. From a strictly hydrological standpoint, the flows of the St. Lawrence and Ottawa rivers are subject to water management plans that do not follow a natural seasonal pattern. Seasonal and interannual variations in water levels are critical for most components of aquatic and riparian ecosystems, as well as for wetlands in relation to the rivers. Numerous studies by the St. Lawrence Centre and its partners focus on the impact of water level regulation on the river's biodiversity (Centre Saint-Laurent, 1996). The impacts of water level fluctuations in these ecosystems are felt, among other things, on the quality and availability of breeding habitats for aquatic fauna. Artificial fluctuations in water levels destroy habitats, dry out spawning grounds, flood turtle and waterfowl nests and intensify shoreline erosion, while the annual emptying of navigation channels kills a large number of fish (FAPAQ, 2003; Saint-Laurent Vision 2000, 1999).

Furthermore, in the aquatic environment, the presence of hydroelectric dams on the St. Lawrence River and its main tributaries constitutes physical barriers that impede the free movement of fish and limit access to certain spawning grounds, particularly for American shad (*Alosa sapidissima*) (Équipe de rétablissement de l'alose savoureuse, 2001) and American eel (*Anguilla rostrata*) (COSEWIC, 2006). These geographic barriers fragment habitat and can lead to the isolation of some populations and reduced gene flow (Jager et al., 2001). In the Montreal area, the combined effects of habitat loss, degradation of spawning sites and isolation of populations after dam construction have decimated fish populations in Lake Saint-François and Lake des Deux-Montagnes (Moisan and Laflamme, 1999).

Despite some improvements brought about by efforts to protect and manage aquatic wildlife and its habitats over the past 30 years, the St. Lawrence is still showing signs of deterioration. Like all the waterways in the St. Lawrence Lowlands, it remains vulnerable to shoreline artificialisation and the wading of commercial ships and pleasure boats. For marine transportation, the river requires the maintenance of the navigation channel, the deposition of dredged sediments and the development and operation of port facilities.

7.4. Transport corridors and services

In the St. Lawrence Lowlands, the road network, which is already well developed, should nevertheless expand over the next few years, notably through the extension of highway and rail lines to serve the increasingly populous suburbs and improve the transportation of goods through urban bypasses.

The road network is one of the most widespread disturbances in the inhabited landscape of North America (Trombulak and Frissell, 2000). Roads are a major cause of fragmentation of formerly contiguous habitats, creating barriers to wildlife movement and limiting access to resources on both sides of the road (Lesmerises et al., 2012). In addition to the road mortality discussed below, this barrier effect can cause functional habitat loss for species unable to cross or avoid roads (Benitez-Lopez et al., 2010; Leblond et al., 2011).

7.5. Use of biological resources

Compared to the Appalachian and Laurentian regions, where forest cover dominates, the exploitation of wood resources in the St. Lawrence Lowlands is now a secondary economic activity. Because of the urbanization and agricultural vocation of the land that prevails and the scarcity of forested areas, logging is a marginal activity on the outskirts of major urban centres. Elsewhere in the territory, production is almost exclusively the responsibility of small forest producers; few large forest companies are still active.

Many woodlot owners are forest producers who earn additional income from their operations. The main products marketed are pulpwood, maple products, lumber and firewood. Forestry operations are mainly cleaning, selective cutting, road construction, planting and drainage. All of these interventions can have a direct impact on biodiversity by modifying the structure of plant communities, fragmenting woodlots and altering the natural flow of surface water. Silvicultural activities were one of the main sources of disturbance, affecting 26% of the wetlands in the St. Lawrence Lowlands between 2004 and 2011 (Pellerin and Poulin, 2013). The Seigneurie de Joly de Lotbinière is the only large forest block on public land. Covering an area of 140 km^2, it is exploited by beneficiaries of supply and forest management contracts (CAAF). In addition, there are 50 maple sugar bush licence holders.

7.6. Invasive and problematic species

The opening up of the North American continent thanks to maritime, road, rail and air transportation networks has allowed the massive arrival of exotic plant and animal species, some of which have succeeded in adapting and proliferating in their new environment. In Quebec, it is in the St. Lawrence Lowlands that invasive alien species are the most abundant, and their numbers continue to grow.

Wetlands and aquatic environments are particularly vulnerable to the proliferation of invasive plants. The most problematic species in terms of biodiversity are common reed (*Phragmites australis*), Japanese knotweed (*Fallopia japonica*), common buckthorn (*Rhamnus cathartica*) and water chestnut (*Trapa natans*). The proportion of invasive plant cover is estimated to reach nearly 45% in the Montréal and Contrecoeur regions (Lavoie et al., 2003). By replacing natural plant cover, these species threaten in particular the richness and biodiversity of wetlands and adjacent farmland. The invasion of common reed in wetlands and road corridors is currently major and increasing in the St. Lawrence Lowlands. When present, common reed can greatly modify the dynamics of floristic communities (Le Groupe Phragmites, 2012), but recent studies have shown minor impacts on fauna in the short and medium term (birds: Gagnon Lupien et al., 2015; amphibians: Mazerolle et al., 2014; fish: Larochelle et al., 2015).

In the aquatic environment, the greatest threats come from the introduction of exotic animal species. In addition to affecting the ecological integrity and food web of the St. Lawrence (Reyjol et al., 2010), these species are potential vectors of pathogens. The river's position between the Great Lakes and the Atlantic and its connections with southern river systems, such as the Mississippi River via Lake Michigan and the Hudson River via Lake Champlain, have for more than a century favoured the introduction of a few non-native species such as common carp (*Cyprinus carpio*) (Mingelbier et al., 2008). Over the past 20 years, the situation of the St. Lawrence River following the invasion of such species has deteriorated. This is mainly due to the rapid colonization of the round goby (*Neogobius melanostomus*), the demographic expansion of tench (*Tinca tinca*) and red roach (*Scardinius erythrophtalmus*) and the detection of the spiny water flea (*Bythotrephes longimanus*). The capture in May 2016 of a reed carp (*Ctenopharyngodon idella*) (one of the four Asian carp species) and the presence of its DNA in several sampling stations are of great concern. Over the next few years, the risk of spreading these new exotic species in the St. Lawrence River and its tributaries is considered high (SLAP, 2018b). These species compete with several native species, including the yellow perch (*Perca flavescens*), and species at risk such as the copper redhorse (*Moxostoma hubbsi*), an endemic species that is in danger of extinction (Bilodeau et al., 2004).

Two bivalves, the zebra mussel (*Dreissena polymorpha*) and the quagga mussel (*Dreissena bugensis*), were probably introduced by the ballast of commercial ships. The presence of these bivalves has a considerable impact on ecosystems and species, particularly the copper redhorse and native mollusc species (Centre Saint-Laurent, 1996; MDDEP, 2002; Équipe de rétablissement du chevalier cuivré, 2004).

Exotic species also affect forest and open environments. One species whose expansion is accelerating is buckthorn, which is invading riparian woodlands and alvars. In forested areas, however, the most remarkable case is that of the small European bark beetle (*Scolytus multistriatus*), the vector of Dutch elm disease. Information on the distribution in Quebec of butternut canker caused by the fungus *Sirococcus clavigignenti-juglandacearum*, responsible for the decline in butternut (*Juglans cinerea*) populations, is limited (COSEWIC, 2003). In contrast, the emerald ash borer (*Agrilus planipennis*), a beetle native to Asia, quickly proved to be highly destructive. Detected in 2008 in Quebec, it has since destroyed thousands of ash trees and continues to spread to new regions, causing considerable economic and ecological damage (NRC, 2018).

Finally, some native species can sometimes become problematic because of their numbers. Since the species has been monitored, white-tailed deer (*Odocoileus virginianus*) have reached their highest density in southern Quebec due to the abundance of food and the absence of their main predator, the eastern wolf (*Canis lycaon*) (Gagnon, 2004). Overpopulation can affect herbaceous and shrub strata to the point of changing the structure of a forest stand (Potvin et al., 2003) and overgrazing compromises the natural regeneration and survival of species in a precarious situation, such as the American ginseng (*Panax quinquefolius*) (Gagnon, 2004). Nest depredation by raccoons (*Procyon lotor*) and striped skunks (*Mephitis mephitis*), two species that have adapted well to urban and peri-urban environments, is a serious threat to the survival of turtles in precarious situations, and the abundance of domestic animals in the suburbs, particularly cats, is responsible for high mortality rates among birds and small mammals (Wood et al., 2003; Blancher, 2013).

7.7. Pollution

Over the centuries, the waterways of the St. Lawrence Lowlands have been neglected by a population that is ignorant or unconcerned about the fragility of this indispensable resource. The St. Lawrence River alone provides drinking water to 80% of Quebec's population (Gratton, 2010). Over the past century, urbanization, industrial activities and agricultural activities have generated a significant load of toxic substances that have found their way into the waterways (SLAP, 2018c). Effluents carry contaminated water from water treatment plants, chemical, food, pulp and paper industries, and agricultural runoff (FAPAQ, 2003). These inputs have contributed to the deterioration of water quality in the immense Great Lakes-St. Lawrence basin and have harmed several species that it shelters. Metals, nutrients, pesticides and emerging substances such as pharmaceuticals are thus detected in the water at concentrations that are sometimes of concern (SLAP, 2018c). In addition, the St. Lawrence River is an important transportation route for Canada and Quebec. Many Canadian and foreign ships using this difficult navigable waterway carry large quantities of petroleum and chemical products. The risk of oil spills is very real since several accidents have already occurred. Although major spills in the St. Lawrence have been infrequent to date, other accidents elsewhere in the world call for vigilance (Guerrier and Paul, 2000).

In terrestrial areas, chemical and biological pesticide applications can significantly reduce bird food sources by destroying populations of insects and other invertebrates. These products contaminate birds indirectly through the degradation of water quality or directly through the ingestion of toxic products (Gauthier et al., 2004).

7.8. Climate change and extreme weather

Climate change is changing the composition and dynamics of ecosystems (Secretariat of the Convention on Biological Diversity, 2007; Ouranos, 2010). Climate change adds to other pressures on biodiversity from human activities. According to Siron (2010), the impacts of climate change on biodiversity could: 1) degrade habitats, some of which could disappear; 2) cause new species to arrive in Quebec, mainly from the south; 3) change the key dates in the life cycle of plant species (e.g., flowering dates) or animal species (migration dates); 4) lengthen the growth periods of certain plants; 5) increase the productivity of certain ecosystems, which could amplify the proliferation of cyanobacteria or facilitate the spread of invasive or disease-carrying species. Disturbances are expected to be greater in habitats already weakened by urban sprawl and the pressure of human activities, particularly in southern Quebec. Climate change may also lead to an increased extinction rate, as well as changes in reproduction periods, animal behaviour and the appearance of new evolutionary traits (Wilby and Perry, 2006).

Climate change will have a significant effect on water quantities in the Great Lakes and the St. Lawrence River and will lead to profound changes in the dynamics of watercourses, as well as the loss of diverse habitats, increased water pollution through the re-suspension of contaminated sediments and the proliferation of invasive emergent plants (Lavoie et al., 2003; Hudon, 2005; Bibeau and Rouleau, 2007). In combination with other factors, changes in spring floods caused by climate change (Boyer et al., 2010) or temperature anomalies have already caused massive fish mortality (Ouellet et al., 2010).

8. Conservation context

The St. Lawrence Lowlands Natural Province straddles eleven administrative regions. It includes all of the Laval, Montreal and Montérégie regions, plus, from west to east, the lowlands and also the more populated areas of the Outaouais, Laurentians, Lanaudière, Mauricie, Centre-du-Québec, Capitale-Nationale, Chaudières-Appalaches and Bas-Saint-Laurent regions. More than four million people, or half of Quebec's population, live there (MELCC, 2018) and are largely settled along the river and its main tributaries. The province's largest cities are located there: Montreal, Quebec City, Laval, Gatineau and Longueuil. As in all temperate regions of the world enjoying the mildest climatic conditions, centuries of agriculture, forestry and urbanization have profoundly altered the landscape of the St. Lawrence Lowlands.

The easily cultivable soils and the abundance of wildlife in this territory allowed the first settlers to meet their food needs first and, later, thanks to the proximity of the river, to meet the needs of commerce. Under the French regime, the seigneuries were in fact cut into long narrow strips perpendicular to the rivers to facilitate the transportation of goods. The alignment of the land is still a characteristic feature of the rural landscape today.

Because of their proximity to the river, the forests of the St. Lawrence Lowlands were among the first to be logged in Quebec. At the time, the main purpose of logging was to meet local construction and heating needs (Quenneville, 2007). However, it was the British regime that truly marked the era of land clearing and during which colonization of the entire St. Lawrence Valley took off (Gauthier and Aubry, 1996). In the midst of the industrial revolution, logging intensified considerably until the 1830s (Johnston, 1991). From the mid-19th century on, the agricultural landscape began to replace the previous forest dominated landscape (Simard and Bouchard, 1996; Filion et al., 2001).

In recent decades, subsistence agriculture has been abandoned in favour of more productive and profitable farming practices. The transformation of the landscape has accelerated. The intensification of agriculture and the increase in cultivated areas have been achieved at the expense of several thousand hectares of natural habitats (Langevin, 1997). On the outskirts of large cities, the agricultural area is exploited to its maximum (Quesnel et al., 2006). Today, urban sprawl is continuing to the detriment of both natural areas and agricultural land (Équiterre, 2009). Despite the disappearance of natural environments and the extreme degradation and fragmentation of what remains of them, the St. Lawrence Lowlands remain the most important area in terms of biodiversity in Quebec (Gratton, 2010; Tardif et al., 2005) and one of the richest ecoregions in North America (Ricketts et al., 1999) and Canada (NCC, 2018).

In Quebec, as in Canada, several laws have been passed under which protected areas can be designated. There are nearly 30 different protection statuses (MELCC, 2018). At the provincial level, the MELCC is responsible for protected areas designated under the *Natural Heritage Conservation Act*. Quebec's national parks are established under the Parks Act, which falls under the jurisdiction of the MFFP, and the MFFP can also designate protected areas under the *Loi sur la conservation et la mise en valeur de la faune* and the *Loi sur les forêts*. The MELCC and the MFFP share responsibility for the *Act respecting threatened and vulnerable species*, which allows for the designation of habitats for threatened and vulnerable plant and animal species. At the federal level, five acts govern the creation of protected areas and fall under the jurisdiction of ECCC, namely the *Canada National Parks Act*, the *Marine Conservation Areas Act*, the *Wildlife Act*, the *Migratory Birds Convention Act*, and the *Species at Risk Act*.

Over the past three decades, numerous government programs have had a significant impact on the protection of biodiversity in Quebec, particularly in the aquatic environments of the St. Lawrence corridor. These include the Eastern Habitat Joint Venture for the conservation of environments heavily used by waterfowl and other migratory birds and the St. Lawrence Action Plan, a Canada-Quebec partnership whose goal is to restore, protect and conserve the environment of the St. Lawrence. Since 1988, four five-year action plans have been carried out by a dozen government partners and numerous collaborators from the private and community sectors. The Intervention Strategy for the Future of Lake Saint-Pierre is an example of an ongoing initiative stimulated, among other things, by the PASL.

Following the United Nations (UN) Conference on Environment and Development held in Rio de Janeiro in 1992, the governments of Quebec and Canada adopted strategies on the conservation of biological diversity. These strategies aim, among other things, to increase the area of protected areas representative of biological diversity, both terrestrial and marine, and to facilitate the conservation of protected areas on private land by individuals, non-governmental conservation organizations and the private sector in general. The challenge of protecting biodiversity on private land is that any government intervention to protect a habitat is considered an infringement of individual property rights. Recognizing the expertise of organizations in protecting natural environments on private lands, the federal and provincial governments launched programs a few years ago to financially support voluntary conservation, also known as private stewardship. The actions taken by conservation organizations are supported financially by governments, foundations, private donations and sometimes even municipalities. In the St. Lawrence Lowlands, the gains in protected areas made in recent years are largely the result of the efforts of conservation organizations.

To date, the register of protected areas accounts for 10.34% of Quebec's territory protected by various statutes of protection. In the St. Lawrence Lowlands, the percentage of protected areas rose from 2.22% in 2002 to 4.50% in 2009 (MDDEP, 2010). It has changed little since then. However, the register does not take into account all legal conservation measures on private land.

At the 2010 UN Conference in Nagoya, the percentage targets for protected areas were raised to 17% of land and inland waters and 10% of marine and coastal areas by 2020. Even with a substantial increase in the area of protected areas and voluntary conservation measures, it is unlikely that these international objectives will be met in Québec. Today, it is recognized that the designation of protected areas will not be enough to stop the erosion of biodiversity and that other measures will have to be adopted. More than anywhere else in Quebec, municipal authorities in the St. Lawrence Lowlands should be at the heart of territorial strategies to protect biodiversity (Boucher and Fontaine, 2010). Already, thanks to the mechanisms of the Act respecting land use planning and development and the powers conferred by the *Municipal Powers Act*, municipal authorities have tools that would make it possible to make substantial gains in biodiversity protection (Boucher and Fontaine, 2010). Several of them have adopted plans over the past few years that aim to protect natural environments, ranging from the Plan métropolitain d'aménagement et de développement (PMAD) de la Communauté métropolitaine de Montréal (2012) to the Plan de conservation des milieux naturels et de réduction de l'empreinte environnementale de la ville de Boucherville (2012). Projects for green spaces, greening or ecological continuities involving citizens are multiplying. Through the regional plans that it requires RCMs and metropolitan communities to adopt, the Act Respecting the Conservation of Wetlands and Watercourses, adopted in 2017, aims to curb the destruction of wetlands and watercourses and to offset losses with net gains through the restoration of degraded environments or the creation of wetlands (MELCC, 2018).

Finally, a more rigorous application of existing policies already included in RCM development plans and municipal urban plans (e.g., the Politique de protection des rives, du littoral et des plaines in flood plains) could also greatly contribute to biodiversity protection. By adopting the "avoid, minimize and compensate" mitigation sequence for all development projects, municipalities could achieve a balance between land development and the conservation of natural environments (Boucher and Fontaine, 2010).

9. Conservation targets

The conservation targets represent different components of the territory that, if protected or managed adequately, would make it possible to maintain the overall biodiversity of the St. Lawrence Lowlands. The selection of sites of interest for biodiversity conservation as well as conservation strategies and actions will be based on the conservation targets. The coarse-filter and fine-filter approaches were used to determine the conservation targets in this atlas (Gérardin et al., 2002; Lemelin and Darveau, 2006; Gratton, 2010).

9.1. Coarse filter targets

The coarse filter targets are designed to capture most of the biodiversity present in a study area by identifying a set of sites that are representative and viable of the various ecosystems present in the St. Lawrence Lowlands. In doing so, they make it possible to conserve both the most frequent environments and the most common species. Five conservation targets for the coarse filter were selected for the Atlas of sites of conservation interest in the St. Lawrence Lowlands (Table 1).

Table 1. Coarse filter conservation targets selected for the Atlas of Sites of Conservation Interest in the St. Lawrence Lowlands

Coarse filter targets	Type of habitat, ecosystem or plant association
Forested areas	Terrestrial environment – temperate forest including riparian environments not composed of wetlands
Wetlands	Marshes, swamps, peatlands, wet meadows, shallow water
Open habitats – old fields	Herbaceous and shrubby regenerating fields
Open habitats - agricultural grasslands	Perennial crops, pastures, natural grasslands
Aquatic environments	Watercourses outside the St. Lawrence Corridor

For the St. Lawrence Corridor, it was not possible to develop a coarse filter because there are no instantaneous, high spatial resolution, continuous images of the entire St. Lawrence Lowlands system. However, fish habitat modelling, which was carried out at high spatial resolution in Lake Saint-Louis and in the stretch between Montreal and Trois-Rivières, has made it possible to develop a methodology similar to the coarse filter in certain portions of the St. Lawrence River corridor, notably in Lake Saint-Pierre.

9.1.1. Forested areas

Over the past 400 years, the pre-colonial forest of the St. Lawrence Lowlands has undergone major upheavals that have profoundly altered its importance within the landscape, as well as its composition, structural characteristics and ecological processes. The most striking example of these changes in the St. Lawrence Lowlands is the transition from a predominantly forested landscape to one in which large-scale annual crops predominate (Jobin et al., 2007; Rioux et al., 2009). It is estimated that these pre-colonial forests were to cover nearly 80% of this ecoregion. However, according to various studies conducted in recent years, the percentage of forested land fell from 34% in 1997 (Rioux et al., 2009) to less than 33% in 2001 (Jobin et al., 2007), and is now only 24% (ECCC and MDDELCC, 2018). This loss of forest area has particularly affected forests belonging to the bioclimatic domain of the hickory maple grove, where the largest urban centres and the greatest concentrations of intensive agricultural operations are found. Thus, the percentage of forest areas is now less than 20% in several RCMs in southwestern Quebec (Jobin et al., 2007), well below the 30% threshold recommended for maintaining a complete assemblage of species (Andrén, 1994; Fahrig, 1997).

In addition to the major losses of forest area caused by agricultural activities and urbanization, logging has also had a marked influence on species composition. It has been estimated that more than 85% of the pre-colonial temperate hardwood forest was composed of tolerant hardwood stands (Frelich and Lorimer, 1991), while a very marked increase in intolerant hardwoods has been observed in recent decades, particularly in regions heavily influenced by human activity, such as the Upper St. Lawrence (Brisson et al., 1988; Bouchard and Domon, 1997). The selective harvesting of certain species, the arrival of exotic insects and pathogens, and the fight against forest fires have also led to the depletion of certain types of stands, including white pine and red oak stands (Thériault and Quenneville, 1998; Doyon, 2002; Gagnon et al., 2003; Majcen, 2003; Doyon and Bouffard, 2009).

Finally, one of the most significant alterations to the forested landscape of the St. Lawrence Lowlands subsequent to colonization is related to the replacement of forest stands dominated by outdated forests by forests where this type of stand now covers only a very small portion of the territory. Thus, it has been estimated that the percentage of areas occupied by overmature forests (i.e., those over 150 years old) within the pre-colonial temperate hardwood forest would have been over 85%, with the other stages of development totalling less than 15% of the area (Frelich and Lorimer, 1991). Today, mature stands would total less than 15% of the area. The major loss of forest area in the St. Lawrence Lowlands has also had the direct effect of a marked decrease in connectivity within these landscapes, and this loss of structural and functional connectivity is likely to become even more pronounced in the coming years (Gonzalez et al., 2013). The constant spread of urbanized areas, which now occupy nearly 10% of the territory, and the increase in the density of the road network contribute to accelerating this fragmentation, making the landscapes very little permeable to the movement of wildlife and plant species (Jobin et al., 2007; Rioux et al., 2009).

9.1.2. Wetlands

The unique and diverse ecological attributes of wetlands provide them with a variety of functions useful to humans (Costanza et al., 1991). These ecological attributes, such as water storage capacity, contribution to biogeochemical cycles and primary productivity, have a role to play in flood prevention, water purification and maintenance of biodiversity.

The benefits resulting from the presence of wetlands are universally recognized, and this recognition is expressed today even in Quebec law, where the ecological functions associated with these environments are listed. Thus, the *Act affirming the collective nature of water resources and promoting better governance of water and associated environments* recognizes, among other things, the functions of:

- as a filter against pollution, as a bulwark against erosion and as a retention of sediments, making it possible, among other things, to prevent and reduce pollution from surface and ground water and the input of sediments from the soil;
- regulation of the water level, allowing the retention and evaporation of part of the precipitation and melt water, thus reducing the risks of flooding and erosion and promoting the recharge of the water table;
- conservation of biological diversity whereby environments or ecosystems provide habitats for food, shelter and reproduction of living species;
- natural sunscreen and windbreaks, by maintaining vegetation to protect water from overheating and to protect soils and crops from wind damage;
- carbon sequestration and mitigating the impacts of climate change;
- related to landscape quality, allowing the conservation of the natural character of an environment and the attributes of associated landscapes, thereby contributing to the value of adjacent lands.

However, this recognition of the services rendered by wetlands is relatively recent, both in Quebec and in other industrialized countries. Wetlands have long been considered unproductive lands that should be developed (Mitsch and Gosselink, 2007). Some regions or states, such as California and Ohio, have lost up to 90% of their original wetland area (Dahl, 1990).

In the St. Lawrence Lowlands of Quebec, it is estimated that wetlands now occupy 10% of the territory, or more than 3,200 km^2. However, this area is much smaller than the area that wetlands were supposed to occupy at the beginning of European colonization. The various studies available indicate that between 40% and 80% of the wetlands in agricultural or urban areas have disappeared, and that this proportion has reached over 85% in the Greater Montreal area (Joly et al., 2008; Gratton, 2010). Other studies indicate that more than 60% of the wetland area has been disturbed in certain sectors of the St. Lawrence Lowlands in the last 50 years alone (Environment Canada, 1986; Pellerin, 2003; Avard et al., 2013).

In addition, the destruction and disturbance of wetlands continues to this day. In a synthesis report on the status of wetlands in Quebec, Pellerin and Poulin (2013) estimate that approximately 19% of the residual wetland area has disappeared during the period between 1990 and 2011. Agricultural and silvicultural activities are the main sources of disturbance, affecting 44% and 26% of the disturbed wetland area, respectively. Industrial and commercial activities and residential development are responsible for only 9% of wetland losses over the same period, but they are the main contributors to wetland area losses in the Montréal and Québec City metropolitan areas (Pellerin and Poulin, 2013).

The conservation objectives associated with wetlands will therefore aim to ensure the sustainability of the services rendered by these ecosystems in the St. Lawrence Lowlands. To this end, special attention will be paid to hydrological functions, which are often overlooked.

9.1.3. Open areas – old field

The presence of many habitat types in an agricultural matrix provides diverse habitats for wildlife and plant species (Fahrig et al., 2011; Environment Canada 2013a). Among the open habitats found in agricultural environments, old fields form a distinct habitat class since they are areas that regenerate following the abandonment of crops or after forest disturbances (cutting, fire). Distinct flora and fauna communities are closely associated with old field, since the structure of the habitats lies between a disturbed environment and a forest-type environment. Depending on the age of the beginning of plant succession, the old field may be herbaceous (dominated by perennial herbaceous plants) or shrubby (relatively low woody vegetation, generally about two metres high). Because of the anthropogenic origin of old field, its abundance and distribution may vary over time. However, there are no reliable data to study their spatio-temporal dynamics in Québec.

Old fields found in urban or peri-urban environments often follow the abandonment of agriculture and are located in areas largely devoted to urban or industrial development, just as other unproductive land is abandoned and reforested (Vouligny and Gariépy, 2008; Environment Canada, 2013b). Another category of old fields includes areas located in sectors subject to periodic management measures to maintain the environment open for the needs of human activities. This is the case for old fields located in power line corridors that are subject to periodic mechanical or chemical maintenance. Certain species, such as the golden-winged warbler (*Vermivora chrysoptera*), a threatened species in Canada (Environment and Climate Change Canada, 2016), benefit from management measures for power line corridors that maintain the habitat structure in a favourable state. The dynamics of these habitats means that their maintenance on the landscape requires management actions to keep the old fields in an open habitat state (DeGraaf and Yamasaki, 2003; Tefft, 2006; Schlossberg and King, 2015). The spatial location of these environments thus varies according to human activities on the territory. Also, the speed at which plant regeneration takes place is closely associated with the type of soil in which these habitats are found, so that some old fields can persist in the landscape without human intervention, as is the case for some alvars.

As the origin and dynamics of old fields are variable, they were grouped into two categories (Figure 4):

- Regenerating old fields of various origins (abandonment of crops, logging);
- Old fields located in power line corridors.

Separate analyses will be conducted to discriminate between regenerating old fields resulting from anthropogenic activities (agriculture, forestry) and those located in power line corridors.

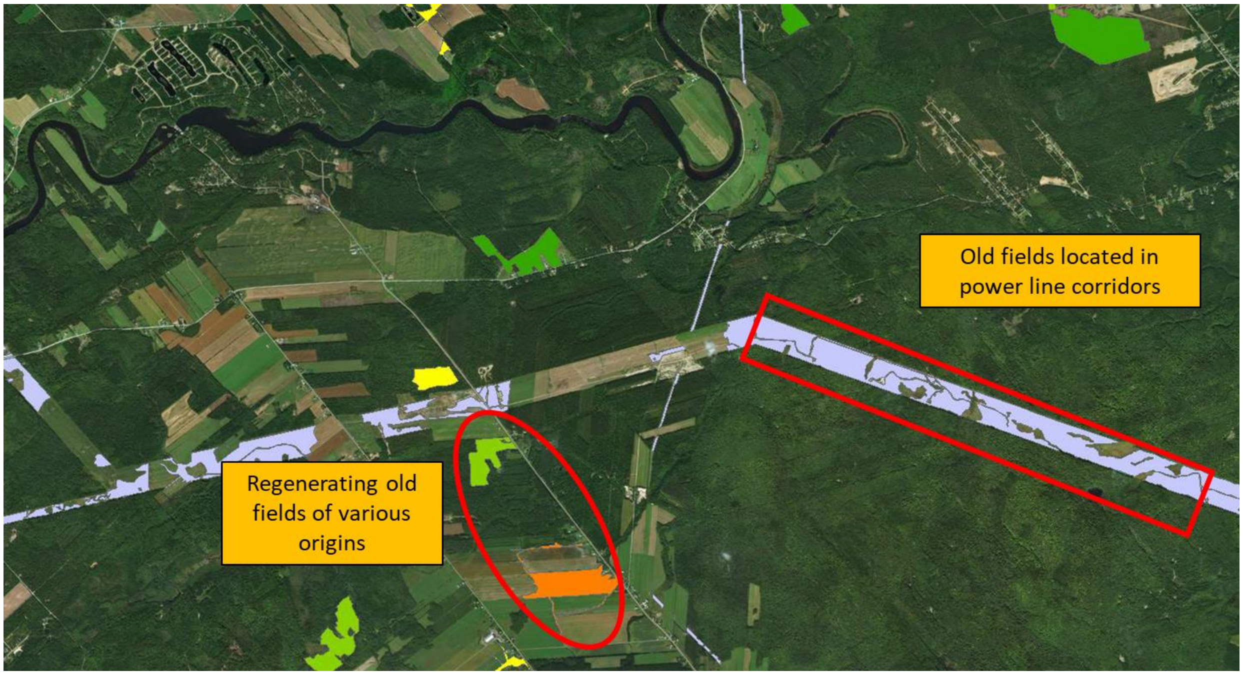


Figure 4. Example illustrating the old fields mapped in the St. Lawrence Lowlands

9.1.4. Open habitats – agricultural grasslands

It is well known that biodiversity in an agricultural landscape is closely associated with the diversity of habitats found there, including various crop types (Benton et al., 2003; McPherson et al., 2009; Fahrig et al., 2011; Environment Canada 2013b). A diversity of natural (woodlands, wetlands, riparian areas) and semi-natural (old field, hedgerows, forages) habitats increases bee pollination and biological pest control in cultivated fields (McPherson et al., 2009), with small habitat patches also being very important for some taxonomic groups (Semlitsch and Bodie 1998; Fahrig et al., 2015; Knapp and Řezáč 2015). Agricultural grasslands support more species than annual crops (corn, soybeans) (McLaughlin and Mineau, 1995; Jobin et al., 1998; Weibull et al., 2003; Burel et al., 2004; McMaster et al., 2005), and this biodiversity is enhanced by the presence of pasture in the agricultural landscape (Jobin et al., 1996; Cerezo et al., 2011). In addition, some species of field birds such as the bobolink require large areas of perennial crops to increase their reproductive success (Environment Canada, 2013a; 2013b).

The observed decline in the populations of several animal species, particularly country birds (Lamoureux and Dion, 2016), is closely associated with the intensification of agriculture that has led to the simplification of landscapes caused by the destruction of wildlife habitats, the conversion of perennial crops to large area annual crops, and farming practices that are not compatible with the maintenance of fauna and flora (pesticides, fertilizers, machinery, drainage and straightening of waterways, etc.) (Tscharntke et al, 2005; Environment Canada, 2013b; Lamoureux and Dion, 2016). Specialist species are usually the first to disappear when habitat diversity decreases in the agricultural landscape (Ekroos et al., 2010; Filippi-Codaccioni et al., 2010). The diverse mosaic of habitats, both in composition and spatial configuration, once present in the agricultural landscape has been transformed, with large areas now covered by field crops with row spacing dominated by corn and soybeans, and wildlife habitats virtually disappeared (Jobin et al., 2007; Latendresse et al., 2008a).

Unlike naturally occurring conservation targets whose plots can be prioritized through multi-criteria analysis, such as forest and wetlands, it is not relevant to prioritize plots of agricultural grassland habitat since these habitats are managed by humans for their own needs. In fact, land cover mapping provides a fixed picture of the situation on the ground at a given time, whereas land cover (crop types) can change from one year to the next due to crop rotations practised by agricultural producers.

Conservation objectives associated with agricultural grasslands will therefore aim to maintain a perennial-dominated agricultural matrix in areas where perennial crops are still widely grown, to maintain existing agricultural grasslands, and to restore agricultural grassland patches in areas where agriculture is dominated by annual crops (McMaster et al., 2005; Shustack et al., 2010; Davis et al., 2013). Thus, conservation actions will be directed towards land management rather than land protection in order to maintain an adequate level of habitat on the landscape to support viable populations of species associated with rural environments. Obviously, the establishment of such mosaics of habitats and crop types must be planned on a large territory scale, as this is beyond the capacity of agricultural producers (Russelle et al., 2007; Harvey et al., 2008; Bretagnolle et al., 2011). In addition, the implementation of biodiversity-friendly agricultural practices in annual crops should be encouraged.

9.1.5. Aquatic environments

Aquatic environments contain a diversity of habitats for many animal and plant species such as fish, amphibians, reptiles and benthic communities. They are also important habitats for the fish species that live in the St. Lawrence and that frequent these habitats during their life cycle, particularly during the spawning period. In southern Quebec, this diversity culminates in the St. Lawrence River and its tributaries, where the wide variety of aquatic habitats supports a rich and diverse fauna.

In the St. Lawrence Lowlands, urbanization and artificialization have altered the quality and diversity of natural environments, including aquatic environments. Agricultural activities, deforestation, urbanization and the presence of dams are believed to be the main sources of habitat modification affecting several freshwater fish species. Such activities disrupt both their physical, chemical and biological integrity and, consequently, the general health of these ecosystems. For example, stream straightening was subsidized in Quebec from 1917 to 1986 to increase drainage efficiency and agricultural land productivity, resulting in the disturbance of more than 30,000 km of streams between 1944 and 1976 (Beaulieu, 2001; Boutin et al., 2003). In addition to generating net habitat losses, this practice contributes to increased bank erosion (Rousseau and Biron, 2009), which in turn causes sedimentation problems in aquatic habitats. Thus, the sites where water is most degraded are located in sectors with high population density and agricultural activity, i.e., in the St. Lawrence Lowlands, particularly in the Montérégie region and around Lake Saint-Pierre (MDDELCC, 2013). Developments carried out directly in watercourses also greatly affect their dynamics and natural processes. Human interventions that limit the mobility of watercourses, such as bank stabilization, are common in riparian areas of urban and agricultural environments (Choné and Biron, 2016).

Given the growing anthropogenic pressures on aquatic environments in the St. Lawrence Lowlands and the negative impacts of climate change on biodiversity and ecosystems, the preservation of a diversity of aquatic habitats and the implementation of conservation actions upstream of territorial development are becoming essential.

9.2. Fine filter targets

Fine filter targets are those that would not have been captured by the coarse filter, but are of high importance for biodiversity conservation. These are scientifically recognized wildlife habitats and other elements of importance to biodiversity. All habitat patches and point occurrences of the fine filter targets are considered sites of conservation interest from the outset because of their unique characteristics. The aim will therefore be to preserve the current biophysical conditions characterising these areas. Sustainable use could be compatible with this objective for some of these territories. Five fine filter targets have been selected (Table 2).

9.2.1. St. Lawrence Corridor

Fish are excellent indicators of the health of aquatic environments because they incorporate spatial and temporal changes in the physical environment and are vulnerable to most environmental pressures and disturbances. They are easy to sample, are useful for measuring the effects of toxic substances, and are of interest to decision makers and the general public because of their high heritage and socio-economic value (Mingelbier et al., 2008).

Table 2. Fine filter conservation targets selected for the Atlas of sites of conservation interest in the St. Lawrence Lowlands

Fine filter targets	Type of habitats, ecosystem or plant association
St. Lawrence Corridor	Elements of importance for the aquatic biodiversity of the St. Lawrence Corridor
Alvars	Open environments on outcrops of limestone or dolomite rocks
Bird colonies	Concentration sites of colonial nesting birds
Important wildlife elements	Various wildlife-related elements (e.g. Chimney Swift roosts, spawning grounds)
Important floristic elements	Location of plants at risk (e.g., occurrences of endangered species)

The St. Lawrence is a vast ecosystem that encompasses a wide variety of aquatic habitats from upstream to downstream. The conditions for aquatic life and the areas of habitat available depend on the following main characteristics: 1) physiography (succession of large fluvial lakes, narrow stretches, archipelagos and rapids), 2) the hydrological regime (seasonal and interannual variations), 3) the very high tide in the Fluvial Estuary, 4) the physicochemical composition (suspended solids, nutrients, contaminants) distinct from the water masses formed in turn by the many tributaries (Morin and Bouchard, 2000; Mingelbier et al.,, 2008). This natural heterogeneity supports a great diversity of fish (La Violette et al., 2003; Foubert, 2017).

The fish community in the St. Lawrence includes some 100 species of freshwater and migratory fish, 24 of which have a precarious status (including species likely to be designated threatened or vulnerable in Quebec and species of special concern and designated threatened or vulnerable by COSEWIC at the federal level) and 34 are subject to recreational fishing (Mingelbier et al., 2016). These species are found along the St. Lawrence River corridor into the brackish waters of the middle estuary and Gulf, as well as in the many branches of the tributaries, depending on their habitat preferences, life stages and anthropogenic pressures acting at various scales (La Violette et al., 2003; Mingelbier et al., 2008; De la Chenelière et al., 2014; Groupe de travail Suivi de l'état du Saint-Laurent, 2014).

Among the many sources of information available on St. Lawrence fish and their habitats, and based on various criteria (diversity, level of precariousness, recognized ecological role, umbrella indicator, exceptional aquatic environments, economic issue), the following conservation targets have been selected as being of interest.

9.2.1.1. Habitats of Aquatic Species at Risk

- Centre de données du patrimoine naturel du Québec (CDPNQ, 2017): an extraction from the CDPNQ database produced a series of occurrences in the form of areas representing the habitat of ten fish species in a precarious situation.
- *Species at Risk Act*: official polygons from the Department of Fisheries and Oceans, representing the critical habitats and ranges of three fish species and the beluga whale (*Delphinapterus leucas*).
- Spawning grounds of lake sturgeon (*Acipenser fulvescens*) (COSEWIC, 2017), dotted.

9.2.1.2. Recognized spawning grounds in the fluvial portion of the St. Lawrence River

The preliminary atlas published by Mingelbier and Leclerc (2001) presents a large database of the habitats of 72 fish species in the St. Lawrence River and its main tributaries. The geographic information comes from a literature review containing more than 141 references, mainly departmental reports and scientific articles, all based on field observations (Bouthillier et al., 1993), most of which were carried out between the 1970s and 1990s.

9.2.2. Alvars

An alvar is an "open, natural habitat in a relatively flat, limestone environment on rocky outcrops and thin, sparsely vegetated soil, consisting mainly of shrubs, herbaceous plants and mosses, where tree growth is almost completely inhibited. These environments are usually flooded in the spring and experience severe droughts in the summer" (Cayouette et al., 2010). These harsh conditions favour the presence of particular plant communities that are home to several rare and threatened species. Alvars are very rare in Quebec. A mapping of known alvars in the province, which are found mainly in the western portion of the Outaouais region (Pontiac) and in the Montérégie region, was recently produced. These sites of interest are important habitats for this particular biodiversity that requires conservation actions.

9.2.3. Bird colonies

This conservation target locates sites where birds nest in mixed colonies, most often on islands in the St. Lawrence. The sites present in the study area have already been prioritized by the Canadian Wildlife Service in order to identify priority colonies for conservation (Chapdelaine and Rail, 2004). A review of these sites of interest has been carried out to consider them in this Atlas (Jean-François Rail, ECCC-SCF, pers. comm., May 2017). Some colonies cited in Chapdelaine and Rail (2004) have been eliminated, while others have been added. In all, 17 priority colonies were retained, including the heronry located on Grande Île in the Berthier-Sorel archipelago, one of the largest colonies of great blue herons (*Ardea herodias*) in North America (Boivin and Côté, 2014).

9.2.4. Significant Wildlife Components

9.2.4.1. Nesting sites and dormitories of the chimney swift

The chimney swift (*Chaetura pelagica*) is an aerial insectivore bird that is a threatened species in Canada. This species now nests almost exclusively in chimneys. Data on nesting sites and dormitories were extracted from the SOS-POP database managed by the Regroupement QuébecOiseaux (RQO). Only R (selected) and precision S sites were retained. Some sites are also used as dormitories or nesting sites. A total of 385 sites have been selected (as of April 2017).

9.2.4.2. Bank swallow Nesting Sites

The bank swallow (*Riparia riparia*) is a threatened species in Canada. It nests in burrows that it digs in soft soil, such as steep riverbanks and sand pits. Data on nesting sites were extracted from the SOS-POP database. Only the R (selected) and precision S sites were selected. A total of 40 sites were selected (as of April 2017).

9.2.4.3. Other occurrences of avian species at risk

Sites with wildlife species in a precarious situation having a high precariousness status (federally endangered or threatened, provincially threatened or vulnerable) were selected to select sites of conservation interest based on the preferred habitats of these species (section 12). Other avian species with a high risk status were not selected for these selection analyses and are shown in the Atlas as point features of conservation interest, namely point occurrences of nesting sites of the red-headed woodpecker (*Melanerpes erythrocephalus*; federally and provincially threatened; n=7), peregrine falcon (*Falco peregrinus*; provincially vulnerable and federally special concern;

n=63) and bald eagle (*Haliaeetus leucocephalus*; provincially vulnerable; n=13). For these species, data were extracted from the CDPNQ database (as of February 2016) and occurrences with a precision of S and a viability of "A" to "E" were retained.

9.2.5. Occurrences of Plants in Precarious Situations

Sites known to host plant species in precarious situations are listed in the CDPNQ database. An analysis of the occurrences of plant species in precarious situations in the St. Lawrence Lowlands was carried out by expert botanists from the MELCC in order to determine priority plant occurrences for conservation (appendices C and D). A total of 807 occurrences were selected (as of January 2016) and each one was given a detailed priority ranking based on its conservation value based on the priority rank of the species, the degree of precision, the viability rating and the biodiversity index given to each occurrence. The majority (n=605) of these occurrences were used to select habitat patches of high conservation value (see section 12); the remaining occurrences with a detailed priority ranking of 10-13 (n=202) are associated with 61 species and are shown in the Atlas as point features of conservation value.

10. Data Sources

Numerous sources of geospatial data were used to produce the Atlas of sites of conservation interest in the St. Lawrence Lowlands.

10.1. Land use in the St. Lawrence Lowlands

The main source of information on the spatial distribution of coarse filter targets is the recent land use mapping of the St. Lawrence Lowlands (ECCC and MDDELCC, 2018) (Figure 5). This mapping was produced by bringing together the most current and accurate source data for various themes. Briefly, the origin of the layers is as follows:

- Forested areas - MFFP fourth decadal ecoforestry maps (SIEF);
- Wetlands - Ducks Unlimited Canada and MELCC detailed mapping;
- Farmland - Financière agricole du Québec's database of insured crops for 2014. If the crop class is unknown, the information from Agriculture Canada's farmland mapping produced in 2014 is used;
- Old fields and Shrublands - a combination of the “FR" code from the MFFP's fourth decadal ecoforestry maps and the "Shrub" class from Agriculture Canada's 2014 mapping;
- Aquatic Environments - Quebec Hydrological Reference Framework of the MELCC;
- Anthropogenic environments - MFFP fourth decadal ecoforestry maps (SIEF);
- Bare soil - codes “GR” (gravel pit) and “DS” (dry bare soil) of the ecoforestry maps, as well as Agriculture Canada's "bare soil" class;
- Roads - classification from the Quebec Topographic Data Base (QTDB).

The spatial boundaries of forest areas, old fields, anthropogenic areas and some roads have been corrected by photo-interpretation using recent images (post-2014; satellite images, Google Earth, etc.). This essential step made it possible to update some obsolete or erroneous data and to fill in areas where no information was available. It should be noted that the land cover mapping used for the Atlas analyses is that which was available in August 2017; minor adjustments were then made to this mapping to account for recent anthropogenic developments that are illustrated in the final version (ECCC and MDDELCC, 2018).

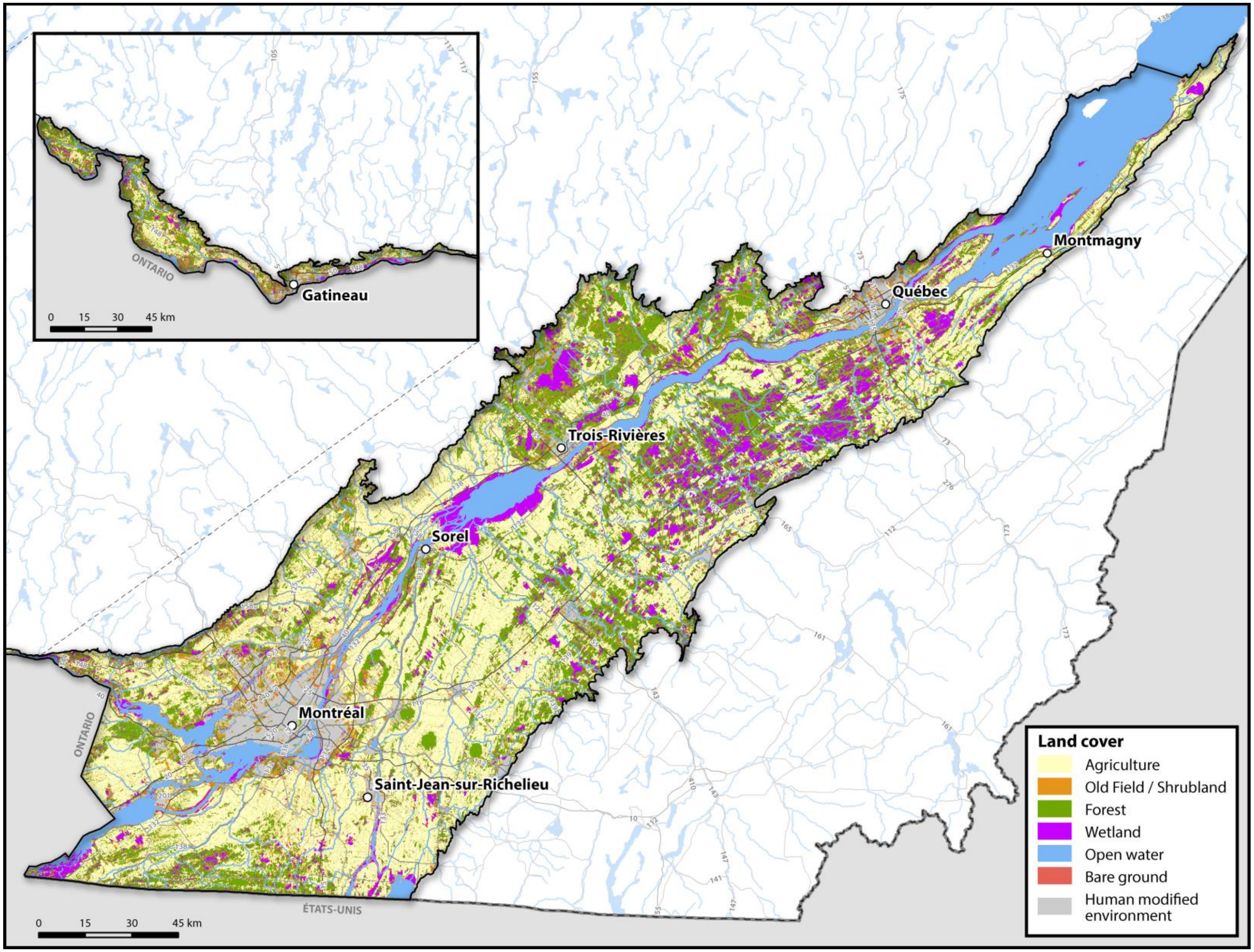


Figure 5. Land Use Mapping in the St. Lawrence Lowlands (Source: ECCC and MDDELCC, 2018)

10.2. Spatial reference units: depositional contexts

Like the analyses of Gérardin et al. (2002), the selection of sites is based on the Cadre écologique de référence du Québec (CERQ). The spatial reference units used in the Atlas are the depositional contexts in the St. Lawrence Lowlands. These contexts are derived from the classification of ecological districts, i.e. level 4 of the MELCC's CERQ (Bellavance et al., 2019). They present a first level of territorial analysis based on Quaternary episodes, particularly during the Upper Wisconsinian (between 23,000 and 10,000 years) and are strongly linked to dominant surface deposits and associated landforms, which are determining variables in the ecosystem analysis of this vast territory. This classification includes nine depositional contexts in the St. Lawrence Lowlands (Table 3; Appendix E).

These contexts form the spatial unit of reference to guide ecosystem analyses and allow for the modulation of conservation objectives and the determination of sites of conservation interest. To account for regional variability in the composition of forest fragments and old fields, these contexts were subdivided among the three natural regions (level 2 of the CERQ) of the St. Lawrence Lowlands for a total of 20 different regional depositional contexts (Figure 6). Table 4 shows the areas (in square kilometres and in percentage) of the seven land use themes in the regional depositional contexts.

10.3. Quebec Hydrographic Network Geobase

The main source of cartographic information on aquatic environments comes from the Geobase of the Quebec Hydrographic Network (GRHQ). The GRHQ is a vectorial and topological representation tool of the surface hydrographic network, which is the common governmental repository for Quebec. It is produced jointly by the MELCC and the Ministère de l'Énergie et des Ressources naturelles (MERN). For the St. Lawrence Lowlands, the hydrographic classes come from the Quebec Topographic Data Base (QTDB) at a scale of 1:20 000.

The units of analysis for aquatic environments generated from this source of information, the Aquatic Ecological Units (AEUs), will be discussed in more detail in Section 13. These AEUs are integrated into a mapping tool that brings together structured information and knowledge on aquatic ecosystems called the Québec Hydrological Reference Framework (QHRF). The QHRF is produced by the MELCC.

10.4. Other sources of data

In addition to the data sources cited above, several other data sources were used to produce this Atlas (see Table 5).

Table 3. Depositional contexts of the St. Lawrence Lowlands (SLL)

			Ecological districts		Area	
Number	**Depositional context**	**Natural region**	**Number**	**%**	**km^2**	**%**
1A_a	Rugged glacial context	All (SLL)	15	12,9	2 168,7	7,1
		B01	14	12,1	2 059,3	6,7
		B02	1	0,9	109,4	0,4
1A_p	Flat glacial context	All (SLL)	12	10,3	4 036,7	13,1
		B01	9	7,8	3 404,9	11,1
		B02	3	2,6	631,7	2,1
3DB	Deltaic context	All (SLL)	8	6,9	2 438,8	7,9
		B01	1	0,9	123	0,4
		B02	6	5,2	1 997,5	6,5
		B03	1	0,9	318,3	1,0
3FA	Recent fluvial context	All (SLL)	7	6,0	2 371,3	7,7
		B01	6	5,2	1 708,1	5,6
		B02	1	0,9	663,3	2,2
3FB	Subrecent fluvial context	All (SLL)	8	6,9	2 023,9	6,6
		B01	4	3,4	1 049,5	3,4
		B02	2	1,7	285,4	0,9
		B03	2	1,7	689,1	2,2
3M	Fluviomarine context	All (SLL)	7	6,0	1 443,3	4,7
		B01	6	5,2	1 085,1	3,5
		B02	1	0,9	358,2	1,2
5A	Calm water context	All (SLL)	36	31,0	9 636,3	31,4
		B01	25	21,6	6 696,0	21,8
		B02	8	6,9	10 737,5	5,7
		B03	3	2,6	1 202,9	3,9
5S	Turbulent water context	All (SLL)	15	12,9	4 975,3	16,2
		B01	2	1,7	1 260,5	4,1
		B02	13	11,2	3 714,8	12,1
6D*	Littoral context	All (SLL; B02)	8	6,9	1 637,2	5,3
Total			116	100,0	30 731,5	100,0

* The figures presented do not include the Isle-aux-Grues archipelago.

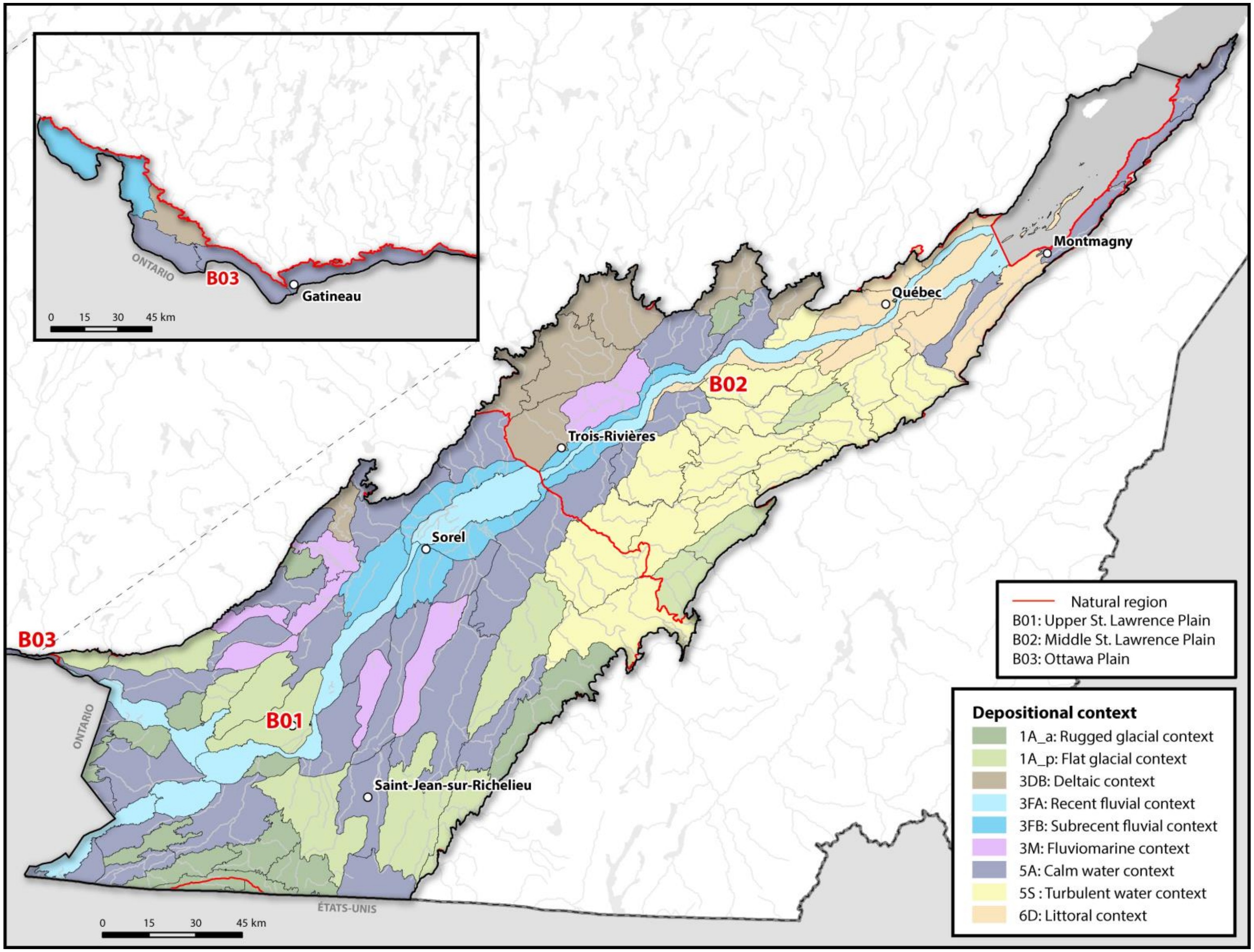


Figure 6. Depositional contexts in the St. Lawrence Lowlands
(The boundaries of the natural regions are indicated by the red line)

Table 4. Areas of the seven major land use classes in depositional contexts (e.g. 1A_a) and regional depositional contexts (e.g. 1A_a B01)

Depositional context	Natural region	Anthropogenic		Forest		Wetland		Agriculture		Old field		Bare ground		Deep water		Total	
		km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
1A_a	All (SLL)	204	0,7	987	3,2	194	0,6	634	2,1	131	0,4	16	0,1	6	0,0	2 173	7,1
	B01	202	0,7	911	3,0	181	0,6	623	2,0	126	0,4	15	0,0	6	0,0	2 064	6,7
	B02	2	0,0	76	0,2	14	0,0	11	0,0	6	0,0	0	0,0	0	0,0	109	0,4
1A_p	All (SLL)	909	3,0	596	1,9	195	0,6	2 083	6,8	190	0,6	24	0,1	47	0,2	4 043	13,2
	B01	843	2,7	472	1,5	151	0,5	1 711	5,6	170	0,6	23	0,1	42	0,1	3 412	11,1
	B02	65	0,2	124	0,4	44	0,1	373	1,2	20	0,1	1	0,0	4	0,0	631	2,1
3DB	All (SLL)	235	0,8	1 141	3,7	338	1,1	502	1,6	137	0,4	22	0,1	58	0,2	2 433	7,9
	B01	26	0,1	52	0,2	5	0,0	25	0,1	7	0,0	4	0,0	3	0,0	123	0,4
	B02	199	0,6	933	3,0	284	0,9	400	1,3	109	0,4	16	0,1	51	0,2	1 992	6,5
	B03	9	0,0	156	0,5	50	0,2	76	0,2	22	0,1	2	0,0	3	0,0	318	1,0
3FA	All (SLL)	175	0,6	67	0,2	336	1,1	165	0,5	51	0,2	6	0,0	1 571	5,1	2 372	7,7
	B01	170	0,6	59	0,2	265	0,9	164	0,5	50	0,2	4	0,0	999	3,3	1 711	5,6
	B02	5	0,0	8	0,0	71	0,2	1	0,0	1	0,0	3	0,0	573	1,9	661	2,2
3FB	All (SLL)	208	0,7	494	1,6	328	1,1	757	2,5	102	0,3	10	0,0	125	0,4	2 023	6,6
	B01	125	0,4	174	0,6	189	0,6	493	1,6	44	0,1	5	0,0	19	0,1	1 049	3,4
	B02	57	0,2	36	0,1	38	0,1	123	0,4	24	0,1	1	0,0	6	0,0	285	0,9
	B03	26	0,1	284	0,9	101	0,3	141	0,5	34	0,1	4	0,0	100	0,3	689	2,2
3M	All (SLL)	222	0,7	450	1,5	140	0,5	538	1,8	67	0,2	15	0,0	12	0,0	1 444	4,7
	B01	199	0,6	336	1,1	74	0,2	403	1,3	52	0,2	14	0,0	8	0,0	1 086	3,5
	B02	22	0,1	114	0,4	65	0,2	135	0,4	16	0,1	1	0,0	4	0,0	358	1,2
5A	All (SLL)	1 128	3,7	1 423	4,6	487	1,6	5 728	18,6	500	1,6	30	0,1	341	1,1	9 637	31,4
	B01	829	2,7	715	2,3	199	0,6	4 467	14,5	311	1,0	16	0,1	168	0,5	6 706	21,8
	B02	131	0,4	430	1,4	135	0,4	912	3,0	102	0,3	6	0,0	12	0,0	1 727	5,6
	B03	168	0,5	278	0,9	153	0,5	349	1,1	87	0,3	7	0,0	161	0,5	1 203	3,9
5S	All (SLL)	287	0,9	1 900	6,2	955	3,1	1 567	5,1	173	0,6	23	0,1	63	0,2	4 968	16,2
	B01	101	0,3	482	1,6	120	0,4	471	1,5	47	0,2	9	0,0	30	0,1	1 260	4,1
	B02	186	0,6	1 417	4,6	835	2,7	1 096	3,6	127	0,4	14	0,0	34	0,1	3 707	12,1
6D*	All (SLL; B02)	358	1,2	372	1,2	168	0,5	596	1,9	103	0,3	13	0,0	14	0,0	1 623	5,3
Total		3 725	12,1	7 431	24,2	3 141	10,2	12 570	40,9	1 455	4,7	158	0,5	2 237	7,3	30 716	100,0

* The figures presented do not include the Isle-aux-Grues archipelago.

Table 5. Source of biophysical data used to produce the Atlas of sites of conservation interest in the St. Lawrence Lowlands

DATA	YEAR/Time Coverage	SOURCE	DESCRIPTION/NOTES
Coarse filter			
Forested areas	2014-2016	ECCC and MELCC	Detailed land use mapping of the St. Lawrence Lowlands (ECCC and MDDELCC, 2018).
Wetlands	2014-2016	ECCC and MELCC	Detailed mapping by Ducks Unlimited Canada and MELCC; integrated with detailed land use mapping of the St. Lawrence Lowlands (ECCC and MDDELCC, 2018).
Open environments (agricultural grasslands and old fields)	2014-2016	ECCC and MELCC	Detailed land use mapping of the St. Lawrence Lowlands (ECCC and MDDELCC, 2018).
Aquatic Environments	2018	MELCC and MERN	Quebec Hydrographic Network Geobase. Vector and topological representation tool of the Quebec hydrographic network (MELCC and MERN).
	2018	MELCC	Québec's Hydrological Reference Framework. Mapping tool gathering structured information and knowledge on the aquatic ecosystems of the Quebec territory (MELCC).
Fine filter			
St. Lawrence Corridor	1960-2017	MFFP and MELCC	Centre de données du patrimoine naturel du Québec (CDPNQ, 2017): habitats of 10 fish species with precarious status under the *Act respecting threatened or vulnerable species*. *Species at Risk Act*: critical habitats and ranges of three fish species and the beluga whale (DFO, 2012ab; DFO, 2014; Robitaille et al., 2011). COSEWIC, 2015: lake sturgeon spawning grounds. Spawning grounds recognized in the fluvial portion of the St. Lawrence between the 1960s and 2000 (Mingelbier and Leclerc, 2001).
Alvars	2010	MELCC	Mapping of known alvars in Quebec (Cayouette et al., 2010)
Bird colonies	2017	ECCC-SCF	Priority bird colonies for conservation extracted from the Quebec Waterfowl Conservation Plan (Chapdelaine and Rail, 2004) and validated by J. F. Rail (CWS, pers. comm.).
Important wildlife elements	Variable	ECCC, RQO, MELCC, MFFP	Location of priority faunal occurrences. The databases consulted, as of February 2016, are as follows: CDPNQ, ECCC Canadian Wildlife Service database, Regroupement QuébecOiseaux, BORAQ, small mammals, critical habitats of species at risk designated in recovery strategies.
Important floristic elements	2016	CDPNQ	Occurrences of threatened, vulnerable or susceptible species extracted from the CDPNQ database (as of January 2016). Critical habitats identified in recovery strategies.

DATA	YEAR/Time Coverage	SOURCE	DESCRIPTION/NOTES
<u>Other data used</u>			
Cadre écologique de référence du Québec (CERQ) and regional depositional contexts	2017	MELCC	The CERQ is a cartographic tool for ecological land classification based on the physical elements of ecosystems, namely geology, relief, surface deposits and the configuration and density of the river system. The depositional contexts are a classification of ecological districts (ERF level 4).
Québec Transmission Lines	2016	Hydro-Québec	Geospatial data of Quebec's power transmission lines.
Quebec Protected Areas Registry	Hiver 2017	MELCC	All protected areas were selected, excluding wildlife habitat (waterfowl concentration areas, bird colonies, bird colonies on cliffs, islands or peninsulas, muskrat habitat, heronry, mudflats, habitat of a threatened or vulnerable wildlife species).
Voluntary Natural Conservation Areas	September 2017	Réseau des milieux naturels (RMN)	Sites subject to conservation measures that are not located on "Crown lands". These are mostly lands owned by individuals, corporations such as non-governmental conservation organizations and municipalities.
Exceptional Forest Ecosystems (EFE)	2016	MFFP	Rare, old and validated EFE.

11. Conservation Objectives

Two main objectives will guide the identification of sites of conservation interest:

1. Maintaining fine filter elements or irreplaceable ecosystems

   All natural environments containing fine filter targets or irreplaceable ecosystems are considered sites of conservation interest. This objective is not incompatible with sustainable land use as long as the biophysical conditions that characterize the habitats of these elements and ecosystems are preserved.

2. Representativeness of all types of ecosystems

   The objective is to ensure that all types of ecosystems characterizing the St. Lawrence Lowlands are represented in the sites of interest for biodiversity conservation, based on a minimum threshold of 20% representativeness of their area per spatial unit of reference. This threshold is based on the Aichi[6] objectives endorsed by the federal and provincial governments to conserve 17% of terrestrial environments.

12. Method for determining sites of conservation interest

The determination of sites of conservation interest for coarse filter targets is based on a selection and prioritization analysis (Figure 7). A selection analysis is first performed to select sites of high conservation importance. These are selection criteria whose values are measured but not prioritized and which become essential elements to be conserved. In a way, they constitute the sites that make up our "repertoire" of protected biodiversity or that should be protected as a priority, such as sites located in whole or in part in protected areas or exceptional forest ecosystems or contiguous to them, exceptional occurrences of species at risk, and sites with a maximum irreplaceability index. They will serve as a starting point for achieving representativeness objectives (e.g., maintaining 20% representativeness of each type of forest environment).

[6] By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes

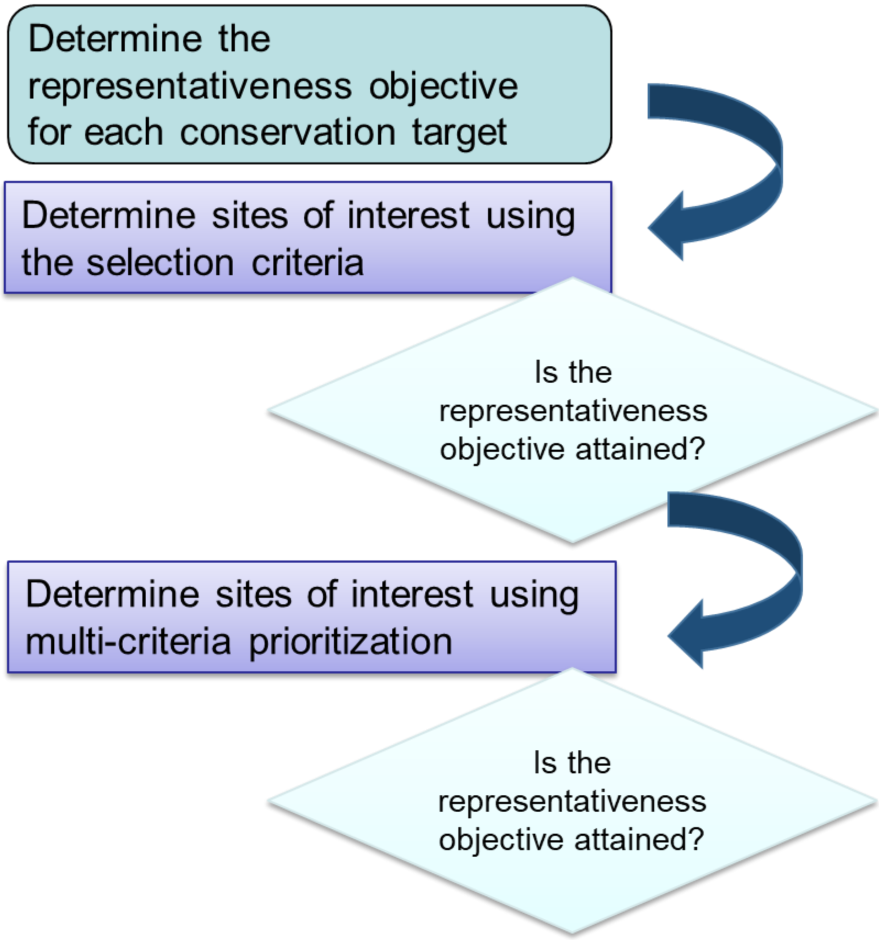


Figure 7. Diagram illustrating the method for determining sites of conservation interest

Subsequently, a site prioritization analysis is conducted on some of the conservation targets using a multi-criteria analysis to rank sites according to their priority for biodiversity conservation or maintenance of ecological functions. All sites, including those that have been selected, are assigned a priority ranking reflecting their conservation value. This prioritization is required to meet the objective of representativeness if the latter was not achieved at the selection stage. For forest fragments and wetland complexes, in cases where the 20% representativity threshold is not met by the selection analysis, the remaining sites are selected in descending order of conservation value to fill gaps in the representation objectives for ecological type/species groupings and wetland types until the 20% threshold is met.

Selection and prioritization analyses are conducted separately for each target based on the spatial reference units that best reflect ecological realities and regional differences. Finally, only habitat patches retained as a unit of analysis (e.g., forest fragments of 10 ha or more) are considered in the selection and prioritization analyses (see Section 13).

12.1. Selection analysis

Selection criteria are used to select sites of high conservation importance. Some of these criteria will be applied to all coarse filter conservation targets, while others apply to only one target. Table 6 shows the selection criteria for each coarse filter conservation target.

Also, given that current knowledge on occurrences of high conservation value in aquatic environments varies greatly depending on the rivers surveyed, this information has been integrated into the elements to be considered in the fine filter and has not been the subject of selection analyses.

Table 6. Selection criteria for forest, wetland and old field areas

Selection Criteria	Source	Forest	Wetlands	Old fields
Public and private protected areas	MELCC, ECCC	X	X	X
Exceptional Forest Ecosystems	MFFP	X	X	
Floristic Occurrences of High Conservation Value	MELCC	X	X	X
Wildlife Occurrences of High Conservation Value	MFFP, ECCC	X	X	X
Irreplaceability (C Plan)	Analysis	X	X	

- Public and private protected areas: habitat patches located in whole or in part in protected areas listed in the Registre des aires protégées au Québec (except designated wildlife habitats; as of January 2017) (MELCC, 2018) or listed in the Répertoire des sites de conservation volontaire du Québec and located on private land (e.g., full title, easement, etc.; as of September 2017; RMN, 2020) (Figure 8), or adjacent to these protected areas. A total of 234 sites from the Registre des aires protégées au Québec and 463 sites where a conservation measure on private land is in effect that are located in or adjacent to the study area were selected for selection (Table 7; Appendix B). Examples include Mont-Saint-Bruno National Park, the Mont-Saint-Hilaire Migratory Bird Sanctuary and the Micocoulier Ecological Reserve, taken from the Registre des aires protégées au Québec, and the conserved Châteauguay-Léry and Lavallière Bay woodlands, taken from the Répertoire des sites de conservation volontaire du Québec. It should be noted that it is possible that the same nature reserve or voluntary conservation area may be listed in both databases; work is underway to harmonize this information.

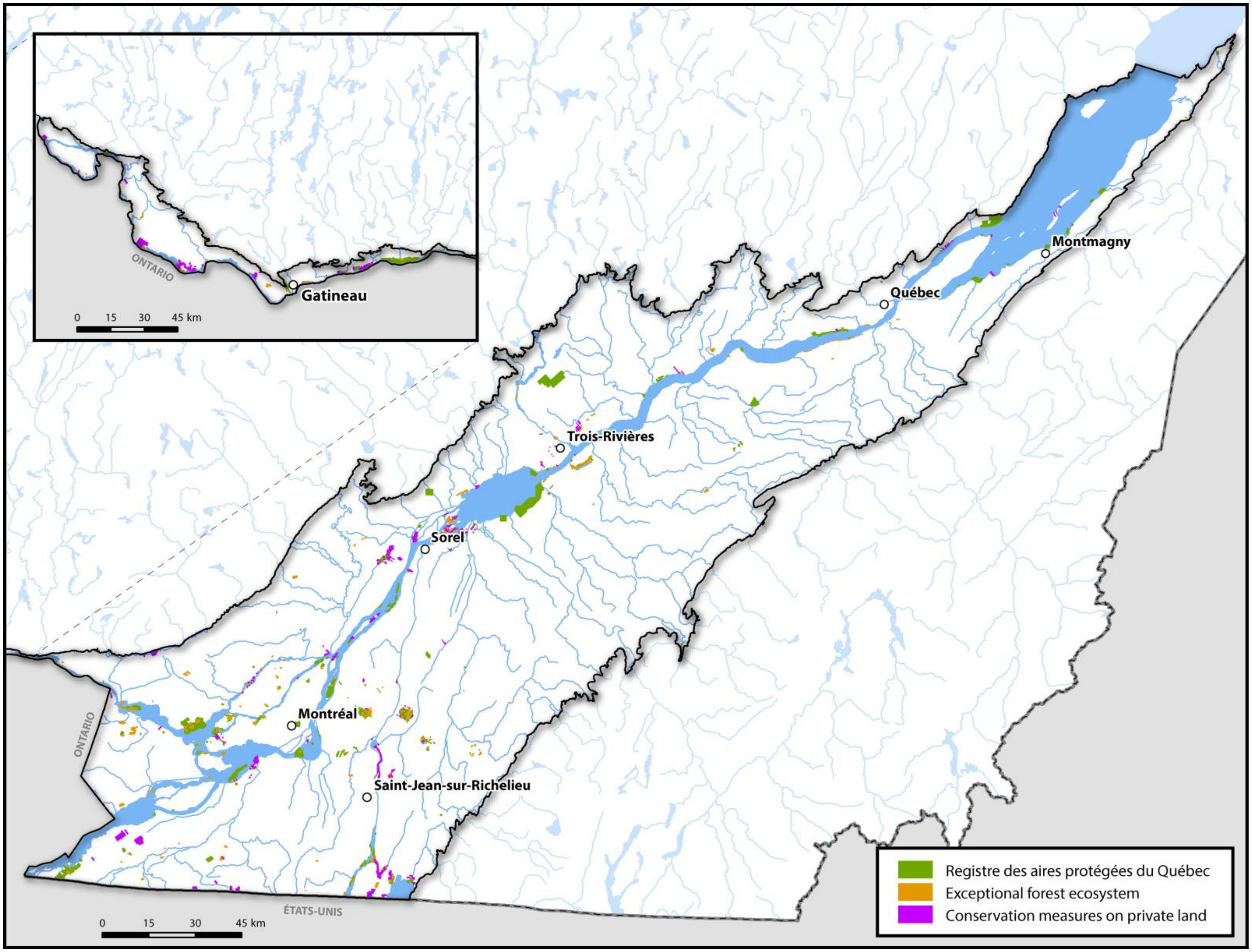


Figure 8. Location of public and private protected areas (conservation measures) and exceptional forest ecosystems in the study area.

Table 7. Types of protected areas selected for habitat patch selection

Source	Head	Type of protected area	Number of sites
Quebec government's Registre des aires protégés	Federal Government	National wildlife area	4
		Migratory bird sanctuary	12
		Park of the National Capital Commission	1
	Provincial Government	National park	4
		Ecological reserve	17
		Biodiversity reserve	1
		Wildlife sanctuary	4
		Habitat or a threatened or vulnerable plan species	18
	Private	Natural reserve	80
		Voluntary natural conservation environment	93
Répertoire des sites de conservation volontaire du Québec	Private	Voluntary natural conservation environment	463

- Exceptional Forest Ecosystem: habitat patches located in whole or in part within or adjacent to rare and old-growth exceptional forest ecosystems (EFE) that have been validated and are located on or adjacent to public and private lands (n=206; as of January 2016) (Figure 8). The MFFP recognizes three types of exceptional forest ecosystems in Quebec: rare forest, old-growth forest and refuge forest (Groupe de travail sur les écosystèmes forestiers exceptionnels, 1997). These ecosystems help maintain the species diversity that characterizes the forest in southern Quebec. On public land, EFEs benefit from legal protection under the *Forest Act*, but this is not the case on private land, where the vast majority of EFEs in the St. Lawrence Lowlands are located. For the Atlas analyses, only rare and ancient EFEs were considered, since refuge forests are already taken into account with floristic occurrences of high conservation value.

- Sites of floristic species of high conservation value: habitat patches with observation points with precision S (150 m) associated with CDPNQ floristic occurrences with a detailed priority ranking from 1 to 9 and from 14 to 23, as described in Appendix C. For unique occurrences in Québec, precision M (1.5 km) and G (8 km) were also considered. A total of 605 occurrences associated with 162 species were selected (Appendix D). The critical habitat polygons of plant species at risk published on the *Species at Risk Act* (SARA; http://www.registrelep.gc.ca/) public registry as of December 2016 are also used as a selection criterion (Figure 9).

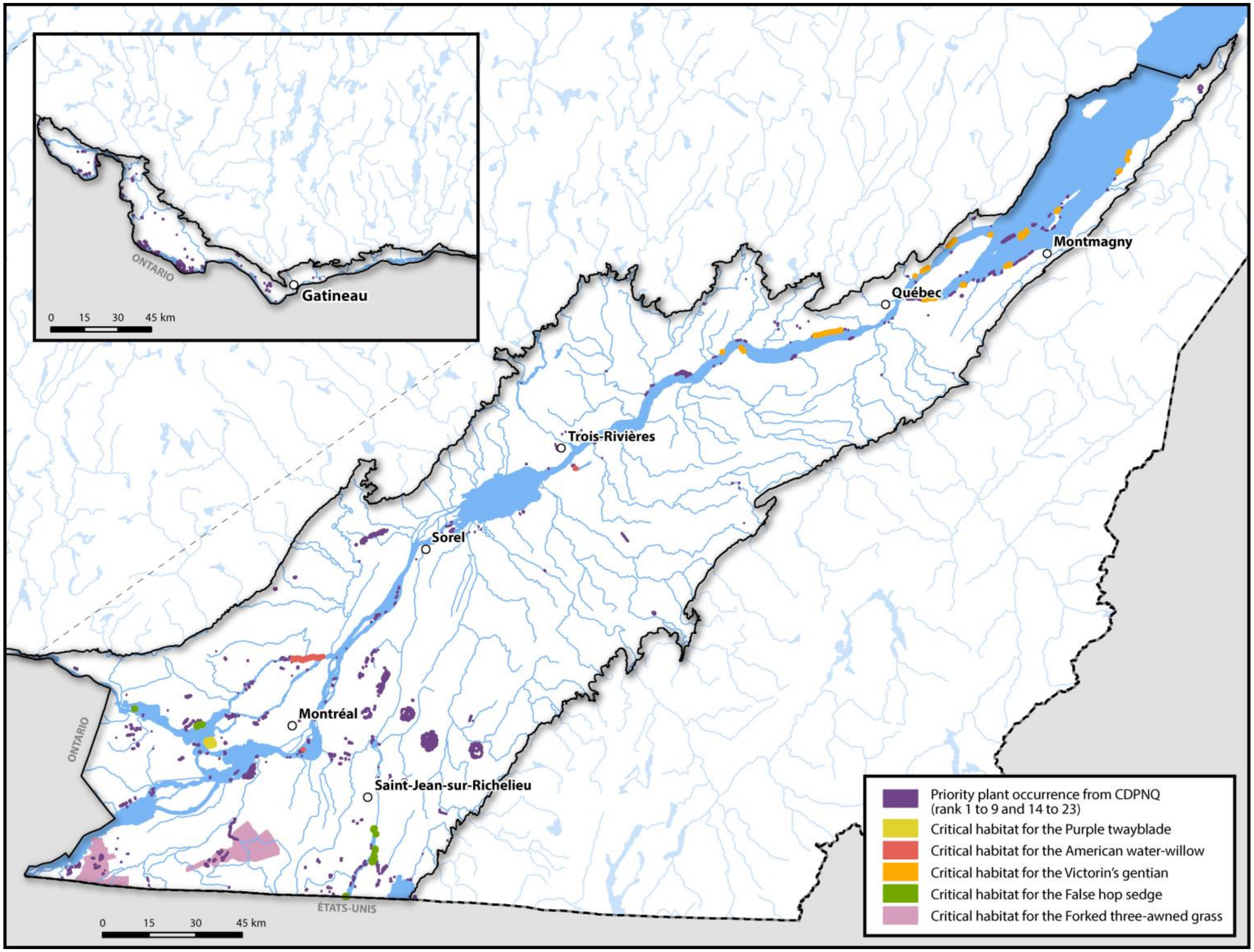


Figure 9. Location of high conservation value floristic occurrences (critical habitats and priority occurrences) (Some data are not shown due to limited public release)

Observation points and critical habitats were projected on the detailed land use mapping (ECCC and MDDELCC, 2018) and only habitat patches associated with species' preferred habitats were selected based on expert judgement (Emmanuelle Fay, ECCC-CWS; Jacques Labrecque, MELCC; Louise Gratton, November 2017). The general habitat classes selected for each species are as follows:

- American Ginseng (*Panax quinquefolius*) – hardwood stand, mixedwood stand;
- American Water-willow (*Justicia americana*) – shallow water, marsh, lotic environment, wet meadow;
- False Hop Segde (*Carex lupuliformis*) – marsh, swamp, lotic environment;
- Forked Three-awned Grass (*Aristida basiramea*) – bare soil, gravel/sand pit;
- Purple Twayblade (*Liparis liliifolia*) – swamp, hardwood stand, mixedwood stand;
- Victorin's Gentian (*Gentianopsis virgata* ssp. *victorinii*) – shallow water, marsh, lotic environment, wet meadow, bare soil.

- Sites of wildlife species with high conservation value: habitat patches where observation points, occurrences and designated critical habitats associated with species with a high legal designation in Canada (endangered, threatened) and Quebec (threatened, vulnerable) are located. Observations of avian, amphibian and reptile species were therefore selected (no mammal observations). Occurrences of precision S[7] and viability A to E[8] were selected (Figure 10; Table 8). A comparison of critical habitat identified and posted on the SARA public registry (as of November 2016) with point data selected from each wildlife database identified relevant data for selection and prioritization analyses. This is because some recent observations may be missing from the source databases and because the critical habitats of several species have recently been reviewed. The stinkpot turtle's critical habitats were not retained as selection criteria since this species is now listed as special concern following the reassessment of its status in 2012.

The following data were retained for selection based on expert advice: herpetofauna, Sylvain Giguère, ECCC-CWS, May 2017; birds, Josée Tardif, ECCC-CWS, June 2017.

---

[7] The levels of precision are : S: to within 150 m, M: to within a mile, and G: to within five miles.

[8] The viability ratings of the occurrences are : A: excellent, B: good, C: fair, D poor, and E: to be determined (Tardif et al., 2016).

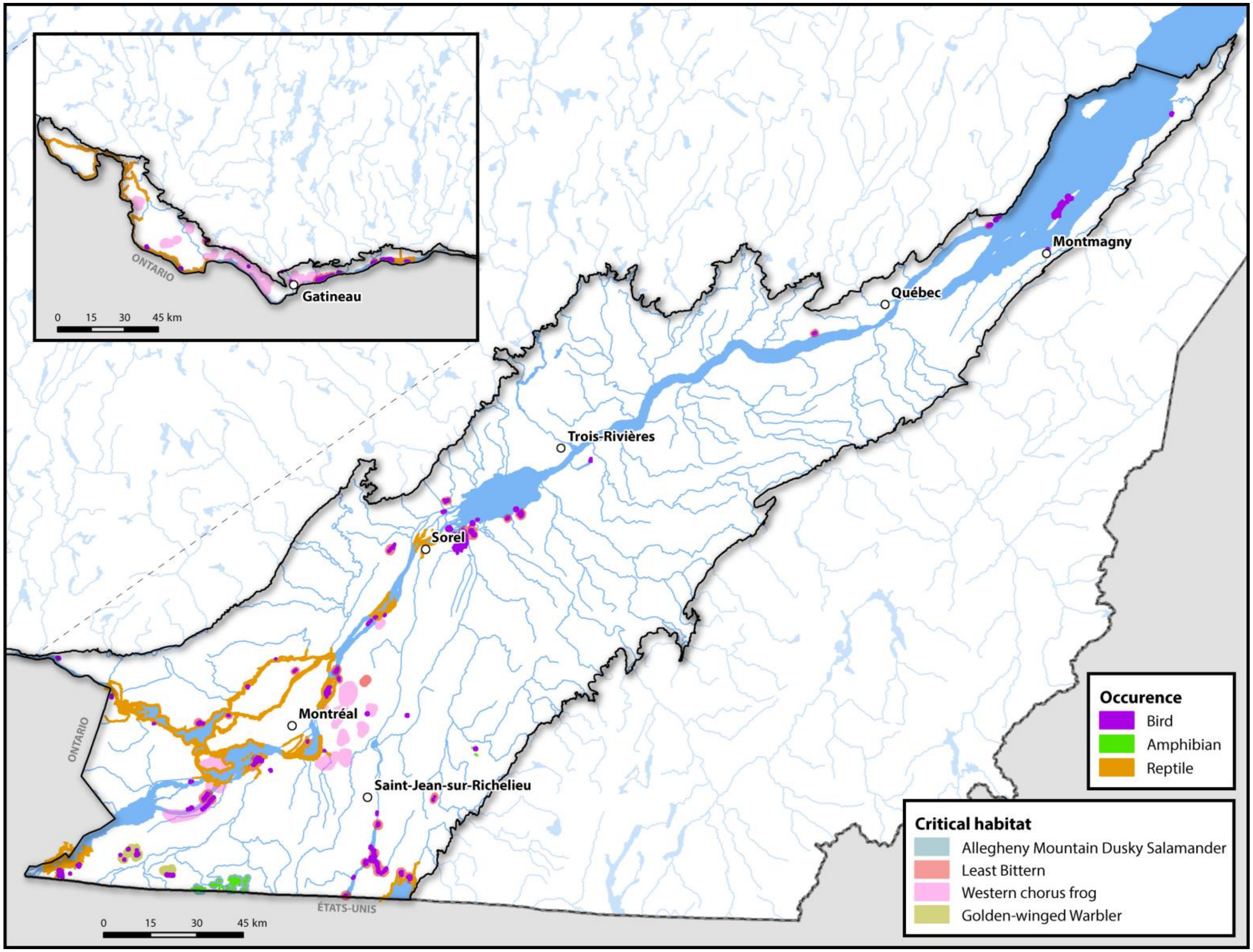


Figure 10. Location of high conservation value wildlife sites (critical habitat and priority occurrences) (Some data are not shown due to limited public release)

Table 8. Source of wildlife data used for selection analyses

Taxonomic group	Species	Points/ occurrences	Critical habitat
Amphibian	Western Chorus Frog		X
Amphibian	Spring Salamander	BORAQ*	
Amphibian	Allegheny Mountain Dusky Salamander	BORAQ	X
Reptile	Wood Turtle	CDPNQ	X
Reptile	Northern Map Turtle	CDPNQ**	
Reptile	Blanding's Turtle		X
Reptile	Spiny Softshell		X
Bird	Cerulean Warbler	CDPNQ	
Bird	Yellow Rail	CDPNQ	
Bird	Least Bittern	CDPNQ	X
Bird	Golden-winged Warbler	CDPNQ	X

* BORAQ: Banque d'observations sur les reptiles et amphibiens du Québec
** Only those occurrences that have a viability index of A or B

As with the flora, observation points, occurrences and critical habitats were projected on the detailed land use mapping (ECCC and MDDELCC, 2018) and only habitat patches associated with the species' preferred habitats were selected based on expert judgement. The general habitat classes selected for each species are as follows:

- Western Chorus Frog (*Pseudacris triseriata*) – perennial crop, bog, wet meadow, plantation, softwood stand, deciduous stand, mixed stand, uncultivated, lentic environment, marsh, swamp, shallow water, old field, shrubby;
- Spring Salamander (*Gyrinophilus porphyriticus*) – plantation, softwood stand, hardwood stand, mixed stand, lotic environment;
- Allegheny Mountain Dusky Salamander (*Desmognathus ochrophaeus*) – bog, plantation, softwood stand, hardwood stand, mixed stand, lotic environment;
- Wood Turtle (*Glyptemys insculpta*) – uncultivated, bog, bare soil, wet meadow, plantation, disturbed stand, deciduous stand, mixed stand, lotic environment, lentic environment, marsh, swamp, shallow water, old field, shrubby environment;
- Northern Map Turtle (*Graptemys geographica*) – bog, barren ground, wet meadow, deciduous stand, mixed stand, lotic environment, lentic environment, marsh, swamp, shallow water;
- Blanding's Turtle (*Emydoidea blandingii*) – bog, barren ground, wet meadow, deciduous stand, mixed stand, lotic environment, lentic environment, marsh, swamp, shallow water, old field, shrubby environment;
- Spiny Softshell (*Apalone spinifera*) – bog, barren ground, wet meadow, deciduous stand, mixed stand, lotic environment, lentic environment, marsh, swamp, shallow water;

- Cerulean Warbler (*Dendroica cerulea*) – hardwood stand, swamp;
- Yellow Rail (*Coturnicops noveboracensis*) – shallow water, swamp, wet meadow;
- Least Bittern (*Ixobrychus exilis*) – shallow water, marsh, swamp, wet meadow, bog;
- Golden-winged Warbler (*Vermivora chrysoptera*) – old field, shrubland, deciduous stand, mixed stand, coniferous stand, swamp, bog.

Irremplaceability of forest fragments and wetlands (C-Plan): an index to measure the representativeness of habitat patches in a spatial reference unit can be calculated with C-Plan software. This index is assigned to each habitat patch based on its area relative to the total area of that habitat class in the spatial reference unit. In the current project, representativeness will be calculated in each of the (regional) depositional contexts, and a habitat patch that hosts the only representative of a given habitat class in a given (regional) depositional context will have a value of 1 and will be selected.

12.2. Prioritization analysis

A multi-criteria prioritization analysis was carried out on all habitat plots. For each target, several criteria to characterize the habitat patches were used to calculate a relative value illustrating their priority for biodiversity conservation or maintenance of ecological functions.

In cases where the selection analyses did not select enough plots to meet the 20% representativity objective for each ecosystem type in a reference spatial unit, a prioritization analysis of the remaining plots identified the plots with the highest conservation value and selected them in order of priority until the minimum 20% representativity threshold was met.

The method for calculating the prioritization rank varied depending on the criteria chosen and the specific objectives of each conservation target. The selection of the prioritization criteria and the methods used for the calculations are largely based on an analysis of the natural environment prioritization methodologies used between 2000 and 2016 in Quebec (Lebel, 2013; Dupont-Hébert, 2017) and on the existing scientific literature.

In general, the different steps for prioritizing each habitat patch are:

- Determination of prioritization criteria;
- Calculation of the value of each prioritization criterion;
- Validation of the criteria using correlation matrices;
- Calculation of the normalized value of each prioritization criterion;
- Assignment of prioritization criteria to two categories: primary and secondary criteria;
- Sum of normalized values of the primary criteria;
- Determination of main priority classes (natural breaks);
- Assigment of a principal priority ranking;
- Sum of the normalized values of the secondary criteria;
- Determination of secondary priority classes (natural breaks);

- Attribution of a secondary priority rank.

Determining secondary prioritization criteria allows for a more refined prioritization of habitat patches within each of the main priority classes. It is therefore assumed that in cases where differences in values for the primary criteria are relatively minor, differences in the secondary criteria can play an important role in conserving biodiversity and ecosystem functionality. The prioritization criteria assigned to the primary and secondary criteria classes have varied somewhat according to the conservation targets. This process of assigning primary and secondary priority rankings is illustrated in Figure 11.

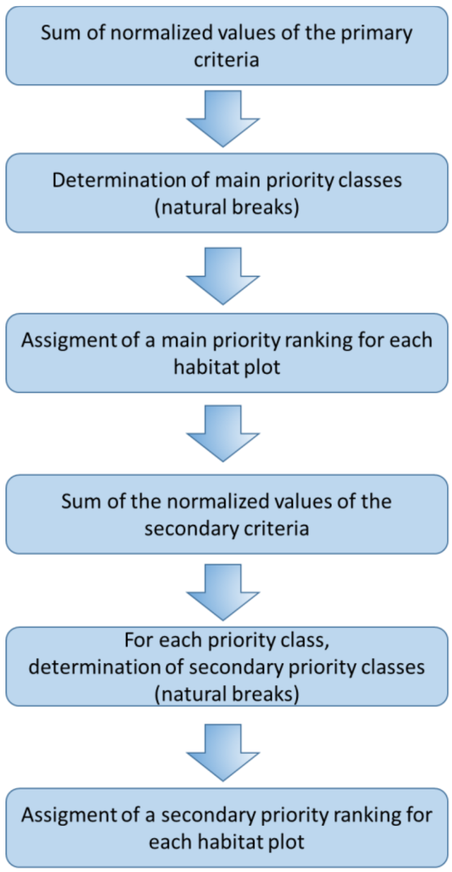


Figure 11. Process for assigning primary and secondary priority rankings to habitat patches

13. Analysis of coarse filter conservation target data

The following sections present the treatment of the data relating to each conservation target of the coarse filter in terms of the objectives pursued, the determination of the units of analysis, the choice of prioritization criteria and the calculation methods used.

13.1. Forested areas

The objective of the analysis of forested areas in the St. Lawrence Lowlands was to identify forest fragments that, first, have the highest conservation value and, second, are representative of the diversity of ecological types and associated forest stands.

13.1.1. Unit of analysis and data analysis

Given that the forests of the St. Lawrence Lowlands are highly fragmented (Bélanger and Grenier, 2002) and often form small wooded patches, it was agreed to select as the unit of analysis a minimum area likely to ensure the conservation of temperate hardwood species communities. This minimum area corresponds to the smallest area capable of maintaining a regime of recurrent natural disturbances (gaps) favourable to the regeneration of tolerant hardwood forest species. This minimum size was estimated at 10 ha by Gratton and Nantel (1999). This unit of analysis, or forest fragment, is therefore defined as a portion of the forest matrix of 10 ha or more that is not fragmented by anthropogenic elements (urbanized areas or areas used for agricultural purposes, roadways, railways, power lines) or open water polygons (lakes, rivers). Portions of the forest matrix connected by undeveloped wetlands or streams not represented by an open water polygon were considered as a single fragment. Maple syrup operations and old fields not subject to periodic cutting were not considered fragmentation elements.

The spatial reference unit for forest fragments is the regional depositional context. Table 9 presents the number and areas of forest fragments of 10 ha and larger present in each context. In particular, it takes into account all fragments located entirely in the St. Lawrence Lowlands. To this first series of fragments were added those that straddle the boundaries of the St. Lawrence Lowlands and those of the Appalachians or Laurentians, whether or not most of these fragments were located within the St. Lawrence Lowlands. Only the area of these fragments that was within the St. Lawrence Lowlands was considered in the compilation of statistics in Table 9.

Table 9. Characteristics of forest fragments in each regional depositional context

Regional depositional context	Number	Area (ha)					
		Average	Standard deviation	Quartile (1st and 3rd)	Minimum*	Maximum	% of forest cover**
1A_a_B01	622	143,0	264,9	18,1; 162,1	0,7	3 584,3	43,2
1A_a_B02	20	500,4	701,1	37,3; 828,1	11,9	2 777,3	91,5
1A_p_B01	732	55,7	171,8	14,3; 44,5	0,4	3 116,7	12,1
1A_p_B02	144	78,5	237,3	15,8; 58,5	0,5	2 640,5	17,9
3DB_B01	66	82,0	105,3	18,2; 97,4	9,9	534,5	44,0
3DB_B02	495	185,5	370,3	17,7; 185,6	0,9	3 239,5	46,0
3DB_B03	74	197,6	294,3	22,2; 230,2	3,7	1 487,3	45,9
3FA_B01	106	40,7	45,5	14,3; 41,7	10,1	227,2	7,2
3FA_B02	5	217,0	241,3	23,2; 465,3	11,9	555,4	60,5
3FB_B01	150	109,5	203,1	17,8; 83,6	10,2	1 001,4	15,9
3FB_B02	37	73,1	116,7	15,1; 76,2	10,2	535,9	9,5
3FB_B03	197	139,0	286,7	16,8; 137,9	0,0	2 118,6	45,1
3M_B01	295	109,0	246,6	16,8; 81,4	1,0	2 782,4	29,6
3M_B02	86	123,3	250,8	16,5; 82,2	10,2	1 532,3	29,6
5A_B01	1 055	53,3	93,7	14,5; 50,1	0,3	1 614,5	8,4
5A_B02	459	81,1	154,3	16,1; 76,3	0,04	1 408,5	21,4
5A_B03	416	60,2	122,6	13,5; 56,2	0,03	1 422,4	24,2
5S_B01	371	121,6	218,6	19,1; 111,1	2,5	1 739,7	35,8
5S_B02	648	216,3	747,1	19,1; 157,4	0,9	15 751,3	37,7
6D_B02	402	83,4	165,3	13,6; 77,2	0,1	1462,9	20,1
Total	**6 380**	**108,9**	**317,8**	**15,6; 84,8**	**0,0**	**15 751,3**	24,2

* Minimum areas of less than 10 ha are those of forest fragments that straddle the boundaries of the study area.
** This percentage does not include woodlots of less than 10 ha.

There are 6,380 forest fragments of more than 10 ha located wholly or partially in the St. Lawrence Lowlands (Figure 12). The area of these forest fragments ranges from 0 to 15,751 ha. It should be noted that two forest fragments located on the Ontario side of the Ottawa River are included in the database because they contain part of a map turtle occurrence whose polygon is related to the Quebec portion of the St. Lawrence Lowlands; however, the statistics for these two fragments were not considered in the results. In addition, the minimum areas of less than 10 ha shown in this table are those of forest fragments that overlap the boundaries of the study area, since the areas were compiled by considering only the portion of the fragments located in the St. Lawrence Lowlands. The average area of the fragments was 109 ha.

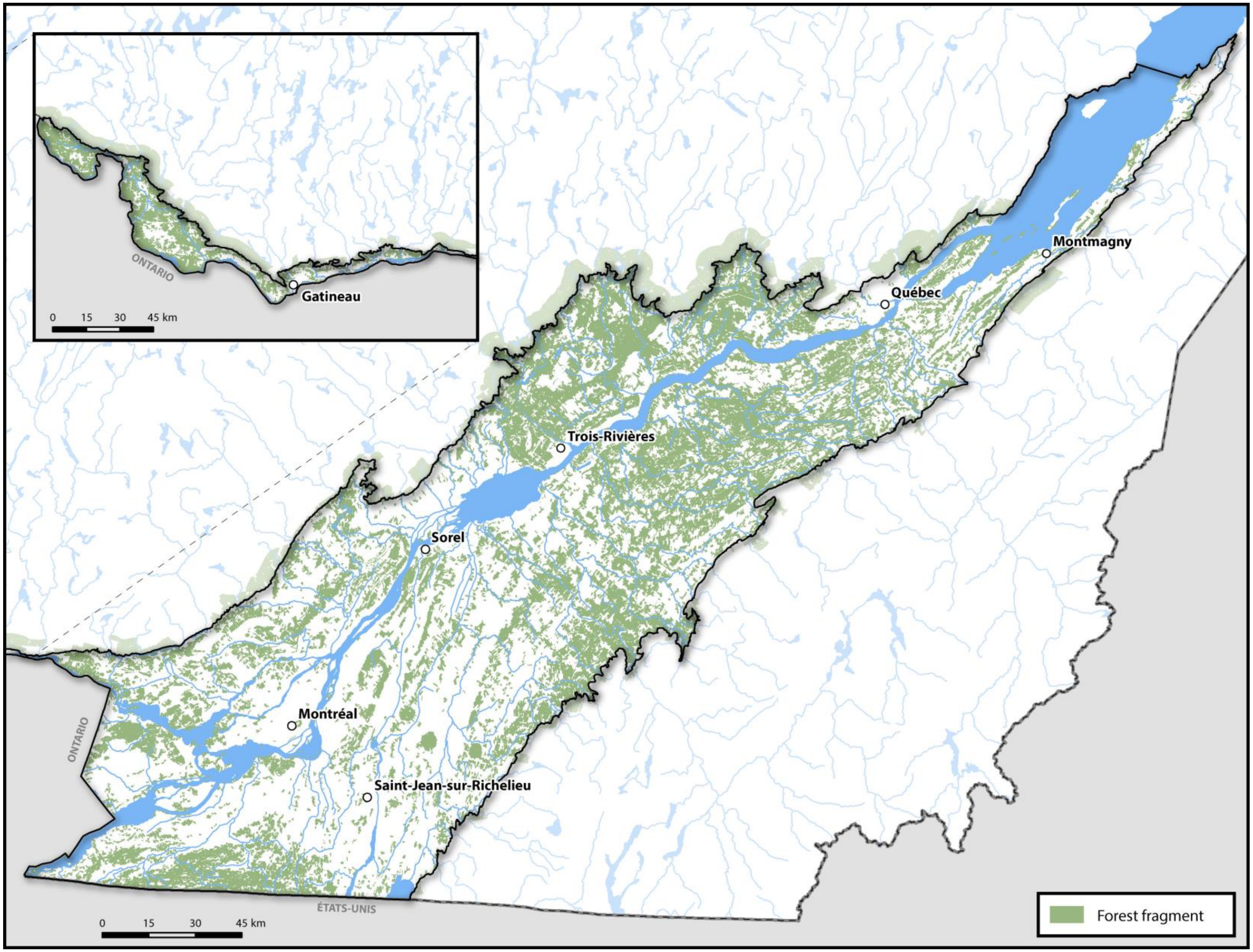


Figure 12. Distribution of forest fragments of 10 ha or more in the St. Lawrence Lowlands

The percentage of occupation of woodlots of 10 ha or more in more than half of the regional depositional contexts is below the 30% threshold recommended to maintain a complete assemblage of species associated with forest ecosystems (Andrén, 1994; Fahrig, 1997). In the St. Lawrence Lowlands as a whole, woodlots of 10 ha or more also cover less than 30% of the territory, or 24.2%. Although these percentages do not take into account woodlots of less than 10 ha, these figures clearly illustrate the significant fragmentation of forest cover in the study area. Moreover, of these 6,380 fragments, only 287 cover more than 500 ha, 87 cover more than 1,000 ha and only one, the Seigneurerie de Joly, covers more than 5,000 ha. The value of the first quartile of the area distribution, meanwhile, is barely 6 ha higher than the minimum area used to define the forest fragments, while the value of the third quartile is less than 100 ha.

In general, the data in Table 9 reflect the influence of regional depositional contexts on land use with the lowest average areas in depositional contexts 1A_p_B01, 1A_p_B02 and 5A_B01 whose flat relief and soils (silty sand to clay and marine clay) favoured intensive agriculture. In the Upper St. Lawrence Plain (B01), this corresponds to the land on either side of the Richelieu River valley and the greater Montreal and Laval metropolitan area, including much of the northern and southern crowns of this region. In this portion of the St. Lawrence Lowlands, the Monteregian Hills and the Fer-à-cheval wooded area north of Mont Saint-Bruno stand out.

Land use is much more pronounced in the Upper St. Lawrence Plain (B01) than in the Middle St. Lawrence Plain (B02). In the latter, which is less conducive to industrial agriculture, forest cover is clearly more present. The exception is the Quebec City metropolitan area and the riverside regions along the south shore of the St. Lawrence, where the population is concentrated. In the Ottawa Plain natural region (B03), the calm water marine context (5A) is characterized by much less forest cover than the deltaic (3DB) and subrecent fluvial (3FB) contexts. This marked difference can be explained by the presence of the Gatineau urban area and the substantial proportion of agricultural land found within the 5A context.

13.1.2. Classification of forest polygons

To simplify data processing, particularly for the calculation of diversity and irreplaceability criteria, a classification of forest polygons that takes into account both the current vegetation (forest stands) and the ecological type assigned to each polygon was produced. This classification was made on the basis of the following characteristics: drainage, trophic conditions (for stands on peat), origin and stage of development of the stands, potential vegetation and current vegetation. These groupings, when applied to the Environment Canada land cover layer, resulted in a detailed classification of 164,710 records. Of these 164,710 records, 16,504 were classified as Stage 2, 16,862 as Stage 3, and 131,344 as Stage 4 and 5. This classification thus made it possible to group the approximately 160,000 polygons extracted from the ecoforestry maps for the study area into 399 ecological type/species groupings (Villeneuve et al., in preparation).

13.1.3. Prioritization of the forest fragments

Although all forest fragments were considered in the selection analysis, the calculation of the prioritization criteria was only done for forest fragments that were located entirely within the study area or that had the majority of their area within the study area. As mentioned previously, the contribution of the selected forest fragments to the achievement of the representativeness objectives was first calculated in each regional depositional context. In cases where the 20% representativeness threshold was not reached, the remaining forest fragments were then analyzed in decreasing order of conservation value and those fragments that could fill the gaps in the representation objectives of the ecological type/species groupings were retained until the desired 20% threshold was reached.

The representativity target has been increased to 40% for some uncommon ecological type groupings/species groupings. This relative rarity may be partly natural, but in most cases it has been accentuated by the impact of human activities. Although these aggregations are not in the majority of cases irreplaceable, their relative rarity and the fact that they are associated in many cases with particular biophysical conditions motivated this decision on the basis of the precautionary principle. Examples include potential black-ash elm groves dominated by silver maple on water sites, potential red oak groves dominated by red oak on xeric sites, or potential white and red pine groves dominated by white pine on mesic or sub-water sites.

To calculate the conservation value of each forest fragment, raw and normalized values were first calculated for each of the primary and secondary prioritization criteria listed in Table 10 for each of the regional depositional contexts. These normalized values were then summed to form, based on this summation, main priority classes using the natural breaks method (five classes). Within each of these main priority classes, the normalized values of the secondary criteria for each fragment were then summed to form secondary priority classes using the natural breaks method (five classes). Two primary and four secondary criteria were selected (Table 10).

Table 10. Primary and secondary criteria used to prioritize forest fragments in the St. Lawrence Lowlands

Primary Prioritization Criteria	Area of interior forest
	Proximity Index
Secondary Prioritization Criteria	Proportion of mature forests
	Shape of the fragments
	Diversity of ecological types/species groups
	Presence of wetlands and riparian areas

Pearson correlation analyses were conducted for each pair of criteria and in each regional depositional context to determine if any of the criteria were redundant. No pair of criteria was highly correlated ($r > 0.7$) across regional depositional contexts, so all primary and secondary criteria were included in the multi-criteria analysis.

13.1.3.1. Area of interior forests

The area of interior forest was calculated by subtracting from each forest fragment the first 100 m of forest on the periphery. According to Harper et al. (2005), the alteration of the microclimate of a forest fragment due to the edge effect is felt up to an average distance of 100 m inside the fragment, resulting in increased wind damage, increased seed mortality and changes in the floristic composition of the undergrowth. This distance also appears to influence the selection of nesting sites by edge and interior bird species (Sandilands and Hounsell, 1994).

13.1.3.2. Proximity Index

The proximity index takes into account, for each fragment analyzed, the distance and area of other forest fragments located within 1 km of the analyzed fragment (McGarigal and Marks, 1995). The following formula was used:

$$\text{Prox} = \sum_{i=1}^{s} \frac{\text{fragment size of i } (m^2)}{(distance, \text{ in meters, between fragment i and the analysed fragment})^2}$$

Where:

Prox = proximity index value of the analyzed fragment

s = number of forest fragments located at a maximum distance of 1 km from the analysed fragment, this distance being calculated from the periphery of the forest fragments

The distance of 1 km represents the upper limit of the dispersal threshold for several species of small mammals as well as small and medium-sized birds (McCabe, 1947; Ostfeld and Manson, 1996; Tittler et al., 2009).

13.1.3.3. Proportion of mature forests

SIEF data were used to calculate the percentage of mature forest within each fragment. Forest stands meeting the following criteria were considered mature forests:

- Deciduous or mixed deciduous-dominated stands - old uneven-aged, old irregular and stands of tiered structure with the main storey in the 90-year age class or older;
- Coniferous or mixed stands that are predominantly coniferous trees with balsam fir, red pine, jack pine or pitch pine as the main species and belonging to the age class 70 years and older;
- Coniferous or mixed stands of predominantly coniferous trees that do not have balsam fir, red pine, jack pine or pitch pine as their main species and are in the 90+ year age class.

13.1.3.4. Shape of the fragment

The fragment shape criterion is designed to compare the area and perimeter of each forest fragment, with the objective of selecting fragments that have the smallest possible perimeter length in proportion to their area (McGarigal and Marks, 1995). The following formula was used:

PER = [(PERcircle/AREAcircle)/(PERfragment/AREAfragment)]

Where:

PER = shape index value of the analyzed fragment
PERcircle = perimeter (m) of a circle having an area equivalent to that of the analyzed fragment
AREAcircle = area (m^2) of a circle with an area equivalent to that of the analyzed fragment
PERfragment = perimeter (m) of the analysed fragment
AREAfragment = area (m^2) of the analyzed fragment

In the case of a circular fragment, this index has a value of 1; the more the shape of the analysed fragment deviates from that of a perfect circle, the more the value of this index decreases.

13.1.3.5. Diversity of ecological types/species groups

This diversity criterion uses Shannon's biodiversity index (McGarigal and Marks, 1995) by considering each ecological type/species grouping within the analyzed fragment as a separate entity. The following formula was used:

$$H' = \sum_{i=1}^{s} (p_i)(log_2 p_i)$$

Where:

H' = value of the diversity index of ecological type/species groupings of the fragment analysed
s = number of ecological type groupings/species groupings present within the analyzed fragment
p_i = proportion covered by the grouping of ecological types/species groupings i within the analysed fragment

The highest diversity values are attributed to fragments that contain a large number of clusters occupying relatively similar areas. Fragments with a small number of clusters with a marked predominance of one cluster over the others in terms of area have a lower value.

13.1.3.6. Presence of wetlands and riparian areas

The criterion for the presence of wetlands and riparian areas is calculated by dividing the length (km) of wetlands and riparian areas present within the fragment by its area (ha). The presence of riparian areas increases the biological diversity and productivity of forest fragments (Environment Canada, 2013a).

For forest fragments bordered by a stream or wetland, the length of the section of stream or wetland bordering the fragment was counted. In the case of forest fragments dissected totally or partially by a watercourse, the length of the watercourse was multiplied by two to account for both banks of the watercourse. Finally, the length of the perimeter of water bodies or wetlands completely included within a fragment was also counted.

13.1.4. Forest fragments straddling the boundaries of the St. Lawrence Lowlands

For forest fragments that straddle the boundaries of the St. Lawrence Lowlands and extend into the outlying natural provinces (southern and central Laurentians, Appalachians, Adirondacks), data processing had to be adjusted. All forest fragments were considered in the selection analysis without consideration of overlap.

In the prioritization analysis for fragments located mostly within the St. Lawrence Lowlands, the values of the criteria for area of interior forest, proximity, presence of riparian environments and fragment shape were calculated by considering the entire forest fragment within a buffer zone of up to 5.1 km beyond the limits of the study area determined from the general land use mapping produced by the Ministère (MDDELCC, 2015a). In this regard, it is possible that the difference in land use between the St. Lawrence Lowlands and the outlying natural provinces may have introduced a bias in the calculation of criteria for fragments that overlap the St. Lawrence Lowlands compared to those that are fully included within these boundaries. However, for the above-mentioned criteria, we judged that the inclusion of the portion located outside the St. Lawrence Lowlands would lead to a less significant bias than the exclusion of this same portion since, by their very nature, the said criteria are very closely linked to the geometric configuration of the fragments.

For the diversity and age-class criteria, the values for the prioritization criteria were calculated by considering only the portion of the forest fragment located within the St. Lawrence Lowlands. For these last two criteria, because of the marked difference in biophysical conditions between the St. Lawrence Lowlands and the outlying natural provinces, which was added to the difference in land use, we felt that including the portion located outside the St. Lawrence Lowlands would lead to a greater bias than excluding this same portion. Moreover, the link between the value of the last two criteria and the geometric configuration of the fragments is not as direct as in the case of the four criteria mentioned above. No prioritization criteria were calculated for forest fragments whose area was mostly outside the St. Lawrence Lowlands, in order to avoid prioritizing forest fragments located largely outside the study area.

13.2. Wetlands

13.2.1. Unit of analysis and data analysis

The unit of analysis is the wetland "complex", an assemblage of adjacent wetlands, whether ponds, marshes, swamps or bogs. The wetland complexes used were produced with an extraction from the detailed wetland mapping of populated areas in southern Quebec dated September 2016. Roads were subtracted from the wetland areas and considered as fragmentation elements, with the exception of small forest roads. The minimum size of the analysis units is 300 m^2. The inclusion of road fragmentation, however, resulted in many wetland complexes smaller than 300 m^2.

In selecting a unit of analysis, the complex was preferred over the wetland itself for two reasons. First, in order to assess the plant diversity (section 13.2.2.1) of each of our units of analysis, it is necessary to have information on the plant structure of each one that provides uniform coverage throughout the St. Lawrence Lowlands. The wetland classes provided by the detailed wetland mapping met this condition. Second, wetland ecosystems are often organized into "complexes" in a natural way. In fact, the wetland ecosystem often presents a variety of plant structures, recognized independently as marshes, swamps, bogs or wooded bogs, when in fact they are all part of the same ecosystem. For example, the same "bog" often has a plant organization ranging from open bog to treed swamp (Grandtner 1960; Gauthier and Grandtner 1975; Campbell and Rochefort 2001). By using the wetland complex, the goal is to achieve a better representation of the wetland ecosystem. For the purposes of analysis, an isolated wetland with a single vegetation structure is also considered a complex.

There are 44,816 wetland complexes in the St. Lawrence Lowlands (Figure 13). Their distribution and characteristics vary significantly depending on the depositional context in which they are established (Table 11).

Table 11. Characteristics of Wetland Complexes in the Depositional Context

Depositional Context	Number	Area (ha)			
		Average	Standard deviation	Minimum	Maximum
1A_a	4 432	4,53	21,89	0,01	542,13
1A_p	4 587	4,27	20,57	0,02	536,21
3DB	6 556	5,28	81,97	0,10	5 932,18
3FA	1 748	21,42	178,24	0,01	6 142,40
3FB	3 515	8,61	67,39	0,01	2 232,35
3M	2 053	7,03	48,37	0,01	1 322,83
5A	11 485	4,47	30,61	0,01	1 386,77
5S	8 082	11,84	86,52	0,02	3 335,72
6D	2 358	8,11	54,56	0,03	1 476,79
Total	**44 816**	**7,20**	**67,37**	**0,01**	**6 142,40**

Some findings are already emerging from these results. For example, it is interesting to note that the Calm water context 5A has the highest number of wetland complexes, but one of the lowest average areas. This can be explained both by the processes leading to the establishment of this regional context and by the contemporary occupation of this territory. Indeed, the calm water context was established at the bottom of the Champlain Sea basin (Appendix E). The dominant deposits are composed of clay loam and silty clay, and contain an appreciable quantity of very fine sand. Soils in this regional context are consequently difficult to drain. The sector is therefore conducive to the appearance of wetlands.

However, these same deposits, combined with the province's high rainfall and mildest weather conditions, also make this sector one of the best agricultural lands in Quebec. This observation is corroborated by Jobin et al. (2003). In fact, their "Intensive Agricultural Landscape - Cash Crops" occupies an area similar to that of the 5A context.

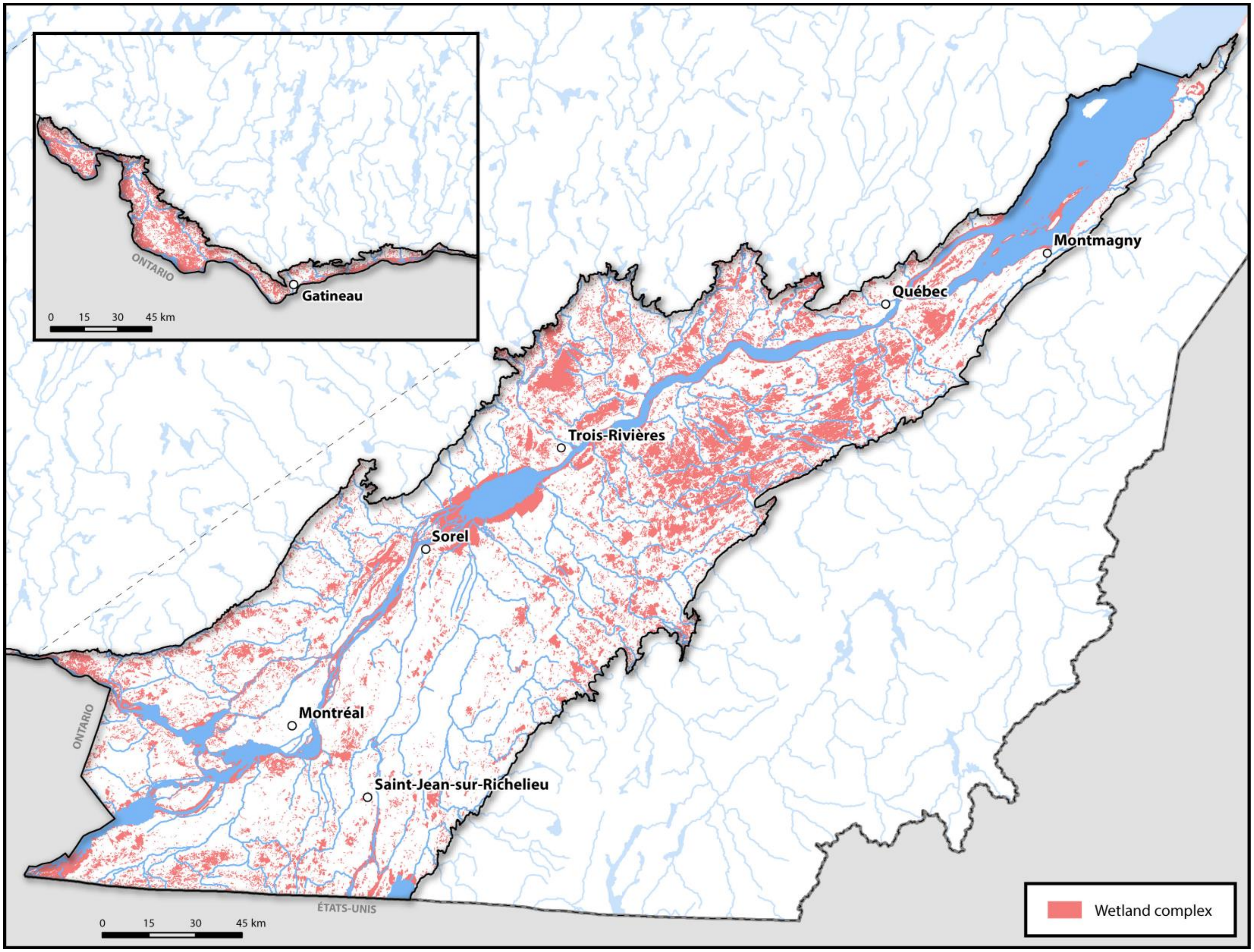


Figure 13. Distribution of wetland complexes in the St. Lawrence Lowlands

This predominance of conditions conducive to wetlands, combined with the agricultural interest in these lands, results in significant conflicts of use. In this regard, Pellerin and Poulin (2013) define this sector as one of the areas with one of the highest proportions of disturbed wetlands, and they state that agriculture is responsible for more than 75% of these disturbances. In light of all this, it is reasonable to assume that this area is characterized by a large number of residual wetland fragments that once occupied large areas, resulting in a large number of small wetland complexes.

13.2.2. Prioritization of wetland complexes

Wetland complexes are the unit of analysis used to identify wetlands of conservation interest. However, the method used differs from that described in Section 12 in a few important respects.

The selection of complexes by the selection criteria (section 12.1) does not have any thresholds to be met. In this first step, the method selects all wetland complexes:

- in contact with a public or private protected area;
- home to an exceptional forest ecosystem on public land;
- containing one or more plant species of high conservation value;
- that is home to one or more wildlife species of high conservation value;
- considered irreplaceable habitat patches on the basis of wetland classes.

Subsequently, the wetland complex prioritization analysis is conducted in accordance with the sequence described in Section 12.2, but is repeated twice: once with hydrological and biogeochemical criteria (hereafter "HB prioritization criteria"), and a second time with vegetative criteria (hereafter "habitat prioritization criteria").

The HB prioritization criteria step (Table 12) had to be modified during the preliminary analysis of the results. The objective of the original method was to identify the most hydrologically and biogeochemically useful wetlands, up to a maximum of 6% of the territory in each regional context. This 6% threshold, reported a few times in the literature (Johnston et al., 1990; Environment Canada, 2013a; Blais et al., in preparation), applies at the sub-watershed level. Given that the databases (detailed wetlands, land use) only cover the St. Lawrence Lowlands and that most of the Lowlands watersheds extend into the Appalachians or the Laurentians, it was originally agreed to apply this threshold to the scale of the depositional contexts.

However, analysis of the preliminary results revealed that the HB step had no influence in the selection of priority wetlands in four regional depositional contexts (3DB, 3FA, 3FB, 5S). Indeed, in these four contexts, the selection analysis already defined a sufficiently large number of wetland complexes that the 6% threshold was already reached even before the HB stage. However, the selected wetland complexes were not the most interesting in terms of the HB criteria. Therefore, we decided to include *all* the most hydrologically and biogeochemically useful wetland complexes, regardless of the selection step.

The Habitat Prioritization Criteria step (Table 12) is intended to complete, if necessary, the identification of wetland complexes of conservation interest already identified in the selection analysis and HB prioritization criteria analysis. The objective is to identify the most useful wetlands in terms of habitat, up to a maximum of 20% of the wetland area in each depositional context.

Pearson correlation analyses were performed for each pair of criteria and in each depositional context to determine whether any of the criteria were redundant. Occasionally, some important correlations ($r > 0.7$) were found. Indeed, primary productivity is related to both water retention and shoreline stabilization. However, these links do not appear systematically in all depositional contexts. Moreover, these criteria belong to different stages of selection. Indeed, primary productivity belongs to the habitat stage, while water retention and shoreline stabilization belong to the HB stage. Consequently, these three criteria were retained despite their correlation.

Table 12. Criteria for pioritizing wetland complexes in the St. Lawrence Lowlands

Habitat Prioritization Criteria	Plant diversity
	Primary productivity
	Area
	Naturalness of the buffer zone
	Proximity to other wetlands
Hydrological and Biogeocheminal Prioritization Criteria (HB)	Hydrological regulation or water retention
	Erosion control or shoreline stabilization
	Groundwater recharge
	Contribution to water quality or short-term nutrient and pollutant uptake
	Contribution to carbon sequestration

13.2.2.1. Plant diversity

A formal assessment of plant diversity requires consideration of two factors: the number of species and the relative abundance of each (Magurran, 1988). No such information is available for the St. Lawrence Lowlands.

Alternatively, it is often accepted that habitat can also be used to assess diversity (Jeanmougin et al., 2014). However, there are a variety of definitions of habitat (Hall et al., 1997). At its strictest, habitat characterization requires defining the set of physical properties of the environment in which an organism, species, or population lives (Odum 1963; Parent 1990; Odum and Barrett

2004). Given the level of detail required to adequately characterize a habitat, it is not possible to map such habitats at the scale of the St. Lawrence Lowlands.

If it were possible to conduct field inventories in each of the wetland complexes, we could use a "community" approach (Jeanmougin et al., 2014) based on phytosociology (Braun-Blanquet, 1964). Such an approach would allow us to study the plant diversity of wetland complexes by characterizing homogeneous species assemblages. Two levels of organization appear particularly promising: plant grouping and plant association. The first has been the subject of major inventory work at the Quebec level (Couillard and Grondin, 1986) and the second is highlighted in MELCC documents (Bazoge et al., 2015). We believe that the use of plant groupings or plant associations would provide a good picture of plant diversity. That being said, although we recommend the use of plant associations in the characterization of wetlands, we do not have data at the scale of the St. Lawrence Lowlands.

In the end, for an exercise carried out on the scale of the St. Lawrence Lowlands, it is advisable to focus on plant organization as it can be observed by photo-interpretation. We will therefore use the available detailed wetland mapping. This classification is based on observable plant structures (Beaulieu et al., 2010), which translates into seven distinct categories: pond, marsh, wet meadow, swamp, treed bog, open bog, open fen.

The Shannon Index was used to characterize the diversity of wetland classes (Adsavakulchai et al., 2004). The index takes the following form:

$$S = -\sum_{i=1}^{n}(pi * ln\, pi)$$

Where:

S = Shannon Index
n = number of wetland classes within a complex
pi = proportion of the area of the complex covered by class i

13.2.2.2. Primary productivity

“Primary productivity" reflects the capacity of an ecosystem to produce plant biomass. In general, the greater this production, the more the ecosystem will be able to maintain a complex and diverse food chain (for a review, see Waide et al, 1999; Mittelbach et al, 2001). In this regard, the primary productivity of northern hemisphere wetlands has been the subject of various studies (e.g. Richardson 1978; Moore 1989; Thormann and Bayley 1997). For example, different classes of wetlands are known to have different rates of primary productivity. In this study, we used primary productivity rates from the work of Campbell et al. (2000), Knud-Hansen et al. (1991) and Korfel et al. (2010).

That being said, these primary productivity rates cannot be uniformly applied to all wetlands in the St. Lawrence Lowlands. Other factors can modulate primary productivity, including physiographic position, length of growing season and soil type (Ontario Ministry of Natural Resources, 2014).

Physiographic position

The primary productivity of a wetland depends on the abundance of nutrients available to it. Well oxygenated water that irrigates the ecosystem also contributes to primary productivity (Mitsch and Gosselink, 2007). Nutrient and oxygen abundance can be estimated by the physiographic position of the ecosystem. There are five physiographic types: isolated, palustrine, lacustrine, riparian and St. Lawrence River riparian. These types are described in Box 1.

Isolated and palustrine wetlands are considered to have low productivity because their water supply comes from precipitation, surface runoff and, to some extent, groundwater circulation. Many raised bogs are considered "isolated". This is especially true since their domed structure often precludes any possibility of enrichment by surface or groundwater runoff.

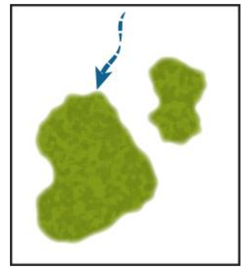
In contrast, lacustrine and riparian wetlands are considered more productive. However, the lacustrine environment is characterized by a volume of water with a slower flow than the riparian environment. The supply of nutrients and oxygen to lacustrine wetlands is therefore slower, resulting in generally lower productivity.

Finally, the riparian wetlands in contact with the St. Lawrence River benefit from the supply of a unique ecosystem extending over 800 km and whose watershed covers a large part of the province of Quebec. The nutrient loading and oxygen availability enjoyed by the wetlands bordering the River make them particularly productive.

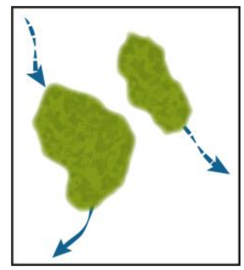
Box 1: THE PHYSIOGRAPHICAL TYPE

The physiographic type is based on the hydrogeomorphic classification (Brinson, 1993; United States Department of Agriculture, 2008) filtered from the Ontario method (Ontario Ministry of Natural Resources, 2014).

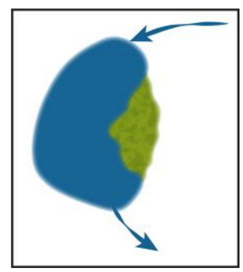
Isolated wetland
A wetland complex that has no surface outlet. It may, however, receive volumes of water from permanent or intermittent watercourse. For geomatics purposes, a tolerance of 5 m has been allowed, i.e., the isolated complex must be located more than 5 m from any downstream hydraulic outflow.



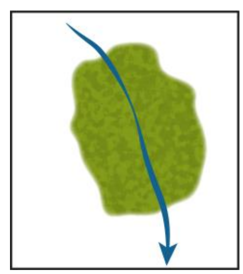
Palustrine wetland
Refers to a wetland complex located at the headwaters, i.e., it gives rise to a permanent or intermittent watercourse as its outlet. It may receive an intermittent tributary. A wetland that is both a palustrine and lacustrine is considered lacustrine.



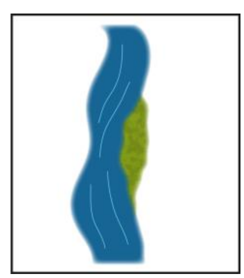
Lacrustine wetland
Refers to a wetland complex adjacent to a body of water. For geomatics purposes, a tolerance of 5 m has been allowed, i.e. the wetland complex must be located within 5 m of the water body. To distinguish the water body from a simple widening of a watercourse, a minimum size of 8 ha is required for a water body to be recognized as such.

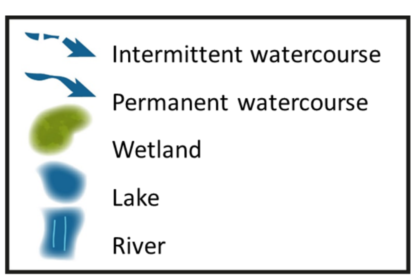


Riparian
Refers to a wetland complex crossed by a permanent watercourse. For geomatics purposes, a tolerance of 5 m has been granted, i.e. a riparian complex located within 5 m of a permanent watercourse is considered riparian.



St. Lawrence River riparian
Refers to a wetland complex crossed or bordering the main stem of the St. Lawrence River. For geomatics purposes, a tolerance of 5 m has been granted, i.e. a riparian complex located within 5 m of the main course of the St. Lawrence River is considered to be riparian to the river.





The calculation of the primary productivity index is expressed as follows:

$$P = PPN \times Fp$$

Where:

P = primary productivity index
PPN = net primary productivity
Fp = physiographic position index

Value of *PPN*:

If the wetland is an open bog = 449
If the wetland is an open fen = 296
If the wetland is a treed bog or swamp = 943
If the wetland is a marsh or wet meadow = 1 034
If the wetland is shallow water or a pond = 400
If the wetland is a complex, it should be weighted according to the proportion of different classes present.

Value of *Fp*:

If the wetland is riparian to the St. Lawrence river = 5
If the wetland is riparian = 4
If the wetland is lacustrine = 3
If the wetland is palustrine = 2
If the wetland is isolated = 1

Note that the length of the growing season was not considered in the calculation of primary productivity since this parameter does not vary sufficiently across the study area to have a significant influence on the results. Similarly, the nature of the soils was not considered since regional differences within the St. Lawrence Lowlands are already reflected in the determination of depositional contexts.

13.2.2.3. Area

The area occupied by a natural environment is probably one of the most widely used ecological indicators. Area can be considered an indicator of most wetland-related ecological functions. For example, the area of a wetland is a recognized indicator of its ability to filter sediment, nutrients and various contaminants (Tiner 1999; Kent 2001). There is also an important relationship between wetland area and water storage capacity (Cedfelt et al., 2000). However, the most frequently cited relationship is between area and biodiversity (Schweiger et al., 2002; Mitsch and Gosselink 2007). In both the descriptive model of island biogeography (MacArthur and Wilson, 1967) and the metapopulation model (Levins, 1969; Hanski, 1999), area is an important variable in the migration balance.

In our work, the area shows a significant correlation only with groundwater recharge (0.59). Since these criteria are at different stages of selection, the area will nevertheless be used.

$$T = \log s$$

Where:

T = wetland complex size criterion
s = complex area (m^2)

13.2.2.4. Naturalness of the buffer zone

Like the area, the naturalness of the buffer zone can be related to a variety of ecological functions. This criterion may primarily reflect the capacity of a natural environment to fulfil its role as a refuge for fauna and flora. The presence of a natural environment at the periphery of the ecosystem generally favours the movement of species affiliated with this ecosystem (Forman and Godron, 1986) and, consequently, the diversity of these species in the environment itself (Houlahan and Findlay, 2003). Conversely, a buffer zone that is absent or dominated by human activities increases the flow of invasive or opportunistic alien species to the wetland, which may result in a decrease in the abundance or diversity of native species (Harris 1989; Ås 1999). It can also be argued that the buffer zone plays a hydrological and biogeochemical role. Buffer strips slow surface runoff and promote sediment retention and nutrient uptake (Houlahan and Findlay, 2004; Dorioz et al., 2006; Gagnon and Gangbazo, 2007).

It therefore appears that the naturalness of the buffer zone can be linked as much to the biological functions as to the hydrological and biogeochemical functions of the wetlands. However, despite this "universal" character, our results show rather the opposite: the naturalness of the buffer zone is not strongly correlated with any of the other criteria.

In the literature, the required width of a buffer zone varies according to the organisms or ecological functions under consideration. It can vary from a few metres for sediment retention (Gagnon and Gangbazo, 2007) to several hundred metres for certain animal species (Environment Canada, 2013a). A distance of 200 m appears conservative given most of the thresholds identified in the literature.

$$ZT = \frac{Smn}{Szt}$$

Where:

ZT = criterion on the naturalness of the buffer zone
Smn = area of natural areas (m^2) within a 200 m buffer zone around the wetland complex
Szt = area of the 200 m buffer zone around the wetland complex

13.2.2.5. Proximity to other wetlands

Habitat degradation and destruction are among the main causes of biodiversity loss worldwide (Sala et al., 2000). The ever-increasing human ecological footprint contributes to the fragmentation and isolation of natural environments within a matrix dominated by human activities (Young et al., 1996). This isolation reduces rates of dispersal and immigration and consequently increases the risk of extinction of animal and plant populations (Haila and Hanski, 1984; Wilcove et al., 1986; Debinski and Holt, 1999).

Ecologists have long assessed the importance of isolation by the distance between patches of natural habitat (MacArthur and Wilson 1967; Wilson and Willis 1975; Gilpin and Diamond 1980). It is now clear that the effects of isolation in continental environments are not limited to distance. The influence of the matrix on natural patches or fragments depends on the type of habitat found within them, the type and intensity of human activities that take place within them, and the degree of similarity between the fragments and the habitats in the matrix (Forman and Godron 1986; Forman 1995; Jules et al., 1999; Houlahan and Findlay 2003; 2004). The intrinsic characteristics of the species under study also play an important role in their susceptibility to isolation. These include, for example, the lifespan of the species (Young et al., 1996), the viability of the seed bank, and the propagation strategies used (Henle et al., 2004).

In an exercise based on all the wetlands in an area the size of the St. Lawrence Lowlands, it is impossible to take into account all the variables related to isolation. The number of animal and plant species involved, as well as the diversity of human activities found on this territory, exceeds existing means. It is therefore necessary to limit ourselves to a few simple variables such as distance and abundance of wetlands.

For this purpose, the proximity index developed by Gustafson and Parker (1992) is used. This simple index takes into account the abundance of wetland areas within a one-kilometre radius of each wetland complex.

$$PROX = \sum_{s=1}^{n} \frac{A_{ijs}}{D_{ijs}^2}$$

Where:

A = area (m²) of the ijs complex located within one kilometre of the ijs complex

D = Euclidean distance (m) between the edge of fragments ijs and ij

13.2.2.6. Hydrological regulation or water retention

Hydrological regulation, or water retention, is an important ecological function of wetlands. By retaining water or delaying its flow, wetlands mitigate the impact of floods on downstream riparian habitats, including the many human communities along streams and water bodies.

Wetlands, by their nature, occupy depressions or are located at the interface between terrestrial and aquatic environments. Consequently, during precipitation or snowmelt, wetlands are flooded by watercourses or intercept ground or surface runoff. However, wetlands often have a varied microtopography (Donat 1995; Vivian-Smith 1997; Campbell and Rochefort 2001) or an assemblage of plant strata of varying shapes and sizes (Mitsch and Gosselink 2007) that contribute to slowing the flow of water and retaining it for a long period of time. In addition, this retention also promotes water infiltration and evapotranspiration by existing vegetation (Price, 2001; Frei et al., 2010). Thus, wetlands spread flood peaks over longer periods of time and contribute to water retention.

Wetlands, particularly peatlands, have long been considered natural "sponges" that can accumulate large volumes of water during high water periods. However, this interpretation does not stand up to scientific analysis. While it is true that wetlands, especially peatlands, are important reservoirs of water, their capacity to store excess volumes during flood periods is often limited (Price, 2001). This capacity depends on the depth of the water table (Clerc, 2009). In most wetlands, the water table remains near the surface for most of the year (Woo and Valverde, 1981; Roulet, 1990; Price, 1997; Clerc, 2009). This is most certainly the case in the spring, when floods are more threatening to human communities. At this time of year, the water table is already high in wetlands or the ground may still be frozen, which impedes water storage (Woo and Winter, 1993). In the end, there is a "sponge" effect of wetlands, but this effect occurs under dry conditions, when the water table in wetlands drops significantly (Clerc, 2009). For these reasons, the presence of organic deposition will not be selected as a variable influencing hydrological regulation.

The importance of a wetland for hydrological regulation may depend on several other factors: physiographic location, size of the wetland, size of the area draining into the wetland (also called the contributing area), abundance of wetlands or water bodies upstream of the wetland, and severity of flooding downstream of the wetland (Ogawa and Male, 1983; 1986). This last factor will not be considered here, however, because we do not have the data needed to take into account the severity of flooding in the St. Lawrence Lowlands.

Physiographic position

Isolated wetlands have no outlets and do not contribute directly to the flow of surrounding watercourses. Water received during periods of melting or precipitation is stored or fed to the water table by infiltration. Consequently, these environments are considered the most efficient in terms of water retention.

Conversely, the wetlands along the St. Lawrence River are not considered to be very effective in this regard. Their size, whatever it may be, is negligible compared to that of the water body they border and its watershed. They therefore have little impact on water retention during high-water periods. As for wetlands characterized by other physiographic positions, their water retention value must be based on a calculation that takes into account their size, the area of their watershed (also called the contributing area) and the abundance of wetlands or water bodies located upstream.

Attenuation coefficient

The attenuation coefficient is based on the ratio between the size of a wetland and its contributing area.

The size of a wetland is a major factor in its hydrological regulation function, as long as the size of the wetland is large in relation to the contributing area that feeds the ecosystem. Otherwise, the influence of the wetland is negligible. Based on the available scientific literature, it is difficult to establish precise thresholds. Nevertheless, some studies have shown that increasing the area of wetlands in a watershed reduces the risk of flooding, but that these positive effects fade away when a 10% threshold is reached (Environment Canada, 2013a). It has also been shown that a watershed with 5-10% wetlands will see a 50% reduction in flood intensity (Johnston et al., 1990).

In calculating an attenuation coefficient, therefore, a maximum value should be assigned to any wetland that is 10% or more of its contributing area. However, there is no reliable threshold below 10%. By default, therefore, it should be assumed that the attenuation coefficient varies directly with the ratio between the two areas. For example, as has been done in Ontario (Ontario Ministry of Natural Resources, 2014) and Washington State (Hruby et al., 1999), the attenuation coefficient is calculated by dividing the area of a wetland by the area of its drained area and multiplying the result by 10. Any wetland complex with an area greater than 10% of its contributing area is assigned a maximum attenuation coefficient of 1.

Retention coefficient

The attenuation coefficient reflects important information. However, the real benefit of a wetland is questionable if it is located downstream of natural environments that already have a water retention role. The function of the retention coefficient is to establish the ratio between the size of a wetland and the areas already having a water retention function upstream of it. These retention areas are not limited to wetlands, but also include lakes and all open bodies of water.

There is no threshold as to the proportion of retention areas that a wetland must represent to obtain a maximum value. By convention, 50% will be used. For example, as has been done in Ontario (Ontario Ministry of Natural Resources, 2014) and Washington State (Hruby et al., 1999), the retention factor is calculated by dividing the area of a wetland by the area of wetlands and water in its contributing area and multiplying the result by 2. Any wetland complex whose area represents more than 50% of the wetlands and water in its contributing area is assigned a retention factor of 1.

The calculation of the hydrological regulation criterion, or water retention, is expressed as follows:

If the wetland is isolated = 1
If the wetland is riparian to the St. Lawrence river = 0
For wetlands characterized by another physiographic position =
(attenuation coefficient + retention coefficient) / 2

Where:

Attenuation coefficient = (wetland area / area of its contributing area) x 10
Retention Coefficient = (wetland area / wetland and water area in its contributing area) x 2

13.2.2.7. Erosion control or shoreline stabilization

All riparian vegetation increases the ability of the shoreline to withstand the shear and pullout forces produced by the current (MDDELCC, 2015b). In assessing their ability to stabilize the shoreline, wetlands are subject to the same scales used to assess the quality of riparian strips.

For example, it is recognized that riparian vegetation slows water flow and promotes sedimentation (Bundesministerium für Land- und Forstwirtschaft, 1994, in Donat, 1995). However, this capacity is influenced by many factors. Herbaceous plants mainly protect the soil surface, while the aerial and root structures of trees and shrubs dissipate the erosive forces of the current through their branches, trunks and roots (Carlson, 1992; Kent, 2001). The species and age of the existing vegetation also play a role, along with various other external factors (stream morphology, soil type, slope, etc.) (Donat, 1995).

However, when assessing wetland erosion control, one must limit oneself to readily available information on the St. Lawrence Lowlands as a whole. Factors requiring a field inventory should also be ruled out. Thus, the criterion developed here uses the physiographic position and wetland class.

<u>Physiographic position</u>

Isolated wetlands have no hydrological linkages. Their contribution to erosion control is therefore negligible. The same is true of palustrine wetlands, which give rise to watercourses but contribute little to their stabilization. These two classes of wetlands do have an indirect role to play in erosion control, in that their role of permanent or temporary water retention leads to a reduction in downstream peak flows. However, water retention has already been assessed in Section 13.2.2.6.

For wetlands characterized by other physiographic positions, their erosion control value must be based on a calculation that takes into account the dominant vegetation expressed by the wetland class. The size of the wetland is excluded from the calculation because this variable is not important in itself. It is the size of the portion of the ecosystem occupying the shoreline and bank of a watercourse that is important. We don't have this information for the whole area.

<u>Wetland class</u>

Trees and shrubs do not have the same role in shoreline stabilization. While it is true that roots generally sink deeper, it is also possible that tree trunks act as a lever when pushed by ice and the fall of the tree causes more substantial damage to the shoreline. Nevertheless, taking such information into account requires a degree of precision that cannot be obtained without an inventory. Therefore, swamps of all types and treed bogs are independently assigned a maximum value.

Swamps and open bogs are generally dominated by small herbaceous or shrubby vegetation. Although this vegetation offers less resistance to current, it is still effective in stabilizing the surface layers of the soil. Marshes and open bogs are therefore given an intermediate value. The MELCC includes both small isolated water bodies and riparian aquatic grass beds in the "pond" category. Submerged or floating vegetation offers little resistance to current and has a reduced stabilization capacity, so "ponds" are given a reduced value.

The calculation of the shoreline stabilization criterion is expressed as follows:

If the wetland is isolated or palustrine = 0

For wetlands characterized by another physiographic position:

Swamp and treed bog = 1
Marshes and open bogs (bog/fen) = 0.6
Ponds = 0.3

When the wetland is a "complex", the score is assigned based on the share of each of the three wetland categories described above.

13.2.2.8. Groundwater recharge

Groundwater recharge is an important ecological function of wetlands. It contributes to the maintenance of aquifers useful for human consumption. Infiltration of water into the ground also contributes to the mitigation of flood flows and the maintenance of a minimum summer flow in streams downstream of the wetland (Kent, 2001; Fournier et al., 2013), as well as contributing to water quality by ensuring better dilution of pollutants (Cronk and Fennessy, 2001).

However, the scientific literature on wetland recharge is fragmentary (Mitsch and Gosselink, 2007). Establishing the water balance of a wetland requires an examination of the surface hydrology and the circulation of water through the soil. The latter generally requires considerable effort and investment by qualified hydrogeologists.

However, a very small number of wetlands are known to have a long-term groundwater recharge function each year (Woo and Valverde, 1981; Kent, 2001; Ontario Ministry of Natural Resources, 2014). For the most part, the contribution of wetlands to groundwater recharge is seasonal or episodic, i.e., it occurs only during snowmelt or periods of heavy precipitation. The reason is simple: many wetlands are underlain by impermeable soils, which limits the possibility of exchange with the water table. This is especially true in the St. Lawrence Lowlands, where 85% of wetlands are peat bogs (Pellerin and Poulin, 2013), i.e., ecosystems that often depend on impermeable soil. Consequently, generally speaking, it is only when the water balance of a wetland is in surplus, i.e., when it overflows, that a wetland truly contributes to groundwater recharge.

It follows from this conclusion that groundwater recharge occurs mainly where wetlands overflow, i.e., at the periphery. The few studies that have looked at this phenomenon point out that small wetlands are more efficient than large ones and that the ratio "perimeter/volume of water stored by the wetland" is an effective indicator of the recharge capacity of a wetland (Kent, 2001; Mitsch and Gosselink, 2007).

However, this ratio is not the only important element of a groundwater recharge criterion. Lacustrine and riparian environments are of less interest in terms of recharge. Their hydrology is dependent on fluctuations in the water of the nearby lake or river. The volumes of water present in these wetlands are generally directed towards the adjacent water environment rather than towards the underlying water table. Consequently, the physiographic position will also be used in the groundwater recharge criterion.

Physiographic position

Lacustrine and St. Lawrence river riparian wetlands are bordered by large bodies of water that are present year-round. Most of their exchanges are with these water bodies. These wetlands are therefore considered to be of zero value for groundwater recharge.

Riparian wetlands also have important exchanges with neighbouring watercourses. During high-water periods, however, these wetlands can receive and temporarily store large volumes of water, thus promoting infiltration for at least part of the year. They are therefore considered to be of average interest for groundwater recharge. Finally, isolated or palustrine wetlands are considered to be of high interest for groundwater recharge for two reasons. First, they have few or no permanent outlets, which ensures water infiltration. Second, they are generally located upstream of watersheds. Recharging the water table through these environments therefore has positive effects over a large area.

Perimeter/area ratio

Since we do not know the volume of water stored in the wetlands of the St. Lawrence Lowlands, we will assume here that volume and area go hand in hand. The "perimeter/area" ratio of each wetland or wetland complex will be used.

The calculation of the groundwater recharge criterion is expressed as follows:

First, for each wetland or complex, the standardized perimeter/area ratio is calculated using the Legendre and Legendre (1998) rank method, referred to here as the R_{ss}.

$$R_{ss} wetland\ X = \frac{R_{ps}\ wetland\ X - R_{ps}\ minimum}{R_{ps}\ maximum - R_{ps}\ minimum}$$

Where:

$$R_{ps} = Perimeter/area$$

The R_{ss} is then multiplied by a value corresponding to the physiographic position of wetland X.

If X is an isolated or palustrine wetland = 1
If X riparian wetland = 0,5
If X is a lacustrine or St. Lawrence river riparian wetland = 0

Since groundwater recharge occurs mainly at the periphery of wetlands, the type of soil found in these areas also affects the quality of water infiltration and the ability of the water to reach the water table. To address this, soil maps were used in the calculation of recharge criteria in Ontario (Ontario Ministry of Natural Resources, 2014). Due to the uncertainty in our own soil maps, particularly at the scale of a small disturbed wetland in the St. Lawrence Lowlands, this aspect will not be addressed here.

13.2.2.9. Contribution to water quality or short-term nutrient and pollutant uptake

The ability of wetlands to purify water is one of the most important functions of wetlands to human communities. The improvement of water quality by wetlands has been extensively documented (e.g., Nichols 1983; Kent 2001; Mitsch and Gosselink 2007) and numerous guides have been written on the construction of artificial wetlands to treat industrial, agricultural or domestic discharges (e.g., Cronk and Fennessy 2001; DeBusk and DeBusk 2001).

The contribution of wetlands to water quality is a complex phenomenon resulting from a range of physicochemical and biological interactions. For example, slower flows promote the deposition of sediments and adsorbed chemicals and their subsequent removal from the water column (Mitsch and Gosselink 2007). The presence of alternately aerobic and anaerobic substrates promotes 1) nitrogen transformation and 2) the precipitation of various chemical compounds (Cronk and Fennessy, 2001). The high primary productivity of wetlands promotes N and P sequestration in plant tissue; however, this process can be reversed when herbaceous plants die and woody vegetation loses its foliage (DeVito et al., 1989). Other wetlands, namely peatlands, have the capacity to accumulate organic matter over the long term, in the form of a deposit called peat.

The location of a wetland in the watershed also affects its water purification function. A wetland crossed by a stream draining an agricultural landscape has a greater purification value than a wetland located at the head of a watershed (Johnston et al., 1990). The type of vegetation in place also plays a role in water purification capacity. Herbaceous plants have a high rate of productivity and will therefore remove a significant amount of nutrients from the surrounding environment. However, these nutrients will be massively released later, when the biomass decomposes. Trees and shrubs sequester a portion of the nutrients over a long period of time, but they nevertheless redeposit a large amount of biomass into the environment in the fall.

In the end, the contribution of wetlands to water quality is manifested primarily through the temporary conversion and capture of nutrients. For this purpose, this criterion will use the physiographic position, wetland type and land use in the contributing area of each wetland.

Physiographic position

The riparian wetlands of the St. Lawrence River are negligible in size in relation to the watercourse that flows through them and its watershed. Their impact on water quality downstream of their position is therefore considered negligible.

The value of the lacustrine wetland depends on its position on the water body. If it is located on the edge of the water body, its effect will be negligible since most of the water volume will never pass through the wetland. On the other hand, the wetland located at the input or output of the water body has a much greater purification value. The distinction between these two types of lacustrine wetlands does not need to be made here, however, since lacustrine wetlands in contact with streams flowing into or originating from them have been classified as "riparian" in our method. Consequently, lacustrine wetlands are considered to be of low water treatment value.

Isolated and palustrine wetlands have few or no permanent outlets. By promoting water retention, they promote the sequestration of nutrients and pollutants. However, they are often located at the head of a watershed and their contributing areas are often small, which limits their actual role in cleaning up water. As a result, isolated and palustrine wetlands are considered to have an average value for water purification.

In the end, riparian wetlands, which are crossed by and regularly flooded by rivers and streams, are given a high value in terms of water treatment.

Wetland class

Marshes and open minerotrophic-type bogs are dominated by fast-growing herbaceous vegetation, which, however, exhibits massive mortality at the end of the growing season. Nevertheless, because the focus here is on processing and temporary nutrient uptake, marshes and fens are assigned a high value.

Swamps, treed bogs and open bogs of the ombrotrophic type are dominated by tree, shrub or moss vegetation that sequesters nutrients at a slower rate but over a longer period of time. They are assigned an average value for contribution to water quality.

Ponds are dominated by fast-growing vegetation, but occupy less than 25% of the area (Bazoge et al., 2015). Consequently, they are assigned a low value for contribution to water quality.

Since all wetlands are subject to annual vegetation growth, no wetland is assigned a value of zero.

Where the wetland is a "complex", the score should be assigned based on the share of each of the three wetland categories described above.

Land cover of the contributory area

Finally, more nutrients and suspended sediments are generally found in surface waters in watersheds dominated by agricultural or urban activities. Consequently, a wetland receiving water from a contributory area dominated by these activities is assigned a maximum value. A wetland receiving water from a watershed dominated by forests or wetlands is assigned a low value.

The calculation of the water quality contribution criterion is expressed as follows:

$$\frac{(\mathrm{Ppp} + \mathrm{Pmh} + \mathrm{Pbv})}{3}$$

Where:

P_{pp} = score associated with the physiographic position:
- If X is a St. Lawrence river riparian wetland = 0
- If X is a lacustrine wetland = 0,3
- If X is an isolated or a palustrine wetland = 0,6
- If X is a riparian wetland = 1

P_{mh} = score associated with the type of wetland:
- If X is a pond = 0,3
- If X is a swamp, treed bog or open ombrotrophic bog = 0,6
- If X is a marsh or a minerotrophic type bog = 1

Where the wetland is a "complex", the score should be assigned based on the share of each of the three wetland categories described above.

P_{bv} = score associated with watershed land cover:
- If the catchment area of X is more than 50% occupied by the themes "agricultural environment and/or anthropogenic environment" = 1
- If the catchment area of X is 30 to 50% occupied by the themes "agricultural and/or anthropogenic environment" = 0,6
- If the catchment area of X is less than 30% occupied by the themes "agricultural and/or anthropogenic environment" = 0,3

13.2.2.10. Contribution to carbon sequestration

Peatlands are ecosystems where the accumulation of organic matter prevails over its decomposition. The rate of accumulation is usually very low, but after several centuries or even millennia, this results in a thick organic deposit, making peatlands important carbon sinks. It is estimated that peatlands in the northern hemisphere store approximately one-third of all terrestrial carbon (Gorham, 1991).

Several phenomena affect carbon accumulation in peatlands. Sphagnum mosses, by their intrinsic properties, promote this process. These mosses contribute to raising the water table, sequestering nutrients and acidifying the environment. Their influence means that the accumulation of organic matter is generally faster in open bogs than it is in forested bogs, where sphagnum mosses are less abundant.

Marshes can also contribute to carbon build-up, although the process by which this build-up occurs is different. While the accumulation of organic matter is the result of the low rate of decomposition in peatlands, the accumulation of organic matter is the result of the strong growth of some common plant species in marshes. Finally, marshes can also contribute to carbon accumulation. Tree growth contributes to carbon sequestration in woody tissues. However, reaching climax and the onset of senescence will help reverse the process and release carbon. As a result, swamps are known to have the capacity to rapidly accumulate carbon, although this storage is not permanent.

The calculation of the carbon sequestration criterion is expressed as follows:

If X is an open bog (ombrotrophic or minetrophic) = 1
If X is a swamp or treed bog = 0,6
If X is a marsh = 0,3
If X is a pond = 0,6

Where the wetland is a "complex", the score should be assigned based on the share of each of the three wetland categories described above.

13.3. Old fields

13.3.1. Unit of analysis and data analysis

Approaches to old field conservation that provide quality attributes for wildlife are rare in Quebec. It is known that old fields that have a regular, non-elongated shape, cover large areas and are located outside power line corridors are more conducive to wildlife (Ribic et al., 2009) than linear old fields, which are less relevant to include in a prioritization exercise. Species associated with old fields are more abundant in the centre than at the edges of the plots; some species may be sensitive to habitat fragmentation (Knick and Rotenberry 1995; Schlossberg and King 2008). In order to identify old fields of conservation interest, a selection of "suitable" old fields was made *a* *priori* to exclude those with reduced potential for biodiversity conservation. Suitable old fields are those that meet the following criteria:

- Minimum area of more than 5 ha;
- Interior old field habitat with a percentage greater than 50% (25 m edge width).

Of all the old fields included in the land use mapping of the St. Lawrence Lowlands (n=133,323), 1,288 suitable old fields were selected for analysis (Figure 14). It should be noted that the only two old fields located in the context of 3FA_B02 (recent fluvial context of the Middle St. Lawrence Plain) as well as the two old fields located in the L'Isle-aux-Grues archipelago were attributed to the neighbouring land context (6D_B02, littoral context of the Middle St. Lawrence Plain).

The area of suitable old fields ranged from 5 to 228 ha, but only 15 of these old fields covered more than 100 ha. The average area of old fields was 17 ha. Table 13 illustrates descriptive statistics of the area of suitable old fields in each regional depositional context.

13.3.2. Prioritization of old fields

To complement the selection analysis that identified old fields of high conservation interest, a multi-criteria prioritization analysis was conducted to identify additional old fields needed to reach the 20% threshold of spatial representativeness in each depositional context. Primary and secondary criteria were selected and, as in the case of the forest fragment analysis, a conservation value was assigned to each old field by first calculating the raw and normalized value of each criterion at the scale of each regional depositional context. The normalized values of the main criteria were then summed and main priority classes were formed using the natural breaks method (four classes). The summation of the normalized values of the secondary criteria for each old field was then performed within each of these primary priority classes. The old fields were then ordered according to their conservation value, and sites were selected in decreasing order to reach the 20% threshold of representativeness. Two primary criteria and three secondary criteria were determined (Table 14).

Table 13. Descriptive statistics of adequate old fields in each regional depositional context

Depositional Context	Number	Area (ha)					
		Total	Average	Standard deviation	Quartile (1^{st} et 3^{rd})	Minimum	Maximum
1A_a_B01	133	1 818,4	13,7	12,3	7,0; 14,9	5,1	100,4
1A_a_B02	11	165,5	15,0	11,6	6,6; 18,6	5,6	45,4
1A_p_B01	118	2 753,9	23,3	28,2	8,2; 25,5	5,0	183,7
1A_p_B02	16	148,3	9,3	4,4	6,3; 11,3	5,0	22,4
3DB_B01	5	67,4	13,5	8,8	7,3; 19,1	5,9	26,2
3DB_B02	119	1 665,5	14,0	11,5	7,2; 15,7	5,1	87,1
3DB_B03	34	437,4	12,9	12,0	6,7; 12,9	5,0	63,3
3FA_B01	61	1 574,8	25,8	36,5	8,4; 27,9	5,1	227,6
3FB_B01	17	197,1	11,6	10,9	6,2; 12,3	5,1	50,1
3FB_B02	30	1 026,6	34,2	37,2	12,0; 48,4	5,2	147,5
3FB_B03	34	555,8	16,3	15,3	6,5; 17,6	5,2	65,5
3M_B01	51	843,3	16,5	11,3	8,8; 20,7	5,4	61,4
3M_B02	10	136,1	13,6	7,8	7,0; 20,3	6,2	26,0
5A_B01	178	3 920,6	22,0	25,7	7,9; 24,9	5,0	170,3
5A_B02	86	1 285,7	15,0	12,0	7,2; 16,9	5,1	65,1
5A_B03	85	1 344,7	15,8	13,9	7,2; 20,2	5,0	96,1
5S_B01	42	632,3	15,1	10,4	7,6; 19,6	5,2	50,4
5S_B02	130	1 601,5	12,3	7,3	6,9; 15,5	5,0	43,7
6D_B02	128	1 733,0	13,5	10,2	7,4; 15,4	5,0	78,9
Total	**1 288**	**21 908,0**	**17,0**	**19,2**	**7,3; 18,0**	**5,0**	**227,6**

Table 14. Primary and secondary criteria used to prioritize old fields in the St. Lawrence Lowlands

Primary prioritization criteria	Area
	Percentage of old field in the buffer zone
Secondary prioritization criteria	Shape
	Distance from wetlands/aquatic environments
	Distance from a power line corridor

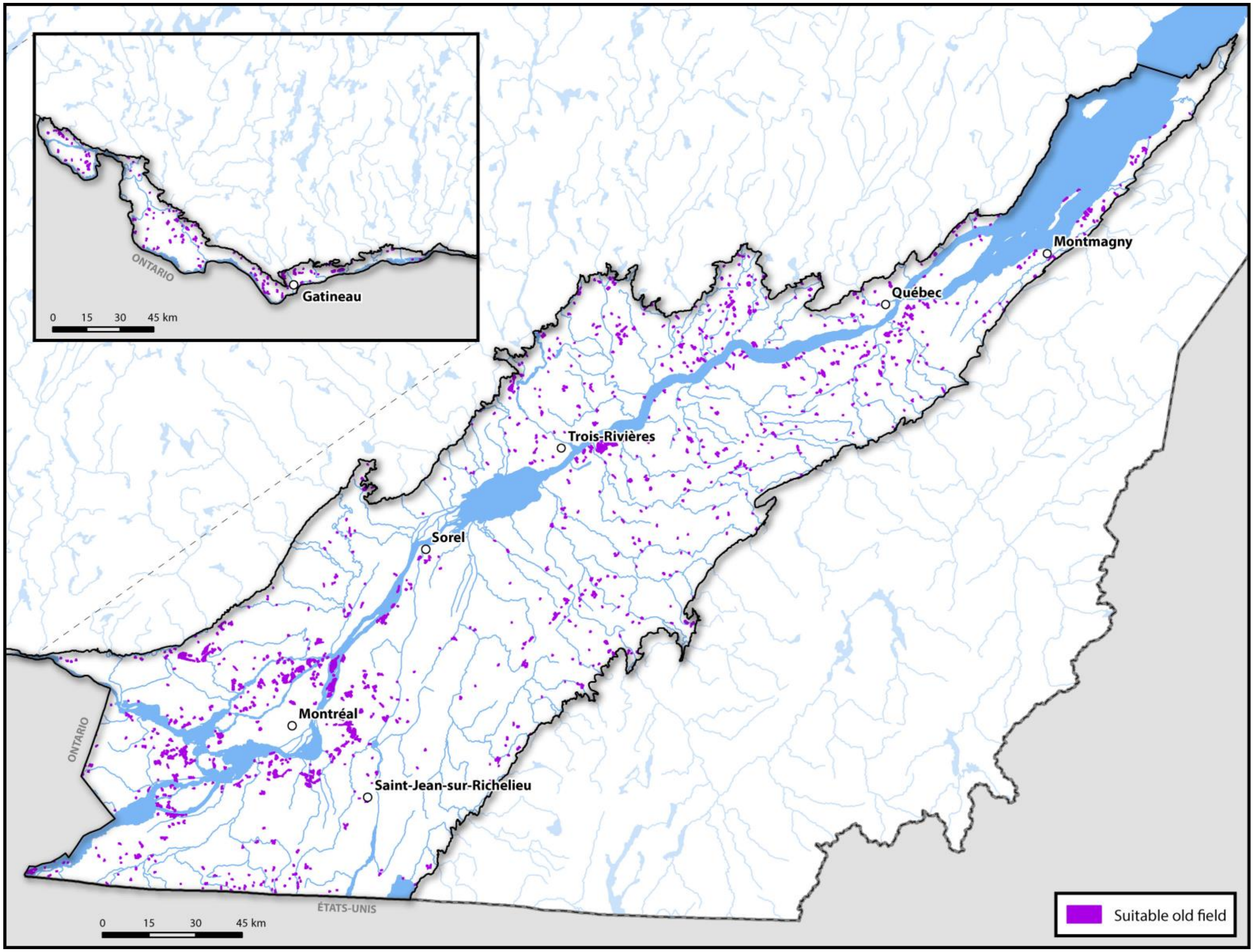


Figure 14. Location of the 1,288 suitable old fields in the St. Lawrence Lowlands

The selected prioritization criteria were compared with each other in each regional depositional context using Pearson correlation analyses to eliminate those that may be redundant ($r > 0.70$). The results showed that the selected criteria were not correlated with each other, allowing all of the criteria to be retained in subsequent analyses.

13.3.2.1. Area

As noted above, the surface area covered by old field directly affects the diversity of wildlife and plant species (The Northeast Upland Habitat Technical Committee 2006; Ribic et al., 2009). Old fields larger than 5 ha are more suitable for birds (Jobin et al., 2013), while old fields larger than 10 ha are more suitable for the golden-winged warbler (Dettmers, 2003).

13.3.2.2. Percentage of old field in the buffer zone

Old fields surrounded by open environments will provide better quality habitats for the wildlife associated with this type of habitat. Old fields that are large and located near other old fields or in various natural environments are home to more diverse wildlife and plant communities (Dettmers, 2003; Tefft, 2006; The Northeast Upland Habitat Technical Committee, 2006). Bird densities have been shown to be higher in old fields that have more than 10% of their land within 1 km (Lehnen 2008 in Environment Canada 2013a). A minimum of 10-20% open space on the periphery of old fields is desirable (The Northeast Upland Habitat Technical Committee, 2006). Conversely, old fields located in urban and suburban environments are often indicative of future development (Vouligny and Gariépy, 2008). The percentage of old fields found in a 1 km buffer zone surrounding suitable old fields was retained as a primary prioritization criterion.

13.3.2.3. Shape

A patch of regularly shaped habitat reduces the length of the edges and the potential negative effects associated with this landscape feature (Forman and Godron, 1986). In addition, regularly shaped, non-elongated old fields with reduced edge length with adjacent habitats are more conducive to wildlife than elongated old fields (Ribic et al., 2009; Jobin et al., 2013). The calculated shape index is the ratio of the ratio of the perimeter and area of the old field analyzed to the ratio of the perimeter and area of a circle of the same size (McGarigal and Marks, 1995).

$$PER = [(PERoldfield/AREAfoldfield) / (PERcircle/AREAcircle)]$$

Where:

PER = value of the shape index of the analysed old field
PERoldfield = perimeter (m) of the old field analysed
AREAoldfield = area (m^2) of old field analysed
PERcircle = perimeter (m) of a circle of an area equivalent to that of the old field analysed
AREAcircle = area (m^2) of a circle with a area equivalent to that of the old field analysed

In the case of a circular old field, this index has a value of 1; the further the shape of the analysed old field deviates from that of a perfect circle, the higher the value of this index.

13.3.2.4. Distance from wetlands and aquatic environments

Natural areas bordering wetlands, including old fields, create buffer zones that limit the impacts of wastewater runoff or agricultural discharges. In addition, old fields provide nesting habitat for many species of ducks that will then use adjacent wetlands and aquatic environments as duckling-rearing habitat (Gauthier and Aubry, 1996; Jobin et al., 2013). Old fields located near wetlands and aquatic environments will therefore have a higher conservation value. The criterion selected is measured as the linear distance of the wetland or aquatic environment closest to the old field under analysis.

13.3.2.5. Distance from a power line corridor

Old fields near power line corridors promote the movement and recruitment of species that use these habitats (The Northeast Upland Habitat Technical Committee 2006). In addition, the golden-winged warbler, a threatened species in Canada (Environment and Climate Change Canada, 2016), requires a mosaic of open and semi-open habitats to complete its breeding cycle, and power line corridors are heavily used by this species in the Montérégie region (Regroupement QuébecOiseaux, 2015). The criterion selected is measured as the linear distance of the power line corridors closest to the old field under analysis.

13.3.3. Old fields located in power line corridors

The spatial and temporal dynamics of the vegetation found in old fields located in power line corridors mean that their maintenance on the landscape requires management actions to maintain them in an open habitat state (DeGraaf and Yamasaki, 2003; Tefft, 2006; Schlossberg and King, 2015). Old fields located in power line corridors will therefore not be the subject of a prioritization exercise as such. Rather, we will aim to develop management methods that allow the needs of species associated with old fields to be taken into account, if possible, in vegetation management plans for power line corridors. For example, the Regroupement QuébecOiseaux and Hydro-Québec (through its subsidiary TransÉnergie) have initiated discussions to this effect in order to consider the needs of the golden-winged warbler in the Montérégie region (Regroupement QuébecOiseaux, 2015).

For the purposes of the Atlas, old fields located in power line corridors were mapped by coupling information extracted from land use mapping of the St. Lawrence Lowlands with geospatial information associated with transmission lines from Hydro-Québec.

The width of the power line corridors selected was modulated according to the voltage of the electric current associated with the lines (Hydro-Québec TransÉnergie, 2013).

49 kV monotern line: 20 m
120 kV tanker line: 30 m
315 kV tanker line: 43 m
735 kV monotern line: 80 m

Figure 15 shows an example of old fields in the power line corridors mapped and Figure 16 illustrates the spatial distribution of old fields in power line corridors in the St. Lawrence Lowlands.

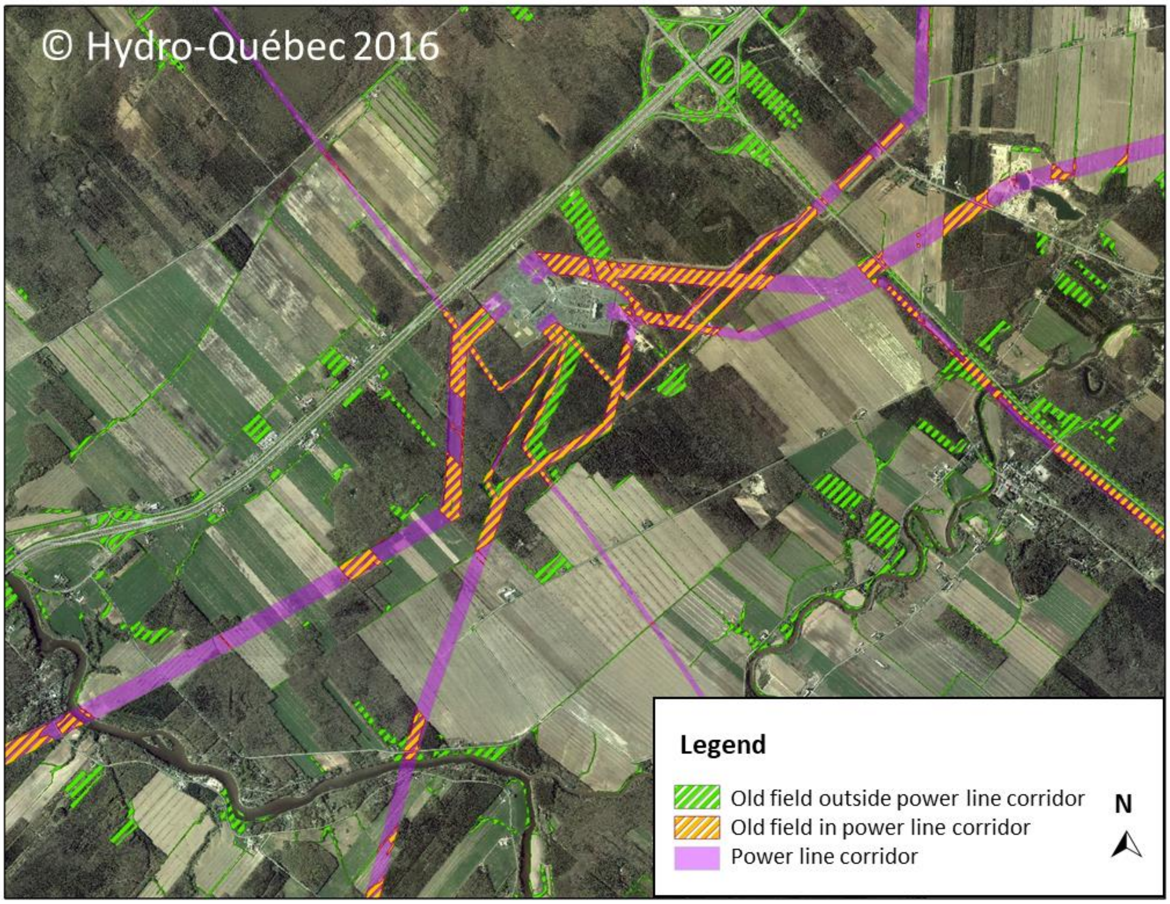


Figure 15. Example illustrating old fields located in power line corridors

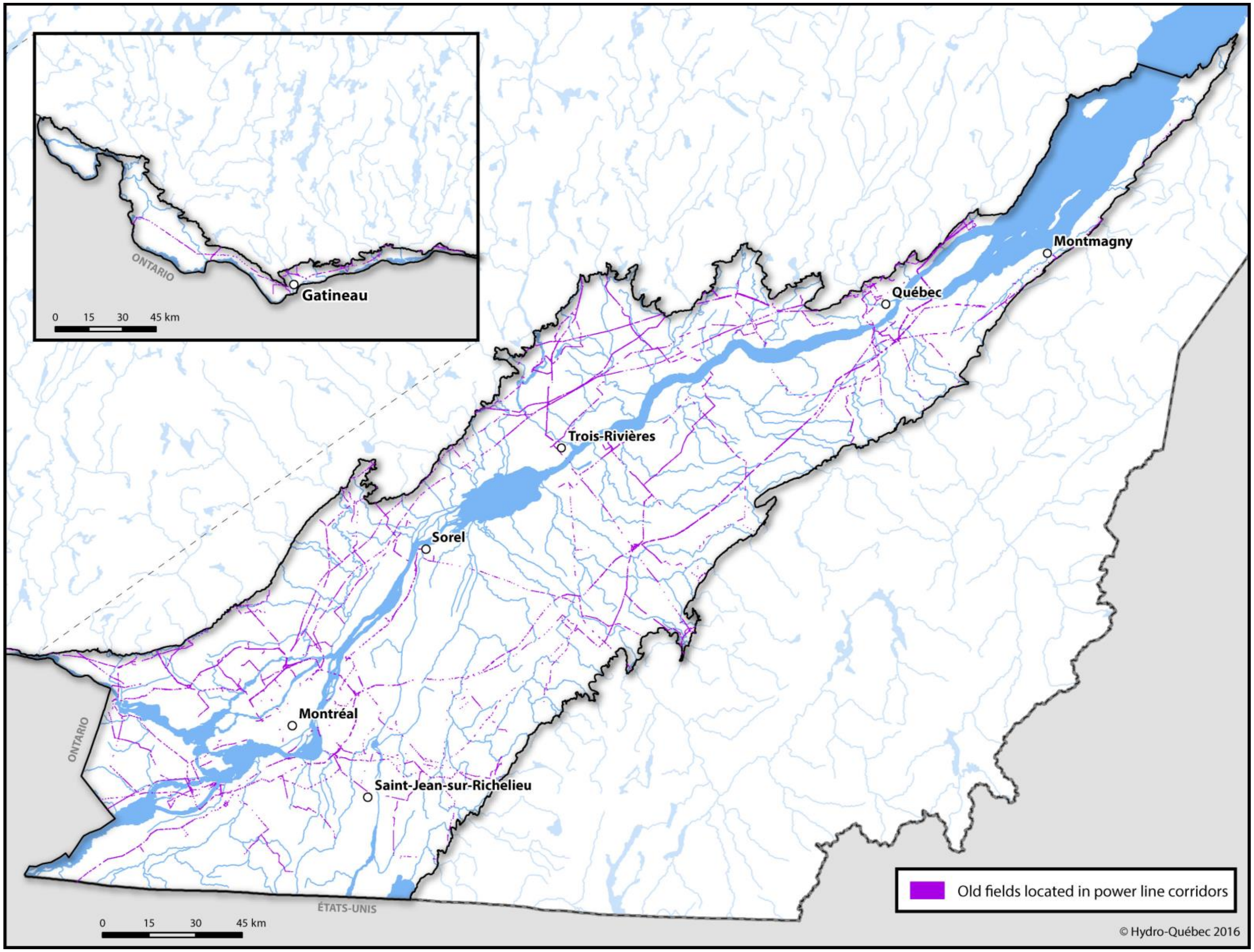


Figure 16. Location of old fields in power line corridors in the St. Lawrence Lowlands

13.4. Agricultural grasslands

13.4.1. Unit of analysis and data analysis

Conservation efforts to maintain an agricultural matrix conducive to wildlife, particularly grassland birds, require identifying areas where habitat availability is favourable and where habitat conservation and restoration actions will be most beneficial (Morgan and Burger, 2008). In order to determine the sectors that will allow the objectives mentioned to be achieved, an analysis of land use and agriculture in the St. Lawrence Lowlands was conducted. The characterization of the culyivated area was based on data from the Financière agricole du Québec (FAQ) (2014) combined with agricultural classes from Agriculture and Agri-Food Canada (AAFC) (2014). The spatial boundaries of the polygons were taken from the FAQ and the land use class was taken primarily from the attributes in the FAQ files. In cases where the land cover class was not defined in the FAQ data, this information was extracted from the AAFC file.

The detailed classes of crop types have been grouped into general classes:

- Annual crops (corn, soybeans, cereals, vegetables, etc.);
- Perennial crops (forage, pasture);
- Specialty crops (orchards, vineyards, berries, etc.);
- Crop not defined.

Before proceeding with the analyses, it was necessary to determine the fragmentation agents of perennial crops (forage and pasture) since plots of perennial crops that are disjointed in the original data file should in fact be merged, as this distinction is not justified from an ecological point of view, at least for grassland birds. This merging of plots that are close to each other makes it possible to calculate more realistically, for example, the average plot size in a given area.

The following parameters were used to determine the perennial crop plots to be merged:

1) Plots less than 50 m apart;
2) Parcels separated by non-binding landscape features primarily open areas, i.e., old fields, annual crops, open wetlands, open water and local and national roads with less than 50 m of power line corridors.

The width of the road corridor, set at 50 m, is the same as that used to determine forest fragmentation agents for forest birds in the Lake Saint-Pierre area (Jobin et al., 2013). This distance is based on the width of corridors in Quebec; only highway corridors (e.g., Highway 40) with a width greater than 50 m (approximately 65 to 90 m) were selected as fragmentation agents. National (e.g., Route 138 and Route 132) and regional (e.g., Route 226 and Route 349) highways, paved or unpaved, with average widths of less than 35 m were not retained as fragmentation agents. This is consistent with observations by Forman et al. (2002) who studied the response of five species of grassland birds (bobolink, eastern meadowlark, upland sandpiper, grasshopper sparrow, Henslow's sparrow [*Ammodramus henslowii*]) to the proximity of roads with variable traffic flows. They then noted that only roads with high daily vehicle flows (more than 15,000 vehicles per day) had a significant impact on the distribution of these species, this flow is only observed on highways in Quebec (see the Ministère des Transports du Québec website at transports.atlas.gouv.qc.ca/Infrastructures/InfrastructuresRoutier.asp). For example, plots of perennial crops separated by a 40 m wide strip of forest will not be merged, as forests are a fragmentation agent of the landscape for grassland birds.

The identification of areas in the St. Lawrence Lowlands that offer an agricultural matrix favourable to biodiversity, and particularly to grassland birds, was based on a multi-criteria analysis. The unit of analysis selected was the topographic complex, i.e., level 5 of the Quebec Ecological Reference Framework (Figure 17).

The St. Lawrence Lowlands are divided into 665 topographic complexes. Of these, 22 have no agricultural parcels (e.g., urban areas), so that 643 topographic complexes were included in the analyses: 325 topographic complexes in natural region B01 (Upper St. Lawrence Plain), including the three topographic complexes in the Covey Hill N01 area, 287 topographic complexes in natural region B02 (Middle St. Lawrence Plain), including the entire X01 area of the Isle-aux-Grues archipelago, and 31 topographic complexes in natural region B03 (Ottawa Plain).

The area of the topographic complexes ranges from 2,3 to 660 km^2, but only 64 of these complexes cover more than 100 km^2. The average area of the topographic complexes is 47 km^2, with those in B03 being the largest (68 km^2), followed by those in B01 (52 km^2) and those in B02 (39 km^2). Table 15 shows descriptive statistics for the area of topographic complexes in the natural regions.

Table 15. Descriptive statistics of the area of topographic complexes in the St. Lawrence Lowlands Natural Regions.

Natural region	Number	Area (km^2)					
		Total	Average	Standard Deviation	Quartile (1st et 3rd)	Minimum	Maximum
Upper St. Lawrence plain (B01)	325	16 754	51,6	49,1	18,7; 68,7	2,3	310,0
Middle St. Lawrence plain (B02)	287	11 057	38,5	45,3	16,1; 51,0	3,5	660,0
Ottawa plain (B03)	31	2 112	68,1	38,3	42,7; 80,6	18,4	197,0
Total	**643**	**29 923**	**46,5**	**47,6**	**18,3; 60,8**	**2,3**	**660,0**

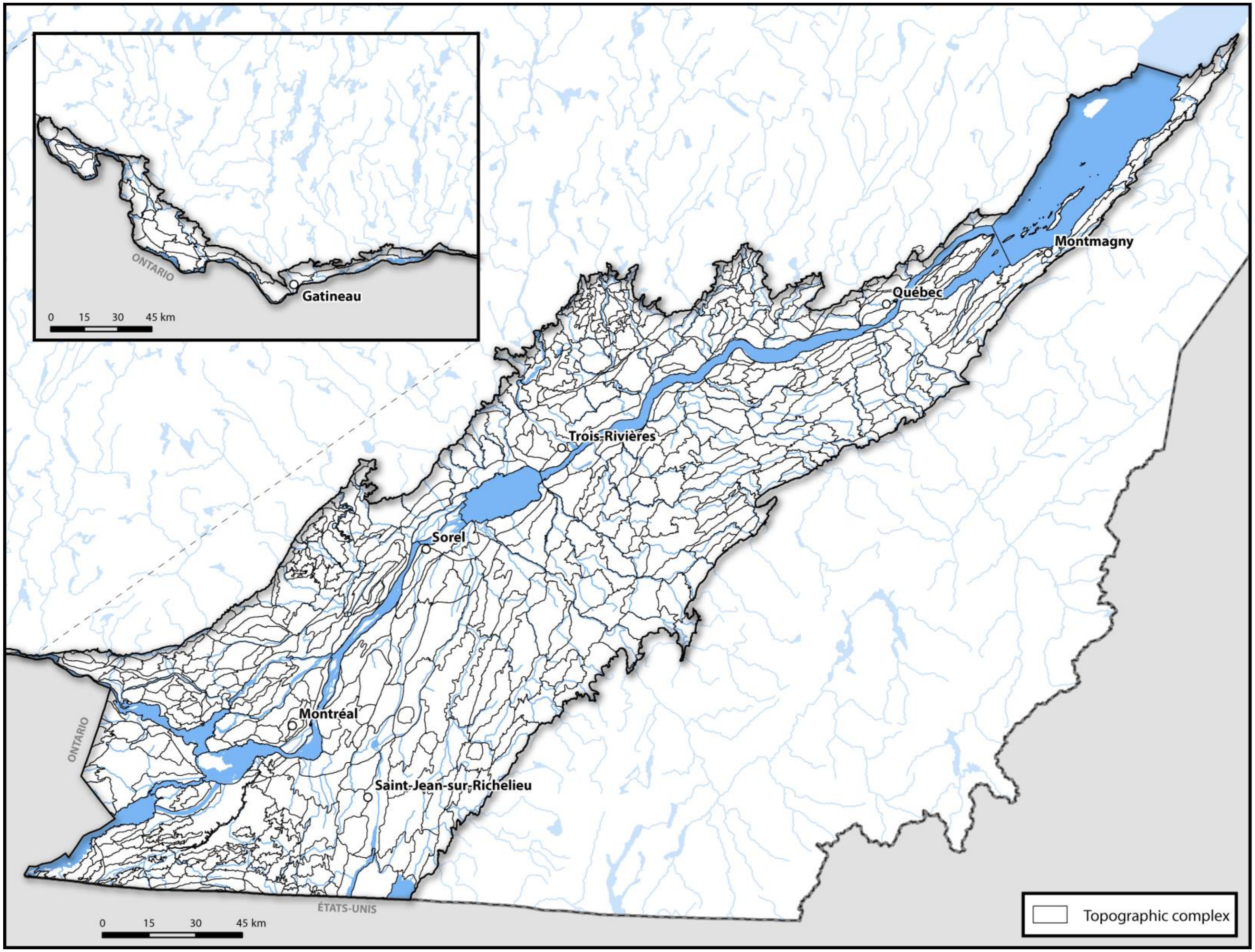


Figure 17. Topographic complexes in the St. Lawrence Lowlands (n=665)

13.4.2. Prioritization of agricultural grasslands within topographic complexes

The prioritization analyses were done separately for each natural region of the St. Lawrence Lowlands. A multi-criteria prioritization analysis was produced to determine the topographic complexes that meet the 20% spatial representativeness threshold in each natural region. Primary and secondary criteria were selected and a conservation value was assigned to each complex by first calculating the raw and normalized value of each criterion at the scale of each natural region. The normalized values of the primary criteria were then summed and primary priority classes were formed using the natural breaks method (four classes). The summation of the normalized values of the secondary criteria in each complex was then performed within each of these primary priority classes. The complexes were then ordered according to their conservation value and those that met the 20% threshold of representativeness were selected in decreasing order.

The prioritization criteria selected are primarily aimed at maintaining a favourable agricultural matrix for grassland birds, since many of these species are showing a marked decline in populations throughout North America. Some of these species, such as the bobolink, the eastern meadowlark and the barn swallow (*Hirundo rustica*), have been designated species at risk in Canada (COSEWIC, 2015). The prioritization criteria are designed to identify areas where (1) agriculture is well established, (2) perennial crops are abundant, and (3) wetlands are present in the agricultural landscape. Four primary criteria and three secondary criteria were selected (Table 16), several of which are based on indicators developed at the farm level in European farming systems (Herzog et al., 2012).

Table 16. Primary and secondary criteria used to prioritize topographic complexes in the St. Lawrence Lowlands

Primary prioritization criteria	Percentage of agricultural environments in each topographic complex
	Relative importance of perennial crops in the topographic complex
	Percentage of perennial crops in the periphery (buffer zone of 1 km)
	Average area of perennial crop plots in the topographic complex
Secondary prioritization criteria	Number of perennial crop plots larger than 100 ha
	Distance of each perennial crop plot to a wetland
	Percentage of wetlands at the periphery (200 m buffer zone)

The selected prioritization criteria were compared to each other separately for each natural region using Pearson correlation analyses to eliminate those that may be redundant ($r > 0.70$). The results showed that the selected criteria were not correlated with each other except for a few pairs of criteria in the Outaouais region for which the coefficient value was between 0.70 and 0.80. All criteria were nevertheless retained in subsequent analyses.

13.4.2.1. Percentage of agricultural environments in each topographic complex

The total area of agricultural environments makes it possible to determine the topographic complexes where agriculture is well present and, at the same time, to consider as a priority the complexes dominated by an agricultural matrix. This criterion is calculated as follows:

$$\text{\% of agricultural cover} = \frac{\text{Area (ha) annual crops} + \text{Area (ha) perennial crops}}{\text{Area (ha) of topographic complex}}$$

13.4.2.2. Relative importance of perennial crops in the topographic complex

Agricultural landscapes dominated by perennial crops are more favourable to grassland birds (Tews, 2008). In addition, annual crops are notoriously unfavourable to grassland species (Jobin et al., 2007; Latendresse et al., 2008b). This criterion is calculated as follows:

$$\text{Relative importance of perennial crops} = \frac{\text{Area (ha) perennial crops}}{\text{Area (ha) annual crops}}$$

13.4.2.3. Percentage of perennial crops in the periphery (buffer zone of 1 km)

An agricultural matrix dominated by perennial crops is favourable to grassland birds. Conversely, fields surrounded by forests are less favourable to grassland birds (Shustack et al., 2010; Environment Canada 2013a; Jobin et al., 2013). The percentage of perennial crops within 1 km of each perennial crop plot was first calculated and averaged as a criterion for prioritizing topographic complexes.

13.4.2.4. Average area of perennial crops in the topographic complex

Grassland birds are sensitive to the size of nesting habitat patches and many of these species require perennial crop patches larger than 50 ha (McPherson et al., 2009; Environment Canada 2013a; Jobin et al., 2013). Therefore, the average area of perennial crop plots was calculated for each topographic complex.

13.4.2.5. Number of perennial crop plots of more than 100 ha

Perennial crop plots of 100 ha favour the presence of the majority of grassalnd bird species that are sensitive to the size of their nesting habitat, while plots larger than 200 ha favour the maintenance of breeding populations of the majority of these species (Environment Canada, 2013a). The number of perennial crop plots larger than 100 ha was therefore calculated for each topographic complex.

13.4.2.6. Distance of each perennial crop plot to a wetland

Many wildlife species require complementary habitats to complete their life cycle. This is the case, for example, for many species of amphibians and reptiles (Daigle and Jutras, 2005; Saumure et al., 2007; Environment Canada, 2013a) and ducks (Masse and Raymond, 1988; Gauthier and Aubry, 1996) that use wetlands as well as adjacent herbaceous environments to breed or raise their young (Environment Canada, 2013a; Jobin et al., 2013). For example, Masse and Raymond (1988) showed that, in the Haut-Richelieu region, all of the nests of blue-winged teals (*Anas discors*) and half of the nests of mallards (*Anas platyrhynchos*) were located within 100 m of a wetland; A similar study in Ontario also showed that 90% of waterfowl nests were within 200 m of a wetland (Henshaw and Leadbeater 1998 in Environment Canada 2013a). In addition, perennial crops located on the periphery of wetlands create buffer zones that reduce sediment runoff and agricultural discharges (pesticides, fertilizers) into these ecosystems. For this prioritization criterion, the minimum distance between each perennial crop plot and the nearest wetland was measured and averaged for each topographic complex.

13.4.2.7. Percentage of wetlands at the periphery (200 m buffer zone)

Just as the proximity of wetlands to a perennial crop is favourable for many wildlife species (see previous criterion), the presence of many wetlands in the landscape surrounding cultivated areas will accentuate these benefits for wildlife (Environment Canada, 2013a). The proportion of wetland area was first calculated within a 200 m buffer zone surrounding each perennial crop plot and then averaged for each topographic complex.

13.5. Aquatic environments

Warning: The mapping and analysis of aquatic environments does not cover all of the St. Lawrence Lowlands due to the lack of LIDAR data for certain sectors. LIDAR data provide a higher level of accuracy for calculating local slope and channel width as well as specific power, an important interpretive variable of the hydro-sedimentary dynamics of a river. The results for the missing sectors will be released at a later date, as soon as the LIDAR data become available.

To promote biodiversity maintenance in the St. Lawrence Lowlands and preserve a diversity of representative aquatic environments providing functional habitats for species, aquatic environments must be treated as “aquatic biotopes”. An aquatic biotope can be defined as a geographic environment whose physical characteristics provide the conditions essential for life and for the development of species that inhabit water. A biotope forms as a result of conditions that vary in space and time, along gradients, for example, from the headwaters (source) of a stream to its mouth. To recognize the diversity of aquatic habitats in a given region, it is important to be able to map, describe and classify them taking into account factors that govern their functioning.

13.5.1. Unit of analysis and data analysis

Mapping of aquatic habitats in the St. Lawrence Lowlands is based on aquatic biotypes—aquatic ecological units corresponding to portions of the surface hydrographic network which present a certain degree of homogeneity in their physical characteristics. The structure, functions and organization of living aquatic communities are largely determined by the structure and processes that shape the biotope (Frissel et al., 1986). Spatialization of the aquatic biotope also makes it possible to reveal the hydromorphological homogeneity of portions of the hydrographic network and to facilitate the integration of knowledge on aquatic ecosystems. The proposed mapping is based on the work of Frissell et al. (1986), who used an ecosystem approach for the spatialization of aquatic ecosystems, like that advocated by the CERQ. Mapping of the AEUs is briefly described in this report. The detailed methodology will be provided in the report on aquatic environments (Blais et al., in preparation). For this Atlas, the AEUs that have been considered are mainly lotic environments, i.e. rivers and streams.

13.5.2. Delineation and description

The delineation of AEUs is closely linked to changes in hydromorphological processes that shape aquatic biotopes, more specifically lotic biotypes. The variables that can be used to distinguish AEUs consist mainly of the flow environment (lentic, wetland, lotic, estuarine), substrate (rocky, clayey, semi-alluvial, alluvial), alluvial landforms (delta, fan, alluvial plain) and different river channel patterns (linear, straightened, pool/riffle, meanders, wandering, etc.). These different variables have been used to delineate and describe the AEUs and will be used later in the typology of the aquatic biotopes.

Several variables are compiled for AEUs in a systematic manner, such as elevation, Strahler stream order, stream power at peak flows, sediment deposition, alkalinity (modelled), mean annual temperature (modelled) and dissolved organic carbon concentration (modelled). Local variables such as the width of the watercourse and the flow gradient are also calculated using LiDAR data on reference points located 100 m apart, extracted from the structured hydrographic network. Finally, variables related to the watershed are compiled for each reference point, including the drainage ratio, average area and average slope of the watershed, and the proportions of geological classes.

13.5.2.1. Mapping

The main source of mapping information for the AEUs is the 1:20,000 maps of the linear surface hydrographic network extracted from the Géobase du réseau hydrographique du Québec (GRHQ). AEUs with a watershed larger than or equal to 50 km^2 were delineated by photo-interpretation of orthophotos, Google Earth images and LiDAR-derived digital elevation models. In order to identify small permanent watercourses, the AEUs with a watershed smaller than 50 km^2 and greater than or equal to 5 km^2 were delineated automatically using an algorithm that detects slope breaks. Intermittent watercourses were therefore not included in the mapping and analysis of aquatic environments in the St. Lawrence Lowlands. Depending on the region to be covered, linear mapping is advocated for the mapping and analysis of the AEUs. A two-dimensional (2D) delineation could be carried out as part of the implementation strategies for aquatic environments of conservation interest.

13.5.2.2. Region covered

For the portion of the St. Lawrence Lowlands located south of the St. Lawrence, a total of 3,414 aquatic ecological units were mapped, specifically 1,348 were photos-interpreted and 2,066 automatically delineated (Figure 18 and Table 17), covering a total stream length of 8,572 km. The average length of the photo-interpreted AEUs is 2,87 km compared with 2,28 km for automatically delineated units. Rectified streams are generally maintained mechanically. Since they are heavily altered, we felt it was more appropriate not to consider them as part of a stream typology based on natural features.

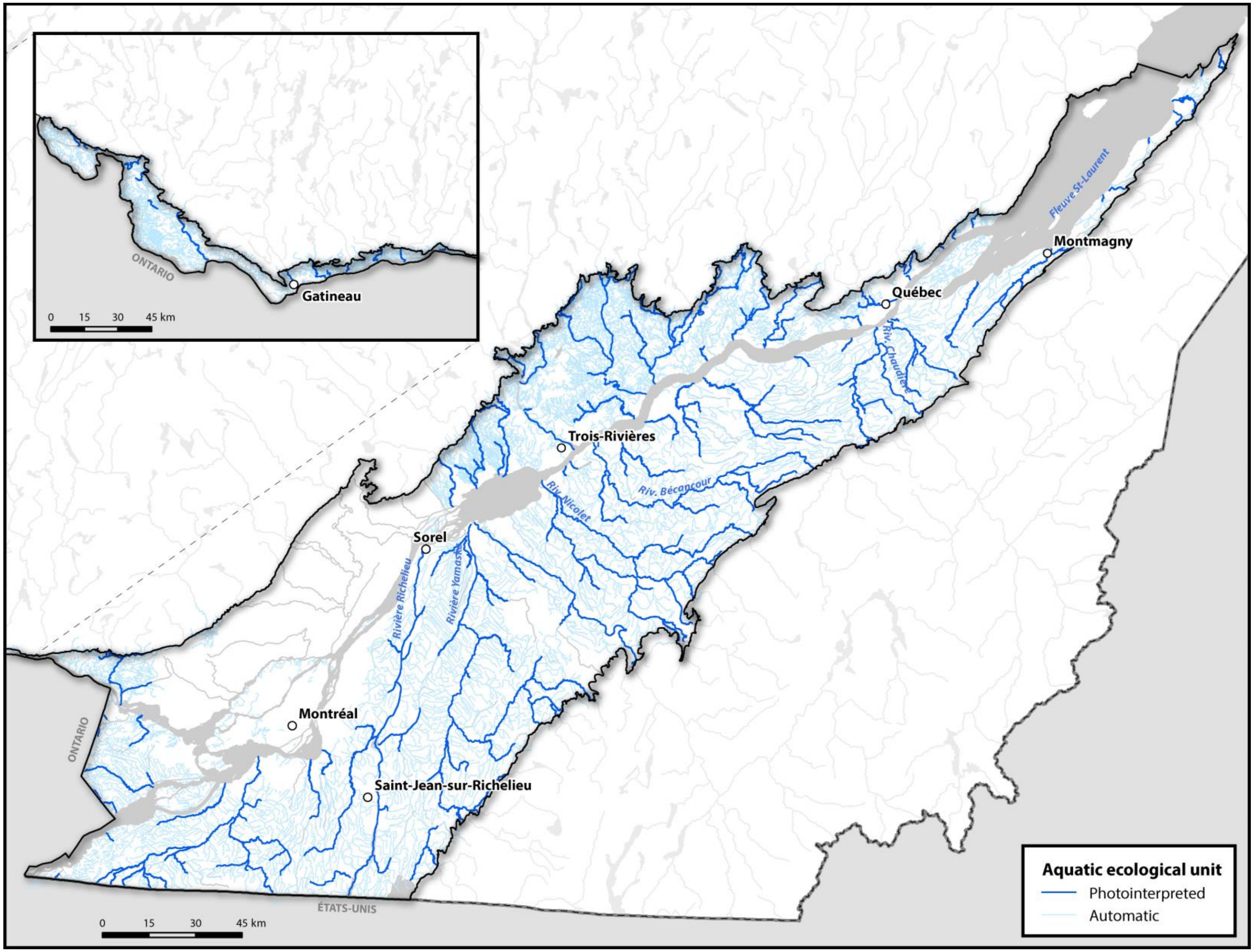


Figure 18. Aquatic ecological units of the St. Lawrence Lowlands

Table 17. Aquatic ecological units of the St. Lawrence Lowlands

Aquatic ecological units		Length (km)				
Method	**Number**	**Total**	**Average**	**Standard deviation**	**Minimum**	**Maximum**
Photo-interpretation	1 348	3 863,22,00	2,87	3,09	0,06	29,90
Automatic	2 066	4 708,62,00	2,28	2,27	0,01	21,29
Total	**3 414**	**8 572,00**				

The mapping of AEUs has been integrated with the Quebec hydrological reference framework (Cadre de référence hydrologique du Québec [CRHQ]), a tool produced by MELCC which contains structured information and knowledge on aquatic ecosystems in Quebec. AEUs are therefore the unit of analysis for aquatic biotopes and are used to compile spatial data in an ecologically consistent manner.

13.5.3. Typology and classification

One of the conservation objectives of the Atlas is to capture the diversity of all the aquatic biotopes in the St. Lawrence Lowlands using a biodiversity representativeness objective of 20%. The typology of aquatic biotopes makes it possible to classify watercourses that share common characteristics. It is assumed that these similarities reflect a specific functioning for each type of biotope and that specific associations can be observed between living species and these types of biotypes. The diversity of biotopes is therefore used as a proxy measure of biodiversity at the scale of the St. Lawrence Lowlands.

The typology must also make it possible to evaluate the different key factors in the functioning of aquatic biotopes. For watercourses, five groups of functional factors in ecosystems are normally recognized: factors related to hydrology, hydraulics, hydromorphology, physicochemistry and biology (Harman et al., 2012). Factors related to biota are not considered since they are greatly influenced by human activities. They will be used later on to interpret the typology results and determine whether the classes represent the spatial variability of the biotic components.

13.5.4. Variables considered

Since biotope characteristics are defined in a multifactorial manner, the variables underpinning this typology have been selected to represent each of the four groups of factors. The variables are size, specific stream power, streambed substrate, alluvial form, river channel pattern, alkalinity, dissolved organic carbon and temperature (Table 18). Several of these variables were also used in the stream classification for the Northern Appalachian-Acadian ecoregion carried out by the Nature Conservancy of Canada (Millar and Olivero-Sheldon, 2017). The detailed methods for calculating the variables will be explained in the methodology report for aquatic environments (Blais et al., in preparation) and are briefly outlined here.

Table 18. Variables considered for the typology of aquatic biotopes

Factors	Variables	Substitute	Method
Hydrology	Size	Watershed size	Spatial analysis
Hydraulic factor	Specific stream power	F, S, W (flow, slope, width)	Equation
Hydromorphology	Streambed substrate	Streambed substrate	Photo-interpretation
	Alluvial form	Alluvial form	Photo-interpretation
	River channel pattern	River channel pattern	Photo-interpretation
Physicochemistry	Alkalinity	Geology, annual crops, clay deposit	Empirical modelling
	Dissolved organic carbon	Organic deposit, slope, wetland, drainage ratio	Empirical modelling
	Temperature	Annual average temperature	Empirical modelling

13.5.4.1. Hydrological factors

Size

The diversity of aquatic species present in a watercourse changes spatially along the hydrographic network (Vannote et al., 1980). According to the river continuum concept (RCC) described by Vannote et al. (1980), changes in the structure and functions of biotic communities can be observed in space and time, which are analogous to the changes in physical habitat that are observed along environmental gradients. As a result, it is possible to detect changes in the structure of biotic communities from headwaters to the river mouth. Watershed size is therefore a relevant indicator for assessing the diversity of aquatic biotopes at the scale of a region. In a study aimed at exploring the links between stream size and biological diversity at the local scale, Vander Vorste et al. (2017) found a significant positive relationship between the diversity of fish and benthic species and stream size. Although the slope of this relationship was highly significant, the amount of variance explained was low. This suggests that other factors play a more important role than size in explaining biodiversity at the local scale, but size is nonetheless a critical indicator. Watershed area in km^2 is one of the measures of stream size considered.

13.5.4.2. Hydraulic factors

Specific stream power at peak flows

There is a direct link between sediment transport and specific stream power, which is the average power available to the water column under peak flow conditions per unit of stream channel width (Bagnold, 1966). This variable can be used to interpret the hydrological and sedimentary dynamics of a watercourse, which is a fundamental aspect of biotopes. Specific stream power is calculated using the following equation:

$$\omega = (g\ \rho\ Q\ S) / w \quad (W/m^2)$$

Variable	Description	Value	Unit
p	Water density	1,000	kg/m^3
g	Gravitational acceleration	9.81	ms^{-2}
Q	Morphogenetic flow (bankfull discharge)	Variable	m^3s^{-1}
w	Stream width at bankfull discharge	Variable	m
s	Slope (m/m)	Variable	Na

The stream width values were modelled, and the flow values were obtained by matching reference stations in the water levels and flow monitoring network with each reference point in the hydrographic network based on similarities in certain variables (average basin gradient, percent deposition, water, etc.). This method was developed prior to the advent of data from Quebec's hydro-climatic atlas (Atlas hydroclimatique du Québec) produced by the government's water expertise branch. Flows derived from the hydro-climatic atlas will be used in the next version of the Atlas.

13.5.4.3. Hydromorphological factors

It is generally recognized that the hydromorphology of streams determines the structures and functions of aquatic biotopes (Schmitt et al., 2011; Amoros and Petts, 1993; Florsheim et al., 2008; Choné and Biron, 2016). Although the characteristics of hydromorphological factors are interrelated, they each contribute in their own way to determining the biotope. River channel pattern reflects the processes governing the hydrological and sedimentary equilibrium of watercourses. The streambed substrate has a strong influence on the spatial distribution of a number of benthic species (Rabeni and Minshall, 1977). Certain alluvial landforms, such as deltas and alluvial fans, play a key role in shaping biotopes.

13.5.4.4. Physicochemical factors

Alkalinity

The alkalinity of water plays a major role in an aquatic environment's capacity to neutralize acids. It also protects aquatic biotypes by buffering inputs of acidity that are likely to cause changes in the pH level. Alkalinity also has a significant influence on the distribution of a number of living species (Hellquist, 1980). A positive relationship has been found between alkalinity and the productivity of certain organisms (Koetsier et al., 1996). For example, the productivity of invertebrates is generally higher in streams with high levels of alkalinity (Osborn, 1981). Alkalinity was determined through empirical modelling of the median value for the growing season (i.e. 8 months, March to October).

Dissolved organic carbon

Dissolved organic carbon (DOC) influences biogeochemical processes, the tropic structure, productivity and carbon balance of aquatic ecosystems (Wetzel, 2001). When high concentrations of DOC are present, they reduce the clarity of the water and can affect the feeding strategies of some species. DOC also plays a major role in the thermal regime of lakes and certain watercourses by limiting the penetration of solar radiation. It can reduce the toxicity of certain contaminants by promoting their adsorption onto charged DOC molecules (Despault, 2016). It can also play a role in the buffering capacity of water. DOC concentration was obtained through empirical modelling of the median value for the growing season (i.e. 8 months, March to October).

Temperature

Temperature influences almost all components of aquatic ecosystems. For example, since fish are ectothermic, their metabolic rate is controlled by the temperature of the water. This temperature controls the rate at which biochemical processes occur, from larval emergence to the basal metabolism of adults. Most species have habitat preferences that include temperature, making temperature one of the fundamental determinants of biotopes and of the spatio-temporal distribution of species. Temperature was obtained using a regression model developed to estimate this variable in a systematic manner across the hydrographic network based on maximum temperature data from a 30-day rolling average of maximum daily temperatures.

13.5.5. Classification method

To determine the types of aquatic biotopes, a hierarchical classification method was used to establish groups, that is, groups of AEUs with similar characteristics depending on the variables considered (stream size, specific stream power, streambed substrate, alluvial landform, river channel pattern, alkalinity, dissolved organic carbon and temperature). Although the method used is based on an ascending hierarchy, there is no intrinsic hierarchy in the variables used. Such a structrure makes it possible to map the result based on the characteristics of individual AEUs or those of AEUs typical of the group (i.e. exemplars) that will be used to describe each type of aquatic biotope. The different classes obtained are interpreted by using boundaries or thresholds for each variable that can be used to assess the distribution of variables in each group. Data related to biotic components (benthos, for example) are used *a posteriori* in a canonical redundancy analysis to check whether the classes, or the different types of aquatic habitats, represent the spatial variability of the communities that are present (benthic communities, for example).

13.5.6. Typology of AEUs

For the St. Lawrence Lowlands, the typology of aquatic biotopes resulting from this classification comprises 48 distinct classes (figures 19a and b; Table 19). General statistics show that certain types of aquatic biotopes are more common, and others more scarce. For example, type 18 is a common aquatic biotope in the St. Lawrence Lowlands. It corresponds to a small, meandering stream with moderate and fairly constant specific stream power during peak flows. This type of stream has a very high alkalinity level, a moderate DOC concentration and a moderate to high temperature. In contrast, type 22 is a rare aquatic biotope in the same region and corresponds to a large braided stream flowing over an alluvial substrate originating from old deltas, which has a very low and unchanging specific stream power during peak flows. This type of stream is characterized by moderate to high alkalinity and DOC along with a very high water temperature in the summer.

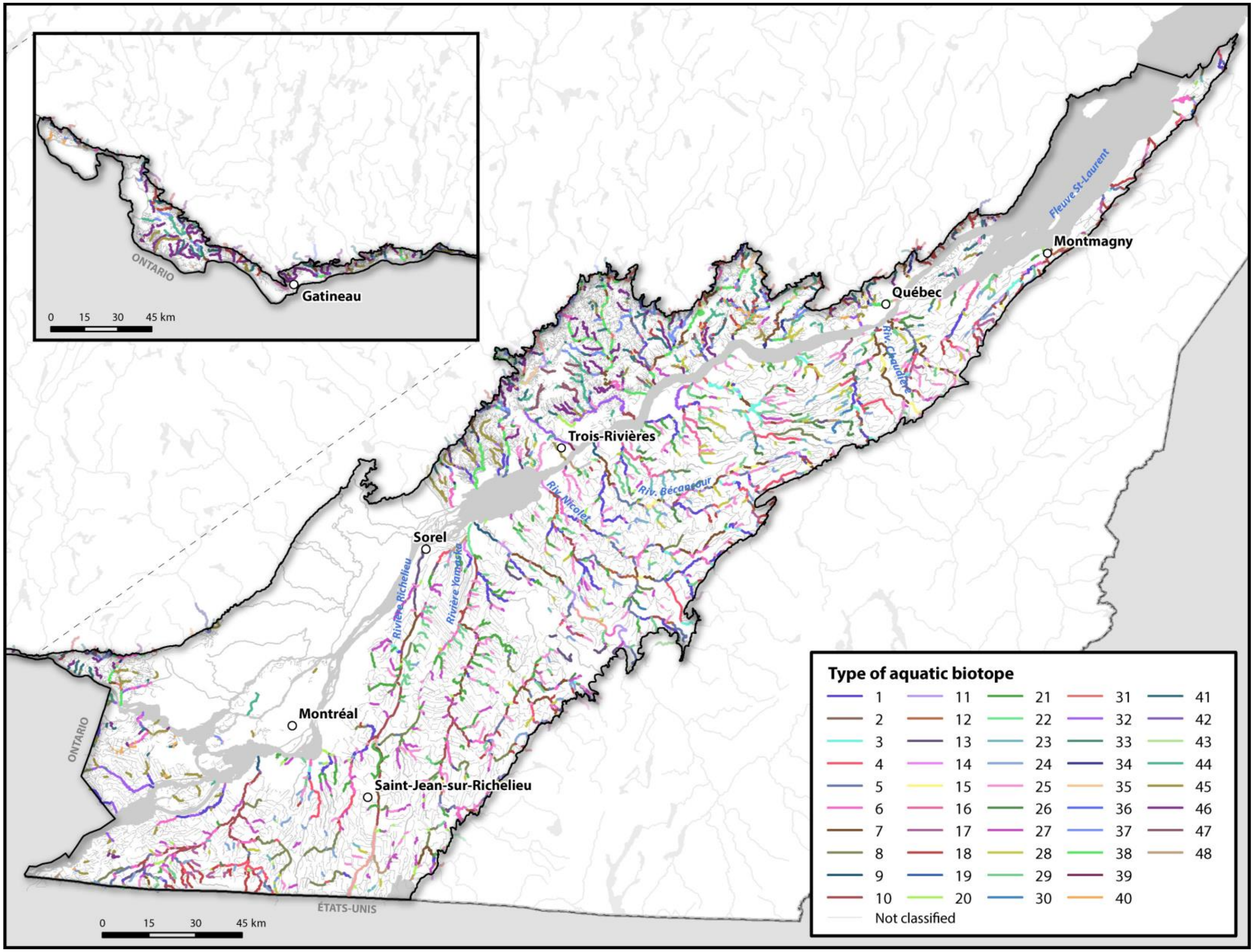


Figure 19a. Typology of aquatic biotopes in the St. Lawrence Lowlands

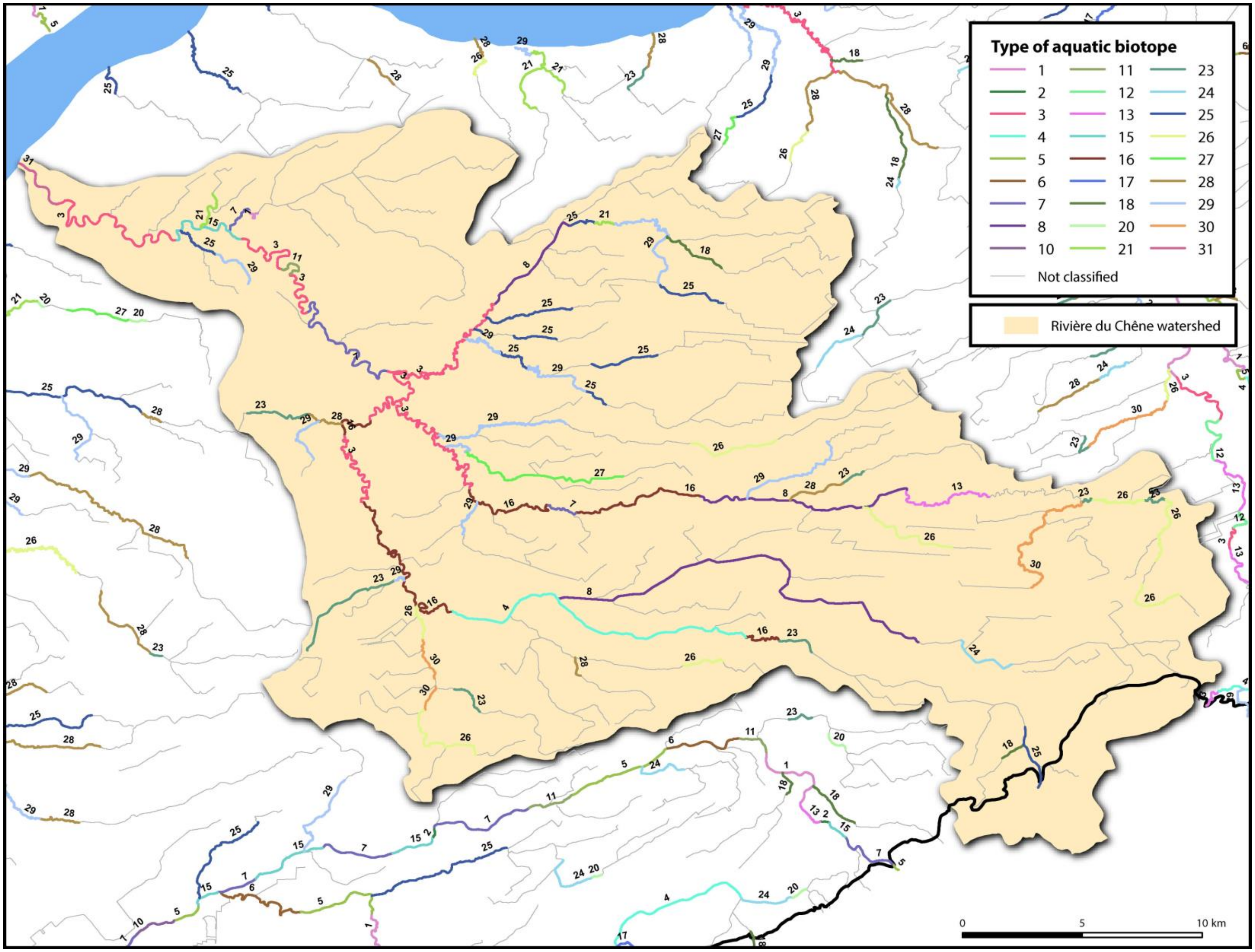


Figure 19b. Excerpt from the typology of aquatic biotopes for the Rivière du Chêne watershed sector

Table 19. General statistics for the typology of aquatic biotopes in the St. Lawrence Lowlands

Aquatic type	Aquatic ecological units		Length	
	Number	%	Km	%
1	153	4,5	537,5	6,3
2	13	0,4	7,6	0,1
3	39	1,1	132,5	1,5
4	51	1,5	204,9	2,4
5	145	4,2	328,8	3,8
6	93	2,7	349,8	4,1
7	160	4,7	407,3	4,8
8	53	1,6	250,5	2,9
9	6	0,2	23,7	0,3
10	52	1,5	264,7	3,1
11	32	0,9	75,5	0,9
12	24	0,7	76,3	0,9
13	41	1,2	123,2	1,4
14	5	0,1	14,1	0,2
15	30	0,9	66,3	0,8
16	53	1,6	121,9	1,4
17	47	1,4	129,7	1,5
18	221	6,5	442,1	5,2
19	1	0,0	3,9	0,0
20	76	2,2	79,4	0,9
21	148	4,3	389,7	4,5
22	1	0,0	10,7	0,1
23	52	1,5	85,4	1,0
24	85	2,5	167,6	2,0
25	265	7,8	549,2	6,4
26	49	1,4	126,4	1,5
27	145	4,2	285,7	3,3
28	91	2,7	179,8	2,1
29	135	4,0	408,1	4,8
30	14	0,4	21,7	0,3
31	19	0,6	39,4	0,5
32	53	1,6	160,0	1,9
33	5	0,1	7,4	0,1
34	53	1,6	83,5	1,0
35	19	0,6	31,5	0,4
36	4	0,1	5,2	0,1
37	145	4,2	316,5	3,7

Aquatic type	Aquatic ecological units		Length	
	Number	%	Km	%
38	104	3,0	256,0	3,0
39	4	0,1	7,9	0,1
40	135	4,0	84,5	1,0
41	170	5,0	366,3	4,3
42	6	0,2	10,6	0,1
43	10	0,3	7,7	0,1
44	73	2,1	195,8	2,3
45	134	3,9	319,9	3,7
46	153	4,5	695,0	8,1
47	28	0,8	71,5	0,8
48	19	0,6	49,0	0,6
Total	**3 414**	**100,0**	**8 571,8**	**100,0**

The descriptive variables for each type of aquatic biotope (the exemplars) are briefly outlined in Appendix F. Detailed descriptions will be provided in the methodology report related to aquatic environments (Blais et al., in preparation).

13.5.7. Prioritization of aquatic environments

To identify the AEUs of interest for biodiversity conservation which would make it possible to attain the 20% representativeness objective for each type of aquatic biotype, two prioritization criteria were selected: centrality and naturalness (Table 20).

Table 20. Criteria for prioritization of aquatic ecological units

Criteria	
	Centrality (representation of the aquatic type)
	Naturalness (local and watershed)

13.5.7.1. Centrality (representation of the aquatic type)

Centrality is integrated into prioritization to take into account the quality of representation of each AEU in relation to the type of aquatic biotope to which it belongs. When the typology is applied to all the AEUs in the St. Lawrence Lowlands, each AEU is more or less similar to the aquatic type with which it is associated. Since certain AEUs may be very different from the type, they are classified as outliers. This class is assigned to AEUs whose Euclidian distance to the central unit in the group is more than 3 times the standard deviation of the mean Euclidian distance of the group.

13.5.7.2. Naturalness (local and watershed)

Naturalness is integrated into prioritization by considering both the local naturalness of the watercourse and that of its watershed. These variables correspond respectively to the relative proportion of the area occupied by natural environments (forests, wetlands) in a 15 m band along watercourses and in the watershed. These two variables are aggregated by multiplying one by the other in order to represent the overall naturalness of each AEU. Multiplication was chosen over addition because it favours AEUs with high values for both variables.

13.5.8. Calculation method

For each of the 48 types of aquatic biotopes, the AEUs were ordered according to the criterion of naturalness (from largest to the smallest). Only AEUs with a mean Euclidian distance smaller than three times the standard deviation (criterion of centrality) were retained. The AEUs which had the highest naturalness values and which were good representatives of the aquatic biotope type were selected first, until 20% of the length of each type was reached. Since the AEUs of interest for the southern portion of the St. Lawrence Lowlands had already been selected in the preliminary version, the prioritization exercise was relaunched only for the AEUs in the northern portion of the St. Lawrence and the Outaouais region.

13.6. Multi-target analysis

The multi-target analysis is intended to illustrate the regions where the sites of conservation interest are concentrated in the study area. The purpose of this exercise is to determine whether there are areas where high quality ecosystem mosaics are concentrated. It should be possible, for example, to determine whether the objectives related to protecting fine-filter elements and to ensuring ecosystem representativeness objectives can be attained in each depositional context at the scale of the St. Lawrence Lowlands based on a minimum of key sites and to guide conservation actions at the regional scale accordingly. With adequate protection and management, these regions should help to increase the contribution of the network of protected areas to biodiversity protection and encourage land-use decisions that favour the maintenance of biodiversity. Several other potential approaches for carrying out this type of analysis could be tested, including the compilation of sites of conservation interest within spatial reference units at a finer level of perception, such as topographic complexes.

The proposed multi-target analysis combines the results of analyses conducted on forest areas, wetlands, old fields and aquatic environments. It can be used to identify sites of interest which contain one or more conservation targets and whose surface area is large enough to ensure the survival of species representative of the conservation targets and the ecological processes sustaining them. For a given region, it may be possible therefore to optimize the number of areas included in conservation planning by grouping several geographically contiguous sites of interest.

The method is straightforward. It involves creating assemblages of at least two conservation targets that are contiguous, by grouping sites retained for forest fragments, wetland complexes, aquatic ecological units and old fields.

14. Results

Given that the geospatial data associated with sites of conservation interest are available to the public, the maps showing the spatial distribution of these sites are provided as an illustration. Users can display and frame the image at the desired spatial scale to better identify the location of these sites.

14.1. Forest fragments of conservation interest

Forest fragments of conservation interest in the St. Lawrence Lowlands include those selected using the criteria defined in section 12.1, to which were added those selected in the prioritization analyses, until the 20% or 40% spatial representativeness objective (as appropriate) was attained in each regional depositional context. The 40% spatial representativeness objective was used for certain groupings of ecological type/species groupings that are naturally scarce.

Table 21 shows the number of forest fragments of conservation interest for each regional depositional context. At the scale of the St. Lawrence Lowlands, 1,281 forest fragments were selected, to which were added 274 forest fragments prioritized with to reach the representativeness objectives, for a total of 1,555 forest fragments considered to be of conservation interest. The percentage of fragments retained, in terms of number of fragments, for each depositional context, varies between 12.0% and 71.7%. In all, 24.4% of the forest fragments were deemed to be of conservation interest at the scale of the St. Lawrence Lowlands.

Table 22 shows the surface area of the fragments that were selected and prioritized for the St. Lawrence Lowlands and for each depositional context. At the scale of the St. Lawrence Lowlands, a total of 326,607 hectares of forest fragments were selected, to which were added 82,298 hectares of forest fragments prioritized to reach the representativeness objectives.

In all, 408,905 hectares of forest fragments were selected. The area covered by the fragments selected, relative to the total area of fragments presented for each context, ranged from 48.9% to 95.2%. However, if this percentage is calculated relative to the total land area of the regional depositional contexts, a sharp decrease in the percentages is observed. The forest fragments selected occupy 14.3% of the land area in the St. Lawrence Lowlands. The land area of the contexts was calculated by subtracting the portion occupied by the St. Lawrence River and the portion covered by the Ottawa River from the total area of the contexts.

Table 21. Number of forest fragments retained in each regional depositional context

Depositional context	Total number of fragments	Number of selected fragments	Number of prioritized fragments 20%/40%	Number of fragments retained	% fragments retained
1A_a_B01	622	127	13/0	140	22,5
1A_a_B02	20	11	0/0	11	55,0
1A_p_B01	732	111	19/0	130	17,8
1A_p_B02	144	21	8/1	30	20,8
3DB_B01	66	13	2/1	16	24,2
3DB_B02	495	72	25/1	98	19,8
3DB_B03	74	39	2/0	41	55,4
3FA_B01	106	**74**	2/0	76	71,7
3FA_B02	5	2	0/0	2	40,0
3FB_B01	150	27	4/2	33	22,0
3FB_B02	37	20	2/0	22	59,5
3FB_B03	197	102	4/0	106	53,8
3M_B01	295	64	7/0	71	24,1
3M_B02	86	18	5/0	23	26,7
5A_B01	1 055	145	67/4	216	20,5
5A_B02	459	54	29/2	85	18,5
5A_B03	416	223	5/0	228	54,8
5S_B01	371	49	14/1	64	17,3
5S_B02	648	40	37/1	78	12,0
6D_B02	402	69	14/2	85	21,1
Total	**6 380**	1 281	259/15	1 555	24,4

The forest fragments retained in the prioritization analysis stand out for their large surface area, their interconnections and the presence of highly diverse forest ecosystems including large proportions of interior forests and mature forests. It can be seen that the 40% representativeness objectives for certain groupings of ecological types / species groupings considered rare were largely achieved further to the attainment of the 20% representativeness objective established for the groupings as a whole.

Table 22. Areas (ha) of forest fragments retained in each regional depositional context

Depositional context	Total area of fragments	Area of selected fragments	Atea of prioritized fragments 20%/40%	Area of fragments retained	% of the area of the fragments*	% of the size of the context**
1A_a_B01	88 947,8	46 290,1	3 568,0/0	49 858,2	56,1	24,2
1A_a_B02	10 008,4	9 524,8	0/0	9 524,8	95,2	87,1
1A_p_B01	40 758,2	17 907,3	2 036,2/0	19 943,5	48,9	5,9
1A_p_B02	11 307,2	5 494,3	1 350,9/62,1	6 907,3	61,1	10,9
3DB_B01	5 410,6	2 688,6	181,1/91,7	2 961,4	54,7	24,1
3DB_B02	91 802,1	32 352,1	16 238,7/81,8	48 672,6	53,0	24,4
3DB_B03	14 624,1	12 616,1	405,5/0	13 021,7	89,0	40,9
3FA_B01	4 310,8	3 199,2	417,6/0	3 616,8	83,9	6,1
3FA_B02	1 085,0	1 020,7	0/0	1 020,7	94,1	56,9
3FB_B01	16 429,7	10 684,9	788,5/61,7	11 535,1	70,2	11,1
3FB_B02	2 704,3	2 343,2	24,1/0	2 367,3	87,5	8,3
3FB_B03	27 381,9	18 824,8	757,1/0	19 581,9	71,5	32,2
3M_B01	32 145,7	19 765,2	2 183,7/0	21 948,9	68,3	20,2
3M_B02	10 607,5	6 888,6	1 323,6/0	8 212,2	77,4	22,9
5A_B01	56 268,8	17 513,0	9 923,6/403,1	27 839,7	49,5	4,2
5A_B02	37 234,4	12 112,1	6 847,8/256,7	19 216,5	51,6	11,1
5A_B03	25 030,7	18 601,2	227,2/0	18 828,4	75,2	18,2
5S_B01	45 108,1	19 537,9	4 610,3/116,7	24 264,9	53,8	19,3
5S_B02	140 173,7	53 037,7	27 372,0/367,1	80 776,9	57,6	21,7
6D_B02	33 525,1	16 204,9	2 502,8/98,6	18 806,3	56,1	11,3
Total	694 864,0	326 606,8	80 758,7/1 539,5	408 905,1	58,8	14,3

* Percentage of the area of forest fragments present within the regional depositional context that have been selected and prioritized.

** Percentage of the land area of each regional depositional context occupied by the selected and prioritized forest fragments.

An additional, modest area of 1,539.5 hectares was required to attain this 40% objective at the scale of the St. Lawrence Lowlands. In comparison, an area of 80,758.7 hectares of forest fragments, in addition to the forest fragments selected, was prioritized in order to achieve the general representativeness objective of 20%.

The number of forest fragments selected with each selection criterion is shown in Table 23. Irreplaceable stands and wildlife occurrences were the most decisive in the selection of forest fragments of conservation interest. The calm water context of the Ottawa Plain (5A_B03) is characterized by a particularly high number of selected fragments due to the presence of wildlife occurrences of interest and, to a lesser extent, due to the presence of protected areas or exceptional forest ecosystems.

Table 23. Number of forest fragments selected with each selection criterion

Depositional context	Public or private protected area	Irreplaceable forest fragment*	Exceptional forest ecosystem	Floristic occurrence	Wildlife occurrence
1A_a_B01	18	50	21	41	44
1A_a_B02	0	11	0	0	0
1A_p_B01	33	49	23	27	38
1A_p_B02	0	21	0	0	0
3DB_B01	0	13	0	0	0
3DB_B02	8	46	5	1	18
3DB_B03	4	16	3	3	29
3FA_B01	15	26	13	20	62
3FA_B02	2	2	2	0	1
3FB_B01	8	27	1	0	0
3FB_B02	8	13	4	0	0
3FB_B03	7	21	6	12	93
3M_B01	10	43	3	21	8
3M_B02	2	13	5	0	0
5A_B01	31	47	17	29	59
5A_B02	3	46	6	2	1
5A_B03	44	32	26	27	193
5S_B01	1	36	0	1	16
5S_B02	2	24	1	0	19
6D_B02	10	55	8	4	5
Total	206	591	144	188	586

* Forest fragments having obtained an irreplaceability value of 1 calculated with C-Plan

The selected and prioritized forest fragments for the entire study area are shown in Figure 20. Among the selected fragments are some well-known areas, including all of the Monteregian Hills, the Fer-à-cheval woods north of Mont Saint-Bruno, and the Covey Hills that straddle the Quebec-New York State border. Still in the portion located south of the St. Lawrence, we can also mention the Sainte-Marie-de-Blandford sector, in the Bécancour RCM, the woodlands located southeast of Acton Vale, the woodlands located on either side of the Saint-François River between Sherbrooke and Drummondville, the woodlands located on either side of the Bécancour River between Saint-Louis-de-Blandford and Lyster as well as the woodland of the Seigneurie de Joly.

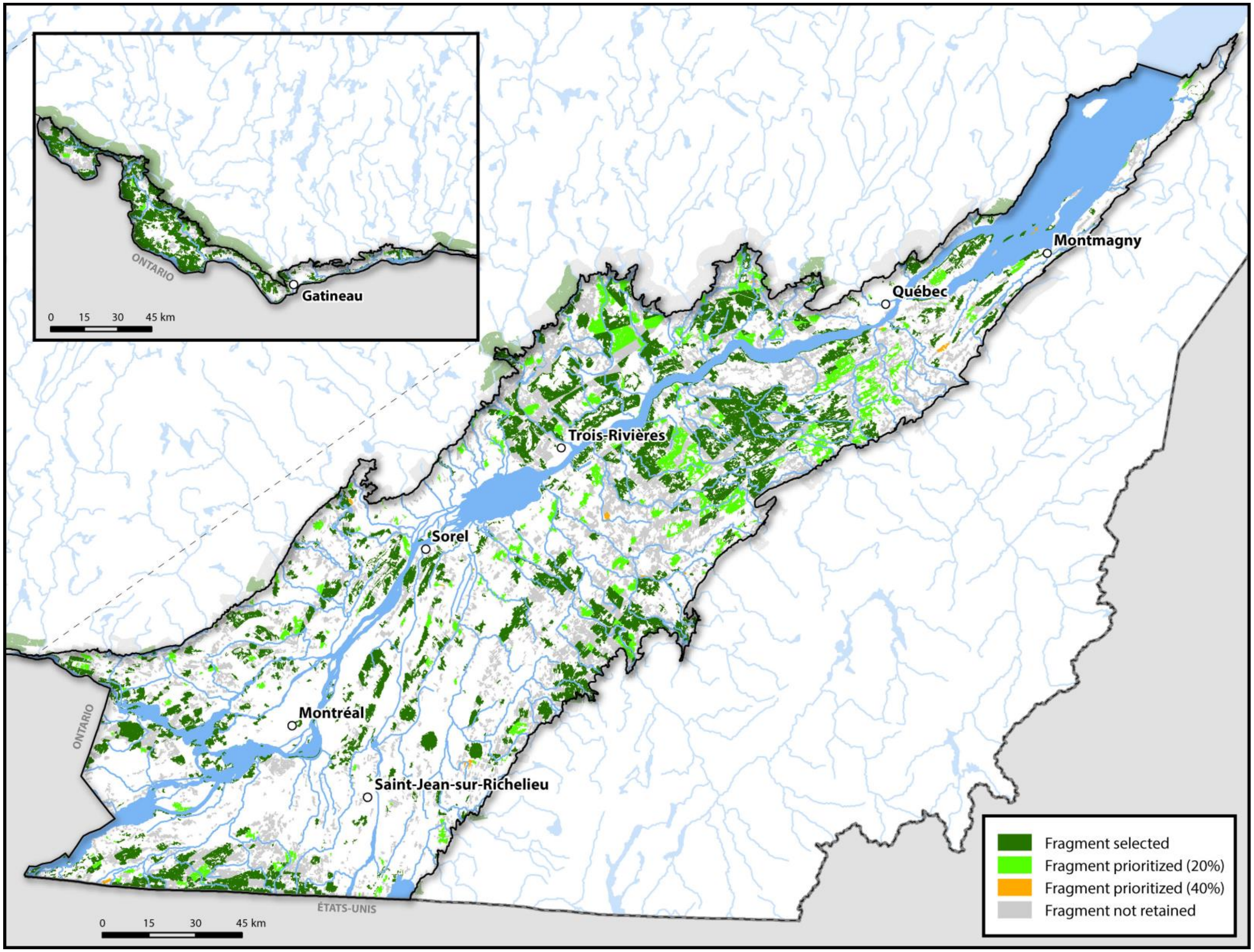


Figure 20. Spatial distribution of forest fragments retained as sites of interest

North of the St. Lawrence, the areas between the municipalities of Saint-Adelphe and Sainte-Anne-de-la-Pérade in the Les Chenaux RCM, the Portneuf sector in the RCM of the same name and the Saint-Félix-de-Valois sector in the Matawinie RCM are among the selected massifs. In addition, the territory located on either side of the St. Lawrence upstream from Sorel-Tracy, including the wooded area associated with the Lanoraie peat bogs, also stands out. Finally, within the Ottawa River valley, the Plaisance, Portage-du-Fort, Quyon and Coulonge rivers, Île-du-Grand-Calumet and Isle-aux-Allumettes sectors, as well as those located south and east of Île-du-Grand-Calumet and the area between Norway Bay and Quyon have been retained as woodlands of interest.

14.2. Wetland complexes of conservation interest

Figure 21 shows the results of the selection and prioritization carried out at the scale of the St. Lawrence Lowlands. From a quick review of the map, two observations can be made. First, the regional depositional contexts clearly played a role in the formation of wetlands in Quebec. The turbulent water context (5S) is characterized by vast plains of fine sand. As the Champlain Sea gradually retreated, it left behind numerous poorly drained depressions where peatlands developed. This is the context corresponding to the largest number of wetlands by far. Similarly, the recent fluvial context (3FA), which is associated with the present-day hydrographic network, contains large expanses of wetlands that developed more recently than peatlands, including the marshes bordering Lake Saint-Pierre.

Also noteworthy is the scarcity of wetlands in certain depositional contexts which nonetheless produced conditions favourable to their appearance. That is the case for the calm water (5A) and flat glacial (1A_p) contexts, which are characterized by a predominance of clay deposits. These soils which are generally imperfectly drained should be conducive to the wetland formation. Here, the confounding factor appears to be agriculture, the main cause of wetland loss in the St. Lawrence Lowlands (Pellerin and Poulin, 2013). Agriculture is also a common activity in the flat glacial (1A_p), calm water (5A) and fluviomarine (3M) contexts, which likely explains the scarcity of wetlands in these areas. Table 24 shows the number of wetland complexes selected in each step, and Table 25 presents the areal extent of the wetland complexes. The most obvious result is the predominant role of the selection analysis in the overall prioritization process. A very large number of wetland complexes were retained in the selection analysis, thereby reducing the scope of the HB step and rendering the Habitat step unnecessary, with the exception of one context.

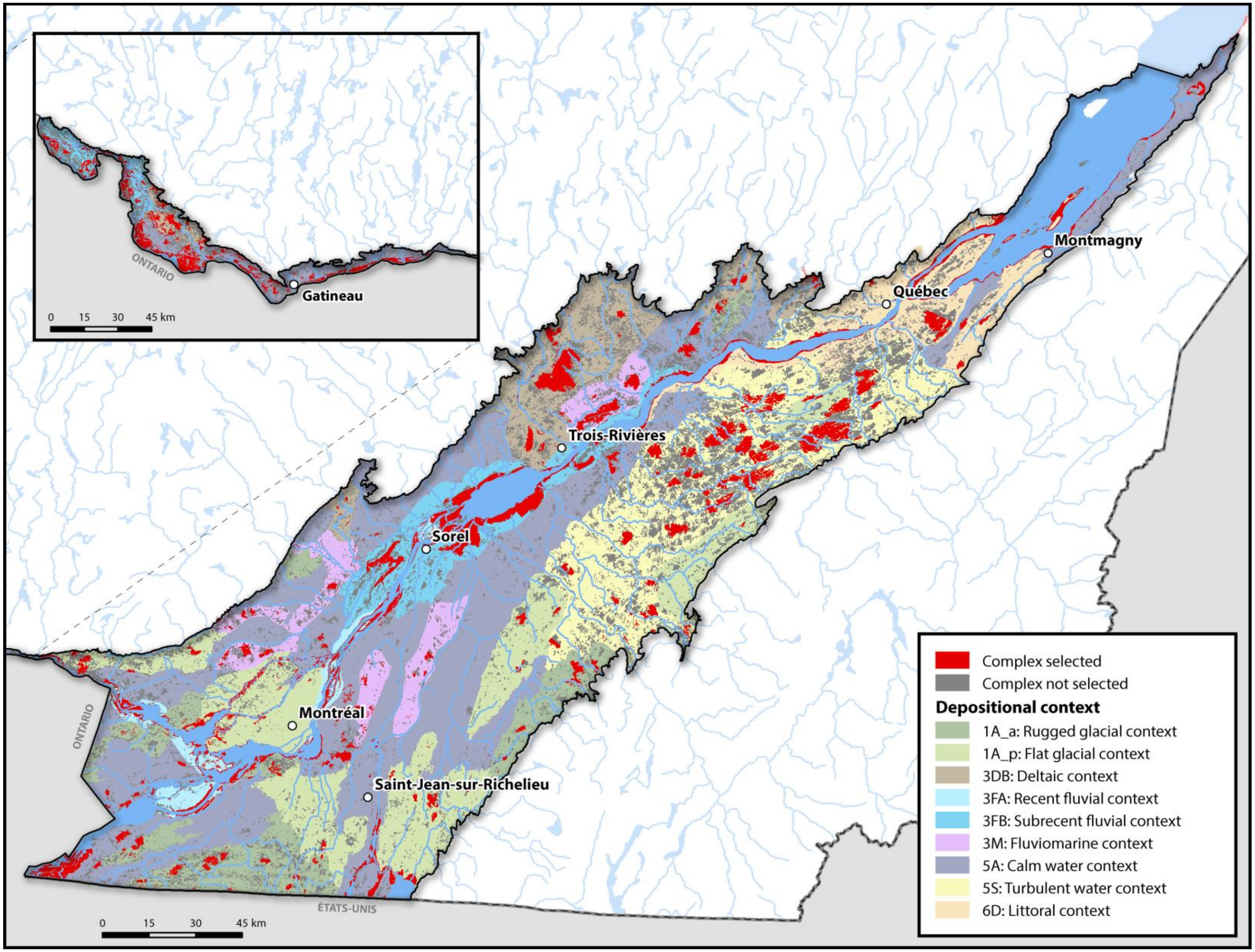


Figure 21. Spatial distribution of wetland complexes retained as sites of interest.

Table 24. Number of wetland complexes retained in each depositional context

Depositional context	Number of wetland complexes	Number of complexes retained at the selection stage	Number of complexes prioritized at the HB stage	Number of complexes prioritized in the Habitat stage	Total number of wetland complexes selected	Percentage of wetland complexes of interest
1A_a	4 432	247	6	0	253	5,71
1A_p	4 587	444	8	2	454	9,90
3DB	6 556	292	1	0	293	4,47
3FA	1 748	778	49	0	827	47,31
3FB	3 515	521	12	0	533	15,16
3M	2 053	124	11	0	135	6,58
5A	11 485	2 237	1	0	2238	19,49
5S	8 082	190	6	0	196	2,43
6D	2 358	67	0	0	67	2,84
Total	**44 816**	**4 900**	**94**	**2**	**4 996**	**11,15**

Table 25. Areas (ha) of wetland complexes retained in each depositional context.

Depositional context	Total area of the complexes	Area of the selected complexes	Area of complexes prioritized at the HB stage	Area of complexes prioritized at the Habitat stage	Total area of the selected complexes	% of the total area of the complexes
1A_a	20 075,82	6 626,44	363,27	0,00	6 989,71	34,82
1A_p	19 579,30	5 248,69	483,93	537,98	6 270,60	32,03
3DB	34 618,99	15 773,77	9,33	0,00	15 783,10	45,59
3FA	37 457,75	32 711,85	584,18	0,00	33 296,03	88,89
3FB	30 257,83	17 673,81	56,93	0,00	17 730,74	58,60
3M	14 431,64	6 949,78	150,46	0,00	7 100,24	49,20
5A	51 365,60	27 447,81	112,13	0,00	27 559,94	53,65
5S	95 685,38	33 526,61	747,04	0,00	34 273,65	35,82
6D	19 119,34	7 264,36	0,00	0,00	7 264,36	37,99
Total	**322 591,65**	**153 223,12**	**2 507,26**	**537,98**	**156 268,36**	**48,44**

The role of the selection analysis can be explained first by the number of plant or animal occurrences identified in wetlands (Table 26). These occurrences alone led to the selection of more than 4,000 wetland complexes, or 80% of the total number selected. Wetlands, on account of the array of abiotic conditions found there, are often characterized by high species richness and the presence of many rare or uncommon species that seek conditions intermediate between terrestrial and aquatic environments (Mitsch and Gosselink, 2007).

Table 26. Number of wetland complexes selected by each of the selection criteria

Depositional context	Public of private protected area	Floristic or wildlife occurrence	Exceptional forest ecosystem	Irremplaceability	Overall result
1A_a	83	146	49	23	247
1A_p	149	325	67	18	444
3DB	16	250	7	30	292
3FA	176	693	47	10	778
3FB	73	463	16	21	521
3M	49	67	26	15	124
5A	478	2 040	122	52	2 237
5S	14	146	5	39	190
6D	23	44	1	10	67
Total	**1 061**	**4 174**	**340**	**218**	**4 900**

This situation is exacerbated by the usage conflicts observed in the St. Lawrence Lowlands, a unique region that is characterized by the most intensive farming activities, the largest urban centres and the most favourable climatic conditions for significant biodiversity in Quebec. In addition to harbouring unique biodiversity, the wetlands of the St. Lawrence Lowlands provide refuges for plant and animal species, which explains the number of threatened or vulnerable species found there. This step alone resulted in the selection of more than 45% of the total wetland area in the St. Lawrence Lowlands.

On its own, the HB step makes it possible to prioritize a relatively modest number of wetland complexes (171), which are quite large. Consequently, without the selection step, the HB step would nonetheless make it possible to prioritize more than 8% of the total wetland area in the Lowlands. The contribution of the HB step is greatly reduced when it is applied after the selection analysis: the 94 wetlands identified account for only 2,507 ha, or less than 1% of the total wetland area in the St. Lawrence Lowlands.

The Habitat step on its own would make it possible to prioritize 1,189 wetland complexes. However, the purpose of this step is to round out the selection of wetlands of conservation interest until a 20% representativeness objective is achieved. In a context where more than 45% of wetland area has already been selected in the previous steps, the Habitat step is only useful in one area: the polygon of the easternmost flat glacial context in the St. Lawrence Lowlands. Based on the assumption that this step makes a negligible contribution to the identification of sites of interest, consideration was given to the possibility of increasing the target by selecting more than 20% of the total wetland area. In the previous steps, more than 623 of the 1,189 most promising wetland complexes were not selected. These 623 complexes cover more than 10,000 ha, which represents more than 3% of the total wetland area in the Lowlands. In the end, this idea was rejected. The habitat criteria retained are merely habitat indicators. In contrast, plant and animal occurrences attest to the presence of habitats. Important habitats are already accorded a prominent place in the selection analysis, and there is no need to add habitats that may not reflect reality.

In the end, the main finding of the work carried out here is as follows: numerous wetland complexes present in the St. Lawrence Lowlands are associated with protected areas, are irreplaceable, they harbour plant and animals occurrences of conservation interest or they harbour exceptional forest ecosystems, that their selection results in a significant decrease in the scope of subsequent steps (HB and Habitat). These steps are not without merit, however. It appears that there is very little overlap between the selection analysis and the subsequent steps. Despite the large number of wetland complexes selected, it includes only 48% of complexes deemed important in the HB step.

If we disregard the additive effect of the different steps and instead consider all three of them equally, only 77 wetland complexes are selected simultaneously in the three steps, for less than 0.8% of the total wetland area in the Lowlands. Such a finding underscores the potential that a cumulative method holds: a portion of the relevant information associated with the ecological potential of wetlands would be lost in a selection process that focuses on only one of the three steps used in the Atlas.

It should also be noted that botanists have for many years taken a keen interest in the St. Lawrence Lowlands, mainly because of the high plant diversity found there but also because of the ease of accessing these lands often located near urban centres. Outside of the St. Lawrence Lowlands, it is conceivable that the selection step would result in the retention of a much smaller number of wetland complexes. In this case, the subsequent steps would be very useful.

14.2.1. The Outaouais valley

The identification of sites of conservation interest in the Outaouais Valley is an important addition to this version of the Atlas. For example, although the Ottawa Plain (B03) represents only 8% of the St. Lawrence Lowlands, it contains nearly 14% of the wetland complexes in our study area. The results also highlight the unique character of this area in terms of the occurrence of plant and wildlife species of interest.

In fact, 1,958 wetland complexes were selected in this region alone, based solely on the presence of flora and fauna species of interest, compared with 2,216 complexes in the rest of the St. Lawrence Lowlands. This means that the addition of the Outaouais Valley results almost doubled the number of wetland complexes selected for the presence of wildlife and plant species of interest. This can be explained in large part by the large number of recognized habitats for four endangered animal species in this region: the least bittern, map turtle, Blanding's turtle and western chorus frog. In the end, these results highlight the major role of the Ottawa Plain in biodiversity conservation at the St. Lawrence Lowlands scale.

14.3. Old fields of conservation interest

Old fields of conservation interest in the St. Lawrence Lowlands are the ones initially selected, to which were added those selected in the multi-criteria prioritization analyses, until the 20% spatial representativeness objective was attained for each regional depositional context. Table 27 shows the number of old fields that were selected and prioritized, to reach the 20% representativeness objective. In all, 198 of the 1,288 suitable old fields have the most potential for conservation in the St. Lawrence Lowlands. The 20% objective was attained or exceeded by tallying the area of the old fields selected in two depositional contexts (3FA_B01; 5A_B01); all these old fields were therefore identified as being of conservation interest. Figure 22 shows the spatial distribution of the old fields of conservation interest in the St. Lawrence Lowlands as a whole.

Table 27. Number of suitable old fields retained to reach the 20 per cent threshold in each regional depositional context

Regional depositional context	Number of suitable old fields	Number of selected old fields	Number of old fields prioritized	Number of old fields retained	% of old fields retained
1A_a_B01	133	14	2	16	12,0
1A_a_B02	11	0	1	1	9,1
1A_p_B01	118	7	4	11	9,3
1A_p_B02	16	0	2	2	12,5
3DB_B01	5	0	1	1	20,0
3DB_B02	119	3	11	14	11,8
3DB_B03	34	4	1	5	14,7
3FA_B01	61	14	0	14	23,0
3FB_B01	17	0	1	1	5,9
3FB_B02	30	0	4	4	13,3
3FB_B03	34	0	3	3	8,8
3M_B01	51	3	4	7	13,7
3M_B02	10	0	2	2	20,0
5A_B01	178	32	0	32	18,0
5A_B02	86	0	7	7	8,1
5A_B03	85	35	0	35	41,2
5S_B01	42	2	4	6	14,3
5S_B02	130	4	13	17	13,1
6D_B02	128	3	17	20	15,6
Total	**1 288**	**121**	**77**	**198**	**15,4**

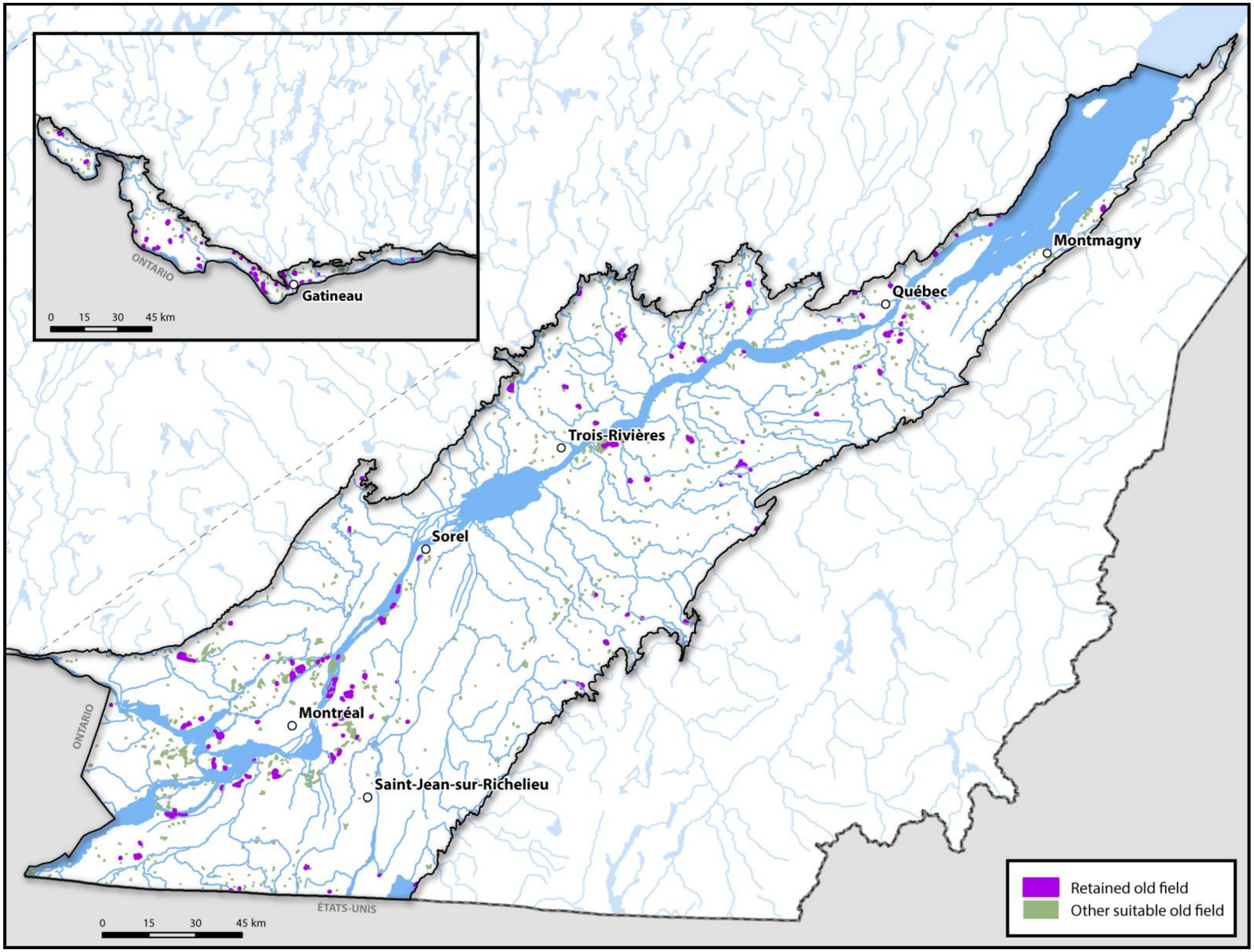


Figure 22. Distribution of the 198 retained old fields whose combined surface area makes it possible to reach the 20% representativeness threshold in each regional depositional context

Overall, 15% of the old fields in the study area were considered to be of conservation interest, with the proportion ranging from 6% to 41% depending on the regional depositional contexts. The total area of the old fields selected accounts for nearly one quarter of the total area of suitable old fields, with this proportion varying between 20% and 42% depending on the regional depositional contexts (Table 28).

Table 28. Total area of old fields and area of old fields retained to reach the 20% threshold of representativeness

Regional depositional context	Area (ha)				% Retained	% Context
	Total	Selected	Prioritized	Retained		
1A_a_B01	1 818,4	263,1	155,3	418,4	23,0	0,01
1A_a_B02	165,5	0,0	45,4	45,4	27,4	0,25
1A_p_B01	2 753,9	266,9	291,3	558,1	20,3	0,01
1A_p_B02	148,3	0,0	34,0	34,0	22,9	0,04
3DB_B01	67,4	0,0	26,2	26,2	38,8	0,32
3DB_B02	1 665,5	70,4	302,5	372,9	22,4	0,01
3DB_B03	437,4	82,2	13,2	95,4	21,8	0,30
3FA_B01	1 574,8	618,0	0,0	618,0	39,2	0,02
3FB_B01	197,1	0,0	50,1	50,1	25,4	0,02
3FB_B02	1 026,6	0,0	266,1	266,1	25,9	0,09
3FB_B03	555,8	0,0	129,3	129,3	23,3	0,19
3M_B01	843,3	85,7	121,1	206,7	24,5	0,02
3M_B02	136,1	0,0	45,9	45,9	33,7	0,09
5A_B01	3 920,6	1 018,1	0,0	1 018,1	26,0	0,00
5A_B02	1 285,7	0,0	259,1	259,1	20,2	0,01
5A_B03	1 344,7	569,2	0,0	569,2	42,3	0,47
5S_B01	632,3	28,9	102,8	131,7	20,8	0,02
5S_B02	1 601,5	36,7	285,3	322,0	20,1	0,01
6D_B02	1 733,0	19,0	328,1	347,1	20,0	0,01
Total	**21 908,0**	**3 058,2**	**2 455,8**	**5 514,0**	**25,2**	**0,18**

More than half of the selected wastelands were selected because of the presence of priority wildlife species (Table 29), particularly in the Outaouais region (5A_B03) where the majority of Blanding's turtle and western chorus frog occurrences in Quebec are concentrated. Elsewhere in the St. Lawrence Lowlands, it is the presence of the western chorus frog, golden-winged warbler and wood Turtle that drives the selection of old fields of interest, mainly in the 5A_B01, 1A_a_B01 atd 3FA_B01 contexts. Finally, it should be noted that more than 40% of the selected old fields were selected because of their proximity to public or private protected areas.

The old fields of conservation interest are mainly located on the periphery of the highly urbanized areas around Montreal (Laval, Boucherville, Longueuil, La Prairie) and Gatineau, and a few clusters of these old fields are located in the regions of Bécancour, Plessisville and Lévis and in the Mauricie (Saint-Stanislas, Saint-Adelphe). The remaining old fields of conservation interest are scattered throughout the St. Lawrence Lowlands. There is also a high number of old fields of interest in the Pontiac region of the Outaouais due to the presence of wildlife species at risk. Otherwise, of old fields of interest are scattered throughout the St. Lawrence Lowlands.

Table 29. Number of selected old fields with each selection criterion

Regional depositional context	Public of private protected area	High value floristic occurrence	High value wildlife occurrence	Overall
1A_a_B01	6	2	6	14
1A_a_B02	0	0	0	0
1A_p_B01	7	0	0	7
1A_p_B02	0	0	0	0
3DB_B01	0	0	0	0
3DB_B02	0	0	3	3
3DB_B03	0	0	4	4
3FA_B01	9	1	5	14
3FB_B01	0	0	0	0
3FB_B02	0	0	0	0
3FB_B03	0	0	0	0
3M_B01	3	0	0	3
3M_B02	0	0	0	0
5A_B01	12	4	17	32
5A_B02	0	0	0	0
5A_B03	12	1	30	35
5S_B01	0	0	2	2
5S_B02	1	0	3	4
6D_B02	3	0	0	3
Total	**53**	**8**	**70**	**121**

14.4. Topographic complexes of conservation interest for agricultural grasslands

Table 30 shows the topographic complexes of conservation interest which have an agricultural matrix presenting favourable conditions for grassland birds in the St. Lawrence Lowlands. These complexes are the ones that made it possible to attain the 20% representativeness objective in each natural region. In all, 124 of the 643 topographic complexes where agricultural fields are present were selected. Figure 23 shows the spatial distribution of the topographic complexes of interest.

Table 30. Descriptive statistics for the topographic complexes selected to reach the 20% threshold of representativeness in each natural region.

	All		Retained		
Natural region	**Number**	**Area (km^2)**	**Number**	**Area(km^2)**	**% Region**
HSL plain (B01)	325	16 754	62	3 373	20,1
MSL plain (B02)	287	11 057	55	2 329	21,1
Ottawa plain (B03)	31	2 112	7	455	21,5
Total	**643**	**29 923**	**124**	**6 157**	**20,6**

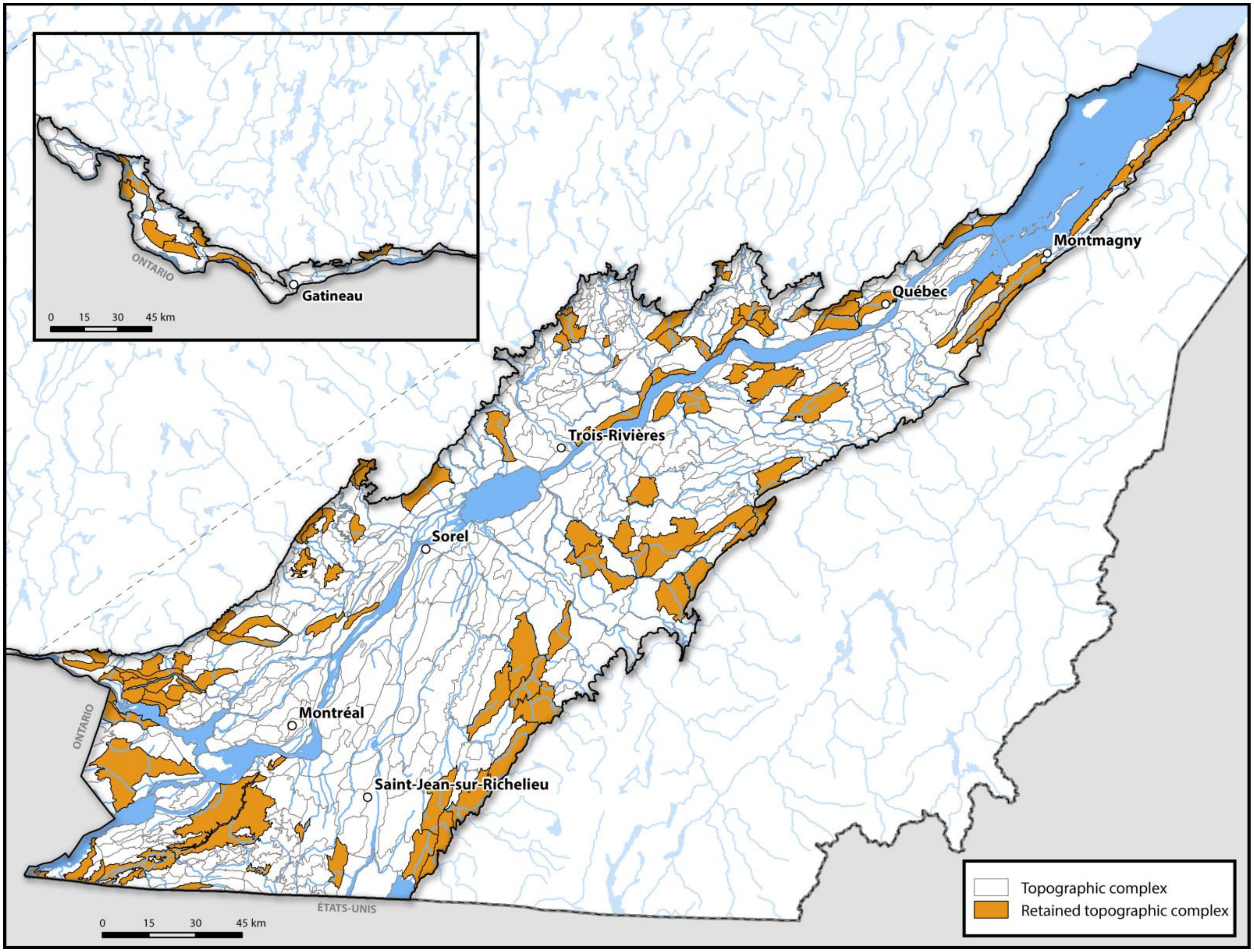


Figure 23. Spatial distribution of the 124 retained topographic complexes whose combined area meets the 20% threshold for each natural region

With regard to the Upper St. Lawrence Plain (B01), the topographic complexes containing agricultural matrices that can support biodiversity are located mainly in the foothills of the Appalachians (Farnham, Granby, Saint-Valérien-de-Milton), in the regions of Saint-Polycarpe, de Saint-Placide/Oka, Saint-Cléophas/Saint-Norbert and the Châteauguay River. In the Middle St. Lawrence Plain (B02), it is the regions located along the St. Lawrence River (Lotbinière, Portneuf, Québec), in Côte-du-Sud, in Bas-Saint-Laurent, in Centre-du-Québec (Daveluyville) and in the foothills of the Appalachians (Victoriaville) where topographic complexes have agricultural matrices offering the most favourable conditions for grassland birds and biodiversity at large. Finally, in the Ottawa plain, six of the seven selected topographic complexes are located in the Pontiac region, west of the city of Gatineau, an area known to host agricultural matrices favourable to grassland birds due to the abundance of pastures and perennial crops associated with beef cattle production (Jobin, 2003).

It is important to note here that identifying areas of high interest for grassland birds helps to guide conservation actions that could support viable populations of these declining species. However, a finer analysis of the spatial distribution of perennial crop plots in the agr icultural landscape will be necessary to better understand regional agricultural dynamics and better target the most relevant actions.

14.5. Aquatic environments of conservation interest

Since LIDAR data coverage was incomplete for part of the St. Lawrence Lowlands north of the St. Lawrence River, some aquatic ecological units were not included in the analysis of aquatic ecological units of interest for biodiversity conservation. The aquatic ecological units in the missing portion will therefore be integrated at a later date, when the LIDAR data become available.

The aquatic environments of conservation interest correspond to the aquatic ecological units in each type of aquatic biotope prioritized taking into account centrality and naturalness until the 20% representativeness objective was attained. The 20% objective corresponds to 20% of the total length of each type of aquatic biotope. The AEUs selected as being of conservation interest make it possible to capture 20% of the diversity of aquatic biotopes at the scale of the St. Lawrence Lowlands (Table 31). Based on the methodology used, 712 AEUs out of a total of 3,414, or a total stream length of 8,572 km, were selected as being of interest for biodiversity conservation (Figure 24). The actual percentage of stream length for each aquatic biotope varies between 20% and 100% in certain cases. The scarcer types of aquatic biotopes with only a few AEUs are fully captured (types 19 and 22).

Table 31: General statistics on aquatic ecological units of conservation interest by aquatic habitat type

Aquatic type	Aquatic ecological units in the St. Lawrence Lowlands		Aquatic ecological units of conservation interest		
	Number	Length (km)	Number	Length (km)	Actual percentage of total length
1	153	537,5	35	113,4	21,1
2	13	7,6	6	3,8	50,2
3	39	132,5	9	32,1	24,2
4	51	204,9	9	40,4	20,0
5	145	328,8	28	65,7	20,0
6	93	349,8	22	76,0	21,7
7	160	407,3	43	85,3	20,9
8	53	250,5	12	53,8	21,5
9	6	23,7	2	7,3	30,8
10	52	264,7	17	65,0	24,6
11	32	75,5	6	21,5	28,5
12	24	76,3	6	26,7	35,0
13	41	123,2	10	27,5	22,3
14	5	14,1	2	4,1	29,4
15	30	66,3	7	15,3	23,1
16	53	121,9	12	24,7	20,2
17	47	129,7	7	25,6	20,0
18	221	442,1	44	88,8	20,1
19	1	3,9	1	3,9	100,0
20	76	79,4	19	28,6	36,0
21	148	389,7	28	83,3	21,4
22	1	10,7	1	10,7	100,0
23	52	85,4	11	17,0	20,0
24	85	167,6	18	34,8	20,7
25	265	549,2	46	111,5	20,3
26	49	126,4	7	24,5	20,0
27	145	285,7	26	58,7	20,5
28	91	179,8	18	41,8	23,3
29	135	408,1	23	89,8	22,0
30	14	21,7	3	5,4	24,9
31	19	39,4	4	14,6	37,0
32	53	160,0	5	46,2	28,8
33	5	7,4	2	3,0	40,4
34	53	83,5	16	16,7	20,0
35	19	31,5	9	7,5	23,9

Aquatic type	Aquatic ecological units in the St. Lawrence Lowlands		Aquatic ecological units of conservation interest		
	Number	Length (km)	Number	Length (km)	Actual percentage of total length
36	4	5,2	2	2,7	52,4
37	145	316,5	35	66,0	20,9
38	104	256,0	25	51,1	20,0
39	4	7,9	2	3,3	42,2
40	135	84,5	23	17,5	20,7
41	170	366,3	29	73,4	20,0
42	6	10,6	2	3,5	33,3
43	10	7,7	2	4,3	55,5
44	73	195,8	17	47,1	24,1
45	134	319,9	26	67,3	21,0
46	153	695,0	24	137,2	20,0
47	28	71,5	7	14,5	20,3
48	19	49,0	4	14,5	29,7
Total	**3 414**	**8 571,8**	**712**	**1 877,9**	**29,4**

This approach for selecting aquatic environments of conservation interest holds promise but it is incomplete without integrating the other conservation targets and considering the notion of connectivity between aquatic habitats. Since aquatic habitats are part of a larger system and connectivity between aquatic habitats is of critical importance, the analysis needs to be enhanced by integrating the concept of network in the process of selecting aquatic environments of conservation interest. Connectivity could thus be integrated into the process, thereby ensuring the creation of groups of AEUs that are spatially linked. The concept of gain of diversity should be used to guide the completion of this aggregation process.

14.6. Coarse-filter sites of interest

Figure 25 shows the sites of interest derived from the coarse-filter analysis which consists of the sites retained further to the selection and prioritization analyses of each conservation target: forest fragments (n=1,555), wetland complexes (n=4,996), old fields (n=198) and aquatic ecological units (n=712). In all, 7,461 sites of interest for biodiversity conservation in the St. Lawrence Lowlands were obtained, to which are added 124 topographical complexes where agricultural matrices favourable to country birds and biodiversity can be found.

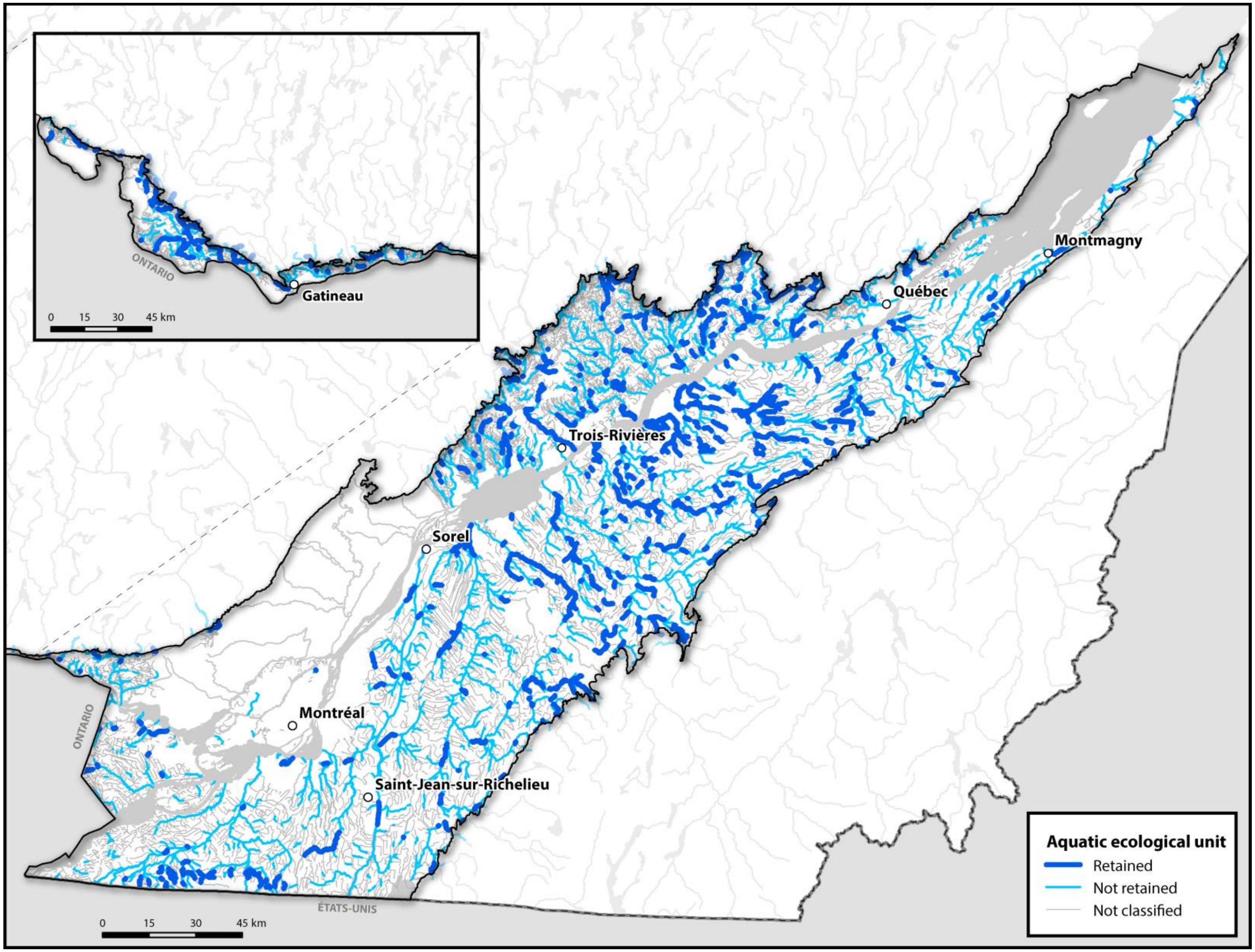


Figure 24. Spatial distribution of aquatic ecological units of conservation interest in the St. Lawrence Lowlands

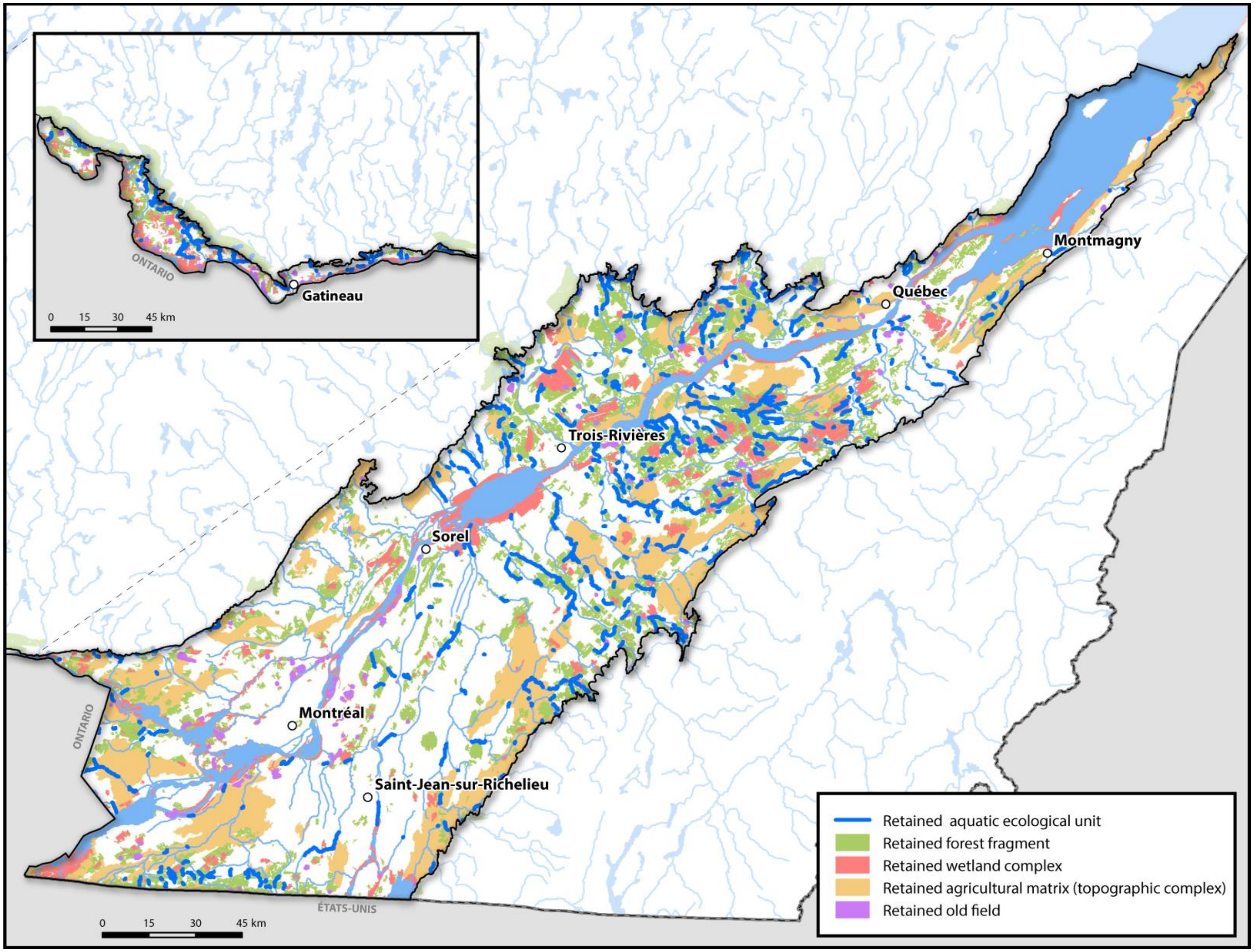


Figure 25. Spatial distribution of sites of interest for biodiversity conservation in the St. Lawrence Lowlands

14.7. Multi-target analysis

The multi-target analysis considers selected sites of interest for forest fragments, wetland complexes, old fields and aquatic ecological units. However, for certain regions of the St. Lawrence Lowlands north of the St. Lawrence River where LIDAR data are incomplete, this analysis considers only three of the four conservation targets since no aquatic ecological units of interest were selected (see Figure 24). This fact must therefore be taken into consideration when interpreting the results for these areas.

Figure 26 shows all the multi-target and single sites selected as sites of interest. Table 32 presents a summary of the results for the St. Lawrence Lowlands as a whole. In all, 728 sites of interest contain at least 2 targets and their areal extent varies between 2 ha and 24,340 ha. Since forests dominate the residual natural cover in the St. Lawrence Lowlands, it is not surprising that 97% (705/728) of the multi-target sites contain forest fragments. In addition, of the 705 multi-target sites with forest fragments, wetland complexes of interest are also present in 87% (606/705) of them. This joint representation of wetlands and forest environments of interest shows that hydromorphic soils that are unsuitable for agriculture have been left undisturbed, thus favouring the maintenance of natural environments.

In terms of surface area, multi-target sites made up of 2, 3 or 4 targets represent 75% of the area occupied by all sites of interest retained for the 4 conservation targets of the atlas, which represents 16% of the St. Lawrence Lowlands. Several of the multi-target sites where there are sites of interest for the 4 conservation targets are located in the Mauricie, Centre-du-Québec and Pontiac regions in the Outaouais.

Table 32. Characteristics of multi-target and single sites

	Multi-target site composition (number of sites and percentage)						
Number of targets	**Number of sites selected**	**Forest fragments**	**Wetland complexes**	**Old fields**	**AEUs**	**% of area of sites of interest***	**% of study area****
4	20	20 (100%)	20 (100%)	20 (100%)	20 (100%)	14,6	3,1
3	108	108 (100%)	105 (97,2%)	50 46,2%)	61 (56,5%)	30,0	6,3
2	600	577 (96,2%)	504 (84,0%)	30 (5,0%)	89 (14,8%)	30,5	6,5
1	3 005	747 (24,9%)	2 039 (67,9%)	53 (1,8%)	166 (5,5%)	24,9	5,3
Total	**3 733**	**1 452 (38,9%)**	**2 668 (71,5%)**	**153 (4,1%)**	**336 (9,0%)**	**100,0**	**21,2**

* Calculated relative to the total area covered by the sites of interest of the four conservation targets (6,845 km^2)

** Calculated relative to the total area of the St. Lawrence Lowlands (32,350 km^2)

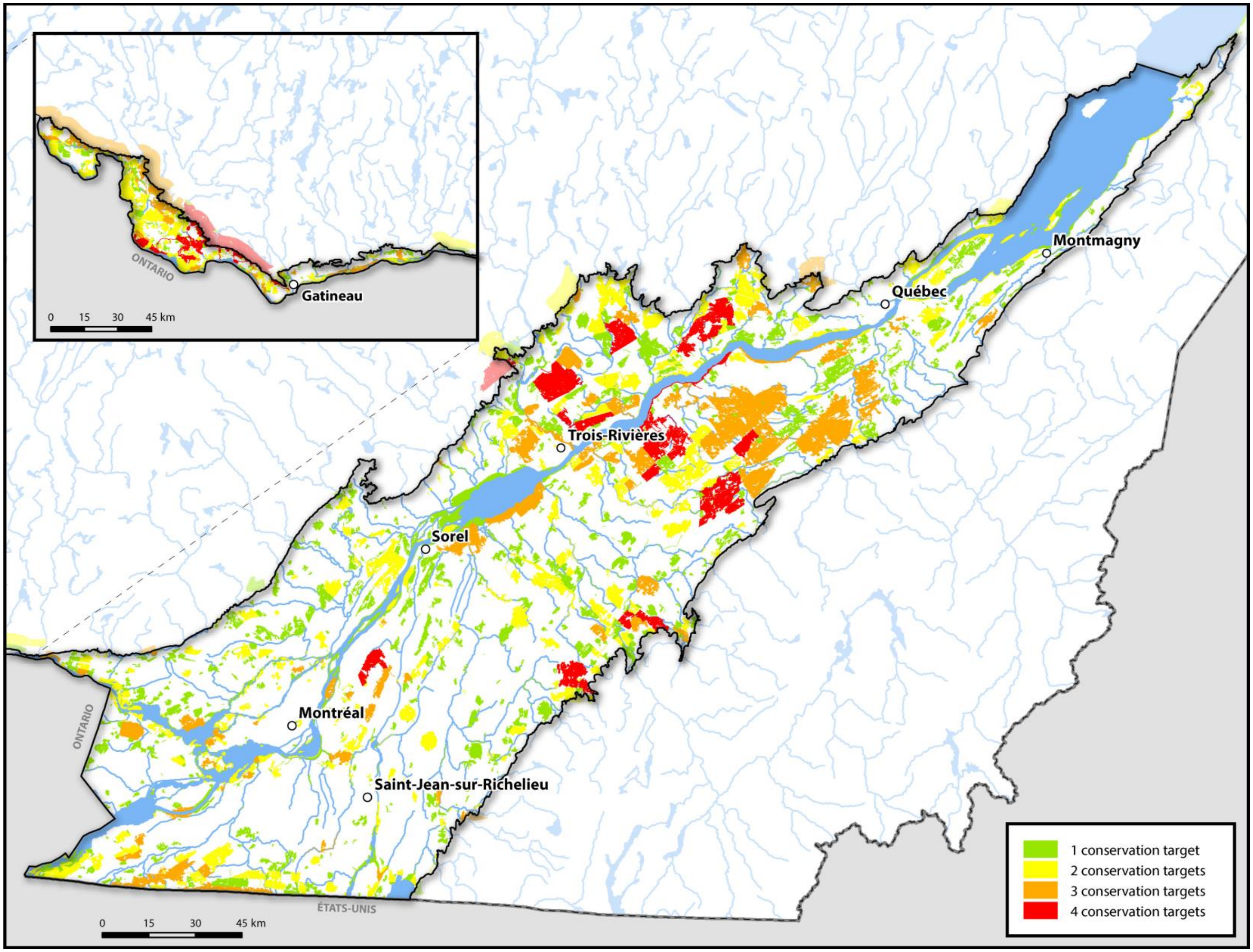


Figure 26. Spatial distribution of multi-target sites of conservation interest in the St. Lawrence Lowlands

There are also several sites of interest of the same conservation target within the same multi-target site. For example, the multi-target site of interest located near Portage-du-Fort in the Outaouais region is composed of 144 selected sites, including 140 wetland complexes, 1 forest fragment, 2 old fields and 1 aquatic ecological unit (Figure 27).

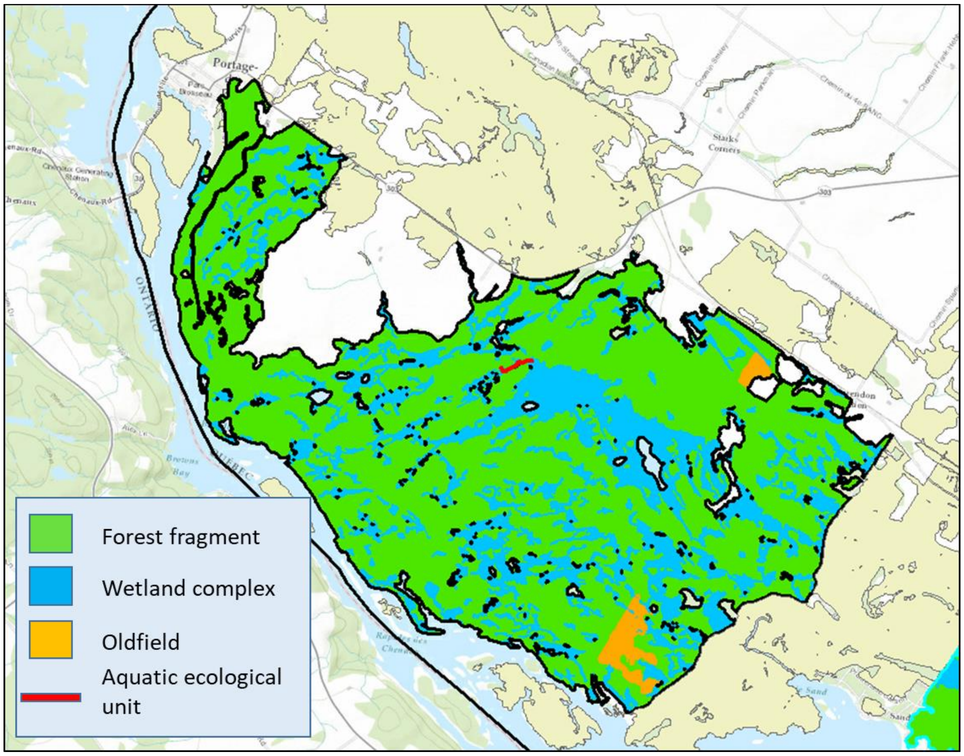


Figure 27. Example of a multi-target site of interest (Portage-du-Fort, Outaouais region)

Table 33 shows the total number of sites of interest for each of the conservation targets selected in the multi-target sites of interest. Note that the sum of the total number of forest fragments and wetland complexes present within the multi-target sites of interest is slightly greater than the total number of sites selected, since many of these sites are made up of map features composed of multiple parts.

Table 33. Total number of sites selected from each of the conservation targets within the multi-target sites of interest

Number of targets	Total number of sites of interest				
	Forest fragments	Wetland complexes	Old fields	AEUs	Total
4	80	524	36	95	735
3	197	964	71	204	1 436
2	632	1 740	38	196	2 606
1	748	2 039	53	217	3 057
Total	**1 657**	**5 267**	**198**	**712**	**7 834**

14.8. Fine-filter sites of interest

14.8.1. St. Lawrence corridor

The following elements in the St. Lawrence corridor have a high value for the conservation of aquatic species and their habitats:

Occurrences of fish species at risk: An extraction from the database of the Centre de données du patrimoine naturel du Québec (CDPNQ, 2017) produced a series of occurrences in the form of areas and points representing the habitat of the targeted species:

- American Shad (*Alosa sapidissima*): migratory species, designated vulnerable under the Quebec *Act respecting threatened or vulnerable species* (LEMV) (5 occurrences in the database);
- Grass Pickerel (*Esox americanus vermiculatus*): species likely to be designated under the LEMV and assessed as Special Concern in Canada under the *Species at Risk Act* (SARA) (4 occurrences);
- Stonecat (*Noturus flavus*): species likely to be designated under the LEMV (53 occurrences);
- Copper Redhorse (*Moxostoma hubbsi*): species designed as threatened under the LEMV and assessed as Endangered in Canada (3 occurrences);
- Eastern Sand Darter (*Ammocrypta pellucida*): species designated as threatened under the LEMV and assessed as Threatened in Canada (37 occurrences);
- Rainbow Smelt (*Osmerus mordax*), St. Lawrence southern estuary population: migratory species, designated vulnerable under the LEMV (9 occurrences);
- Lake Sturgeon (*Acipenser fulvescens*): migratory species, likely to be designated as threatened or vulnerable under the LEMV (21 occurrences);
- Channel Darter (*Percina copelandi*): species designated as vulnerable under the LEMV and assessed as Threatened in Canada (62 occurrences);
- Northern Brook Lamprey (*Ichthyomyzon fossor*): species designated as threatened under the LEMV and assessed as Special Concern in Canada (5 occurrences);
- Bridle Shiner (*Notropis bifrenatus*): species designated as vulnerable under the LEMV and assessed as Special Concern in Canada (48 occurrences).

Figure 28 illustrates the habitat distribution of these ten species, all species combined, in the St. Lawrence River corridor and its tributaries.

Critical habitat (CH) identified under the *Species at Risk Act*: Official polygons from the Department of Fisheries and Oceans, representing critical habitats and the range of the following species (Figure 29):

- Eastern Sand Darter (3 CH and 1 distribution) (DFO, 2014);
- Copper Redhorse (13 CH) (DFO, 2012b);

- Striped Bass (*Morone saxatilis*) (1 CH and 2 distributions) (Robitaille et al., 2011);
- Beluga (1 CH and 1 distribution in the middle estuary) (DFO, 2012a);

Lake Sturgeon spawning grounds (COSEWIC, 2017): Figure 30 shows the distribution of the 34 known spawning grounds of lake sturgeon in southern Quebec (shown as points), the majority of which are natural spawning sites and a few are constructed sites. These spawning grounds are typical swift-water habitats, located mainly at the mouths of tributaries of the St. Lawrence as well as in the St. Lawrence river corridor, at the base of sometimes impassable weirs; the substrate is a heterogeneous mixture of sand, gravels, cobbles, pebbles and even boulders.

Known spawning grounds in the fluvial section of the St. Lawrence system: Figure 31 shows the distribution of the spawning grounds of 72 fish species combined which are present in the fluvial section of the St. Lawrence and its main tributaries (Mingelbier and Leclerc, 2001). There are more than 325 areas (polygons) and 225 points representing the habitats of the fish species selected. Most of the data come from the 1970s (22 references), 1980s (117) and 1990s (57), and some data are from the 1940s (1), 1950s (1) and 1960s (3).

The database associated with these spawning grounds also contains a toponymical description of the water body, a qualitative indication of current velocity (slow, mixed and rapid), the short and long reference with a sequential number, year of publication, and a list of bibliographic references (141 in all).

It should be noted that a "general public" version of the Atlas of Sites of Conservation interest in the St. Lawrence Lowlands which is to be produced soon will include insets describing exceptional aquatic environments, such as the mouths of the main tributaries of the St. Lawrence, the deep natural trenches in the St. Lawrence, and the maximum turbidity zone in the Middle Estuary, as well as important sites at Lake Saint-Pierre.

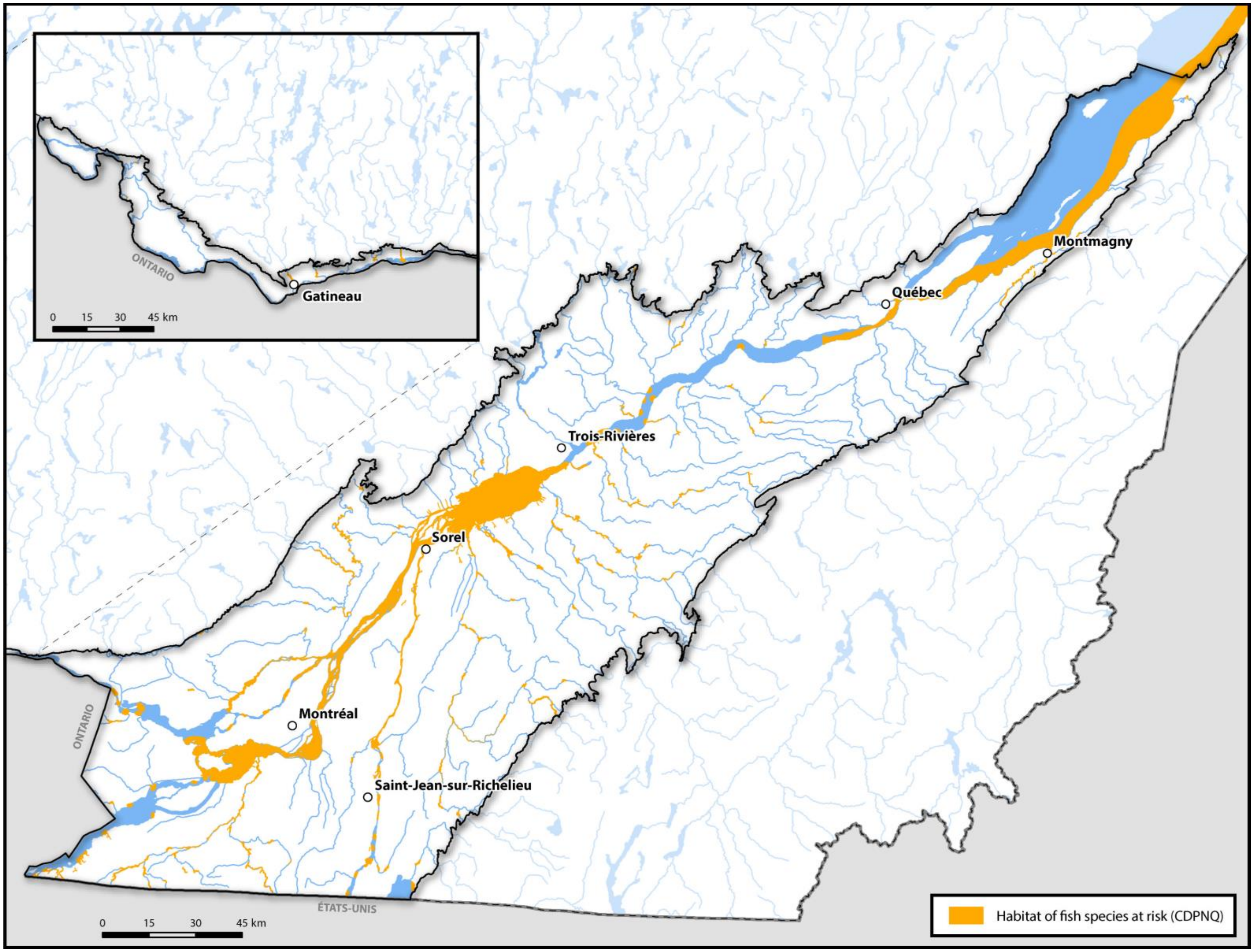


Figure 28. Habitats of fish species at risk (CDPNQ, 2017)

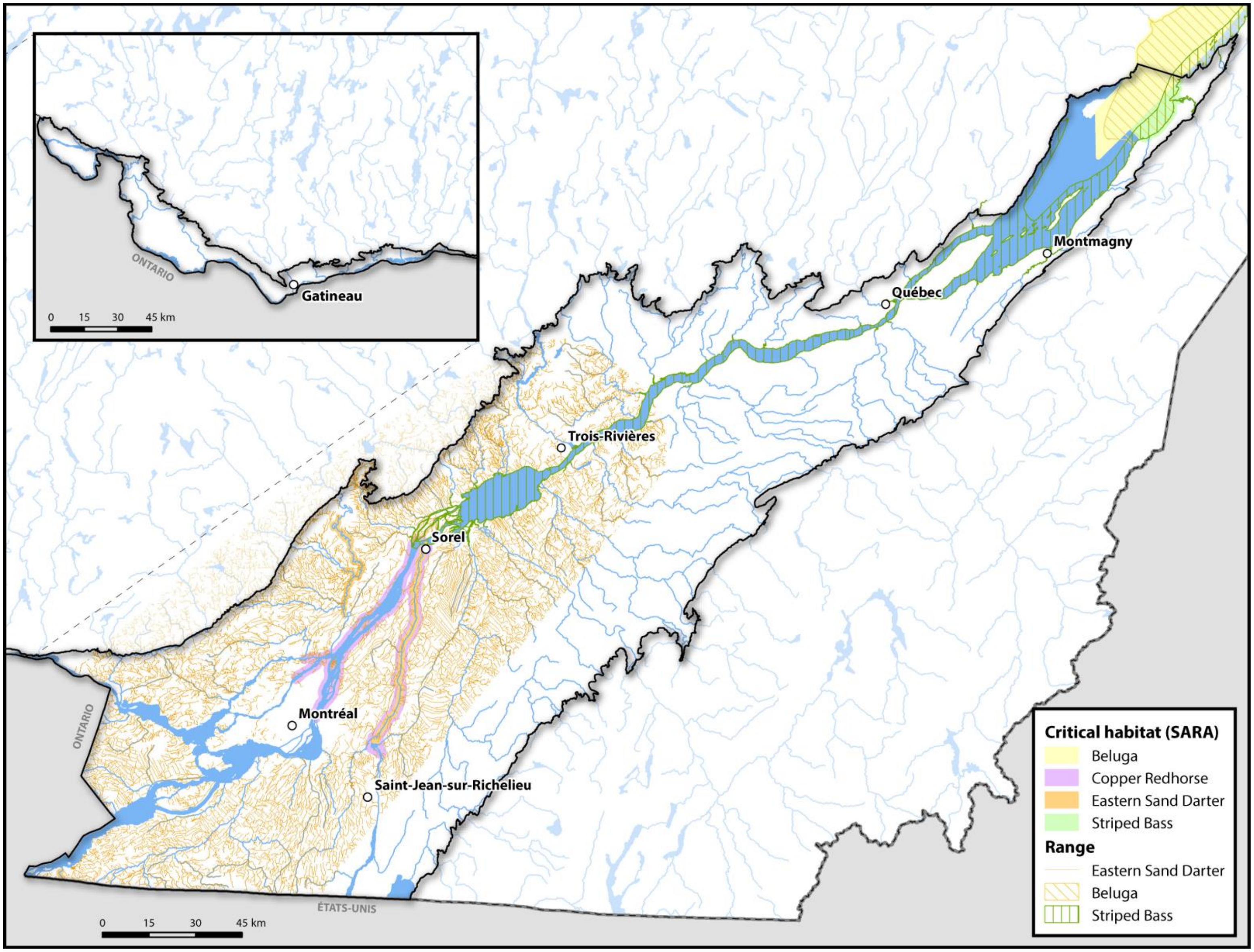


Figure 29. Critical habitats and distribution of sand darter, copper redhorse, striped bass and beluga whales in the study area

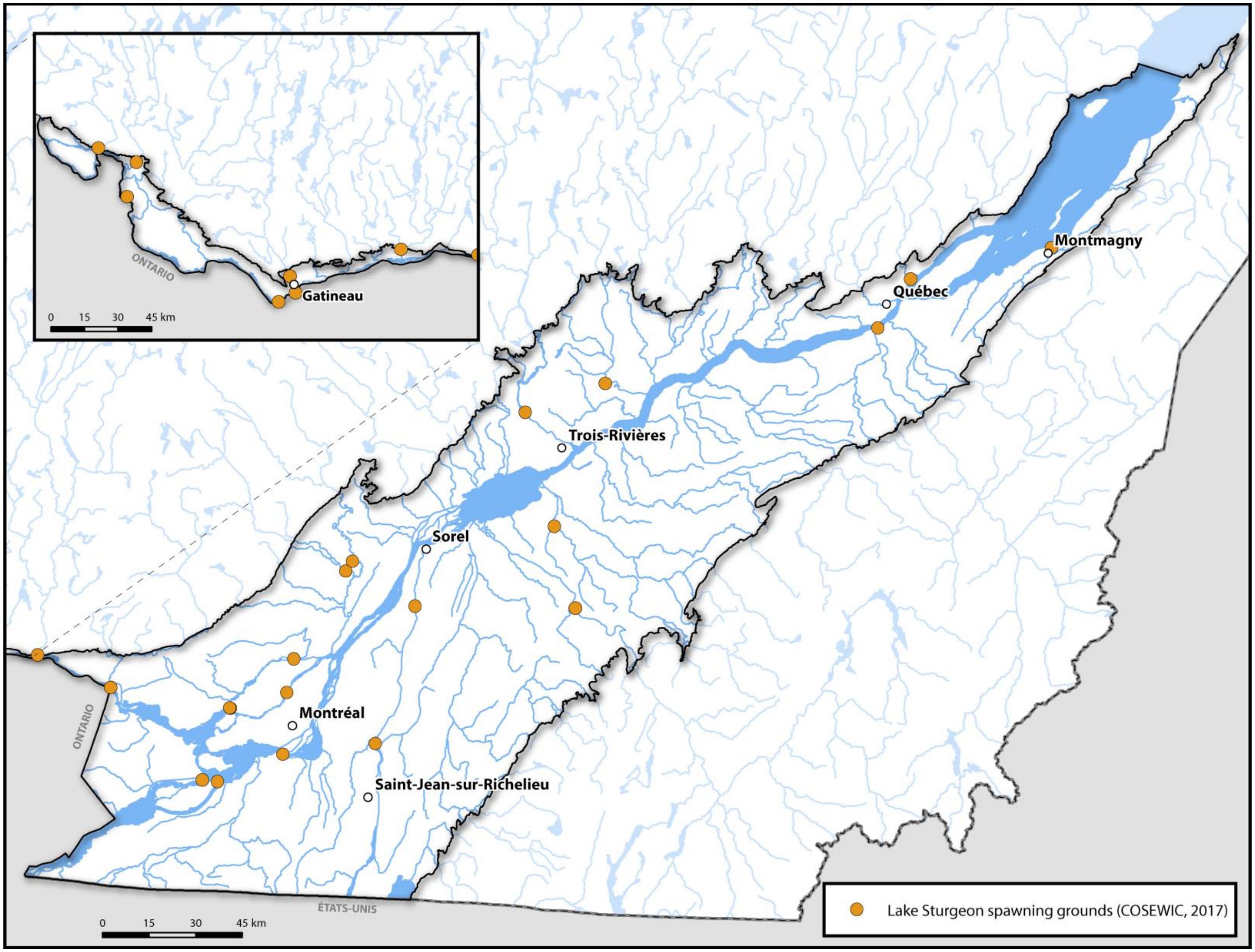


Figure 30. Known Lake Sturgeon spawning grounds in the St. Lawrence system

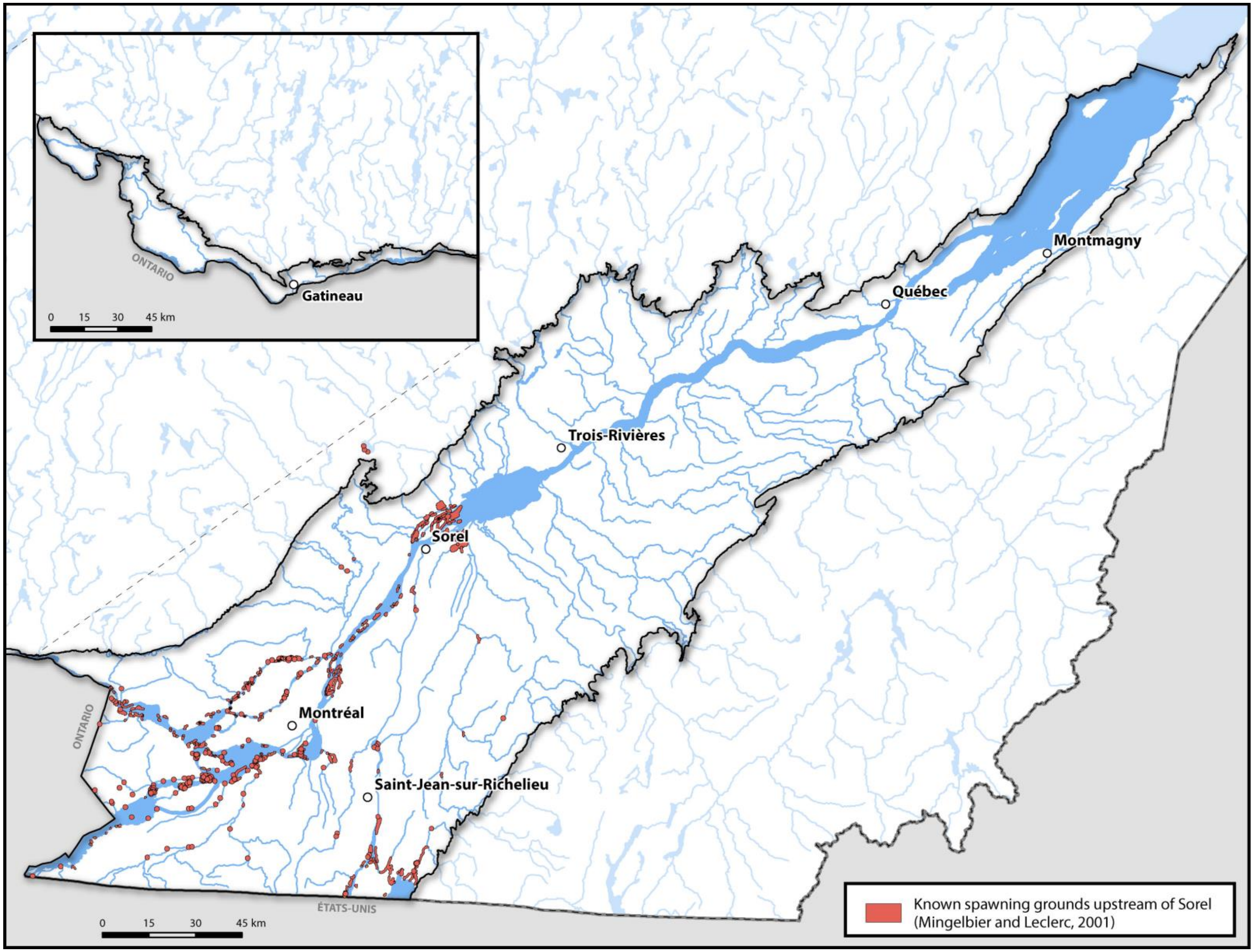


Figure 31. Known spawning grounds in the fluvial portion of the St. Lawrence system, upstream of Sorel

14.8.2. Important wildlife elements

Figure 32 shows the distribution of nests of bird species at risk that were not considered during the selection of habitat patches of interest. It can be seen that the nesting and roosting sites of chimney swifts, a species that is now closely linked to chimneys, are mostly located in urban centres like Montreal, Quebec City, Trois-Rivières and Saint-Hyacinthe as well as in many other cities and towns.

Bank swallow colonies, although typically associated with sandy shorelines along the St. Lawrence and its tributaries, are also often found in sand and gravel pits in all regions of the St. Lawrence Lowlands. Two diurnal raptor species, the peregrine falcon and the bald eagle, show encouraging signs of recovery with expanding populations. All the known nests of bald eagles are located near large bodies of water (St. Lawrence River, Lake Champlain) while peregrine falcons may build their nests in quarries and on anthropogenic structures such as buildings and bridges.

There are many large bird colonies in the fluvial estuary downstream from Île d'Orléans (Isle-aux-Grues, Pilier de Bois, Pilier de Pierre, Batture aux Loups marins) and around Grande Île de Berthier, and a number of other colonies are found in the Montreal area (Lachine Rapids, Îles de la Paix, Parc national d'Oka, Beauharnois Canal).

14.8.3. Important plant elements

Figure 33 shows the alvars and the 202 plant occurrences given a priority ranking of 10 to 13 (appendix C) which are associated with 61 different species. Most of the 28 alvars in Quebec are located in the Outaouais region whereas some others are located in the regions of Hemmingford, Laval, Joliette and Pointe-des-Cascades.

Among the 202 illustrated occurrences, the plant species that are associated with more than 5 occurrences are as follows: *Cardamine concatenate* (12), *Carex folliculate* (10), *Woodwardia virginica* (10), *Wolffia borealis* (9), *Cicuta maculata* var. *victorinii* (8), *Ranunculus flabellaris* (8), *Carya ovata* var. *ovata* (7), *Cypripedium arietinum* (7), *Bromus kalmia* (6), *Floerkea proserpinacoides* (6), *Isoetes tuckermanii* (6), *Panax quinquefolius* (6) and *Zizania aquatica* var. *brevis* (6). The great majority of these occurrences are located in the fluvial estuary of the St. Lawrence and in the Montérégie region (Haut-Richelieu, Saint-Amable, Châteauguay, Île Perrot, Monteregian hills).

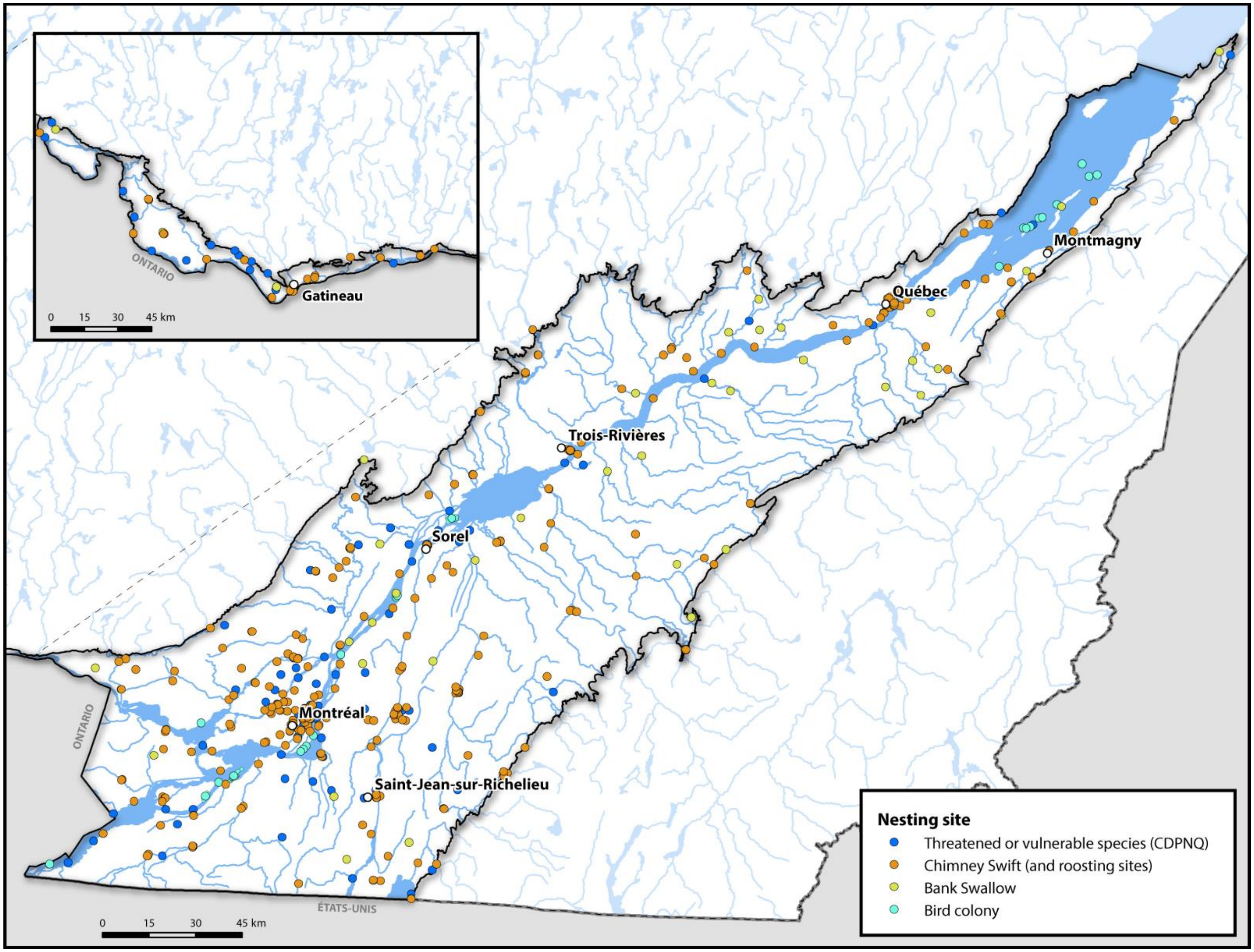


Figure 32. Distribution of bird colonies (n=17) and nesting sites of the chimney swift (n=385), the bank swallow (n=40) and other threatened or vulnerable bird species in Quebec (n=83) in the St. Lawrence Lowlands

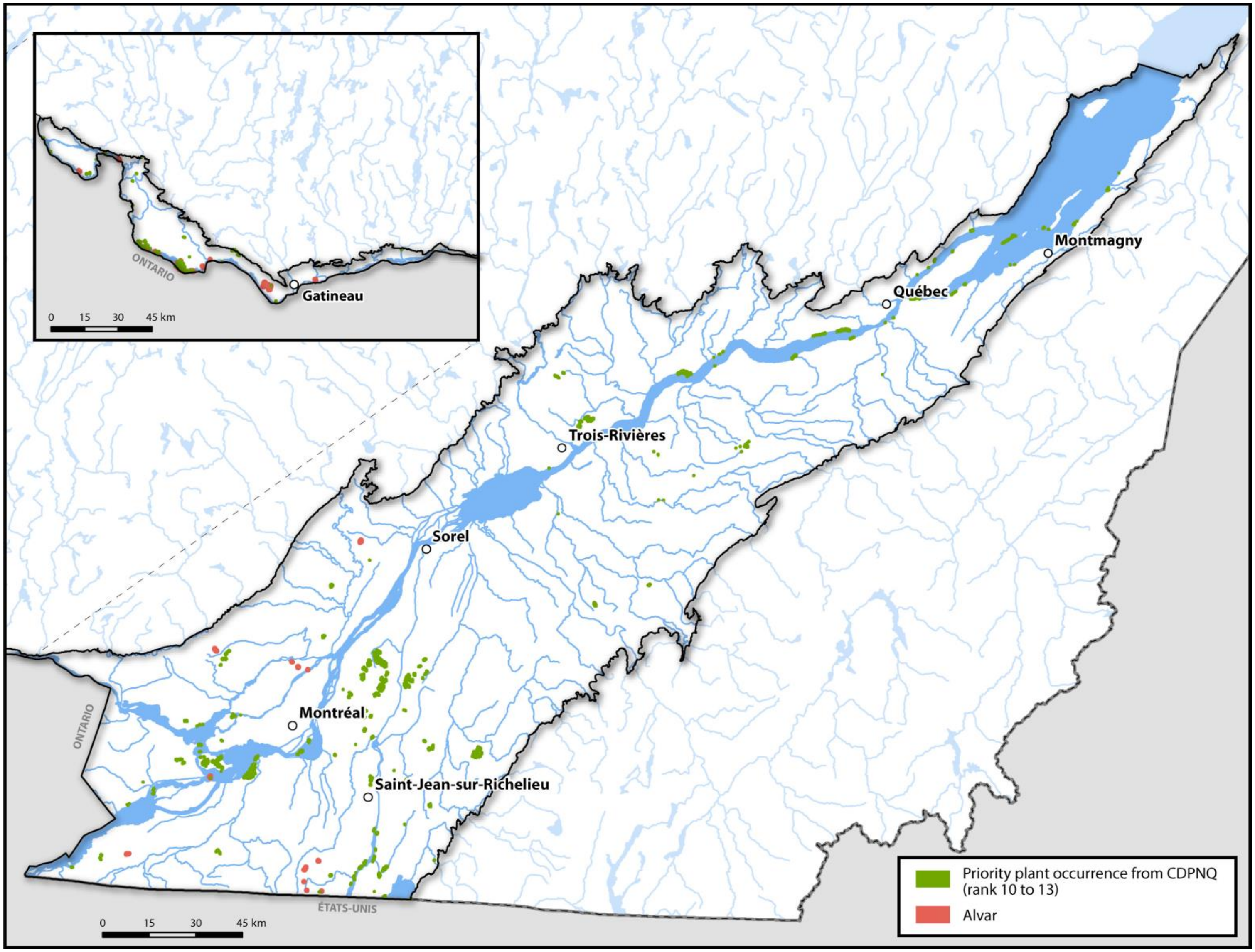


Figure 33. Distribution of the 11 alvars (red) and 202 occurrences of plant species with a detailed priority ranking ranging from 10 to 13 (green) in the study area

15. Open standards conservation plan

This Atlas identifies areas where conservation actions could be implemented. According to the Open Standards framework (CMP, 2013), the Atlas includes only the first steps in developing a conservation plan, namely the identification of conservation targets. In order to develop an action plan leading to concrete and achievable conservation strategies, several steps will have to be taken, first by looking at the St. Lawrence Lowlands as a whole, but eventually at the scale of smaller territorial units, given the wide disparity in anthropogenic influence in the study area.

These steps, briefly described below based on the CMP standards (2013) and the guide by Lapointe et al. (2015), are as follows:

1) Viability analysis of targets;
2) Threat analysis;
3) Situation analysis;
4) Determination of goals for each conservation target;
5) Planification of the conservation strategies and actions;
6) Monitoring plan.

15.1. Viability analysis

Viability analysis is conducted to identify the key ecological attributes that will determine the "health" status of conservation targets, be it an ecosystem or a specific population of a plant or animal species. Specifically, viability indicates the ability of a conservation target to withstand and recover from most natural or human disturbances and thus survive for many generations. An ecological attribute is an aspect of the biology or ecology of a target that, if missing or altered, would ultimately lead to the loss or extreme degradation of that target. There are three categories of attributes that determine the health status of a conservation target: size, condition, and geographic context (CMP, 2013). Whenever possible, all three attribute categories are used to qualify the viability of a target, and generally the number of ecological attributes is limited to five.

- **Size** is a measure of the area occupied by the occurrence of a target (for an ecosystem) or a measure of the abundance of the occurrence of a target (for a species or population).
- The **condition** is a measure of the biological composition, structure and biotic interactions that characterize the space in which the target is located.
- **Geographic context** is an assessment of the target's environment, including:
  a) *the ecological processes and regimes*, which maintain the presence of the target, such as floods, fire regimes and other natural disturbances;
  b) *connectivity*, which allows the target species to access habitats and resources or to respond to environmental change through dispersal or migration.

For each ecological attribute, an indicator is identified. This unit of information must be measurable over time in order to document changes in the health status of the target. For each indicator, the degree of variation tolerated, or viability threshold, establishes minimum criteria for designating a conservation target in "good condition". This degree of variation corresponds to the limits of natural variation of the target, which are the minimum conditions for the target to survive. If the attribute falls outside these limits, then it is a degraded attribute whose maintenance may require human management interventions. To simplify the analysis of key ecological attributes and to classify the status of conservation targets (CMP, 2013), the indicator values are ordered into four classes:

- Low - increasingly difficult to restore; may result in extinction;
- Medium - outside the range of variation tolerated; requires human intervention;
- Good - indicator within the tolerated degree of variation; requires some intervention to maintain;
- Very good - desired ecological status; requires little intervention to maintain.

15.2. Threat analysis

The list of threats briefly presented in section 7 must be completed and the description of the threats must be clarified by a review of the literature specific to the study area. Each of the threats will be evaluated to determine which ones will have the most critical effects on the maintenance of the targets within a given time frame (e.g., ten years). To achieve this, the open standards suggest a threat ranking method that determines the scope, severity and irreversibility of each threat for each target. A preliminary assessment will be validated by experts supporting the project team. Where possible (depending on the nature of the threat and available data), a map showing the spatial footprint and intensity of specific threats will be produced to support the assessment of their relative scope and severity. Based on this assessment, threats will be ranked from highest to lowest. Some threats may not be assessed due to lack of data or knowledge. If, in the opinion of experts, these are likely to be significant in the short to medium term, a knowledge acquisition strategy may be included in the action plan.

15.3. Situation analysis

The situation analysis, or diagnosis, aims to describe how past human activities have modified land use and how, in the near future, these activities are likely to directly or indirectly affect the biodiversity of the area under study. It makes it possible to describe the relationships between the biological environment and the social, economic, political and institutional systems and drivers that disrupt the conservation targets. On the one hand, a brief description of the current socio-economic situation and emerging trends will help identify sectors of activity (e.g., urban sprawl) or specific activities and phenomena (e.g., proliferation of exotic species) that may have an impact on the conservation targets. Based on this diagnosis, the contributing factors (also referred to as indirect threats or underlying causes) that give rise to the most significant direct threats and that ultimately affect the conservation targets will be identified. The development of a conceptual model allows visualization of the links (chain of factors) between a threat(s) and the factors. On the other hand, this analysis also aims to identify the conservation context, i.e., the stakeholders (individuals, organizations, institutions) and conditions (interests, regulatory tools, resources, etc.) that could constitute constraints or opportunities with regard to the implementation of the conservation plan (e.g., new legislative measures). This portion of the analysis helps to identify stakeholder interests and relationships that deserve special attention as they may affect the success or failure of conservation strategies.

15.4. Determination of goals for each conservation target

Goals are explicit statements of what the conservation plan wishes to accomplish in the study area. Goals are linked to conservation targets, are outcome-oriented, measurable, time-bound and specific. They are usually based on the future state of health sought for each of the targets as previously established by the viability analysis. Since targets may include multiple indicators, each of which has a desired future state, there may be multiple goals for each target or multiple indicators may be combined and incorporated into a single goal statement for a target. While some desired future states may be achievable during the implementation of the conservation plan (e.g., within 15 years), in many cases the required time frame may be longer (e.g., 25, 50, 100 years or more). Setting such long-term goals allows the project team and potential partners to understand the magnitude of what is required to ensure the protection of all biodiversity in perpetuity. In this case, the goal of implementing the conservation plan will be an intermediate goal towards achieving the desired future state.

15.5. Planification of the conservation strategies and actions

Strategy planning involves determining where and how to intervene. The first step is to decide on which contributing factors an intervention(s) would be most likely to achieve the goals of the conservation plan; these are the key points of intervention. For each of these points, a list of strategies based on literature, current practices, or creative actions by the project team and experts will be produced. Each of the selected strategies will have to specify the desired result(s) of its implementation. The open standards suggest starting from the conceptual model to translate each chain of factors into a results chain. This in effect describes the assumptions expressed in terms of expected results about the mitigation of a direct threat and the influence exerted on a contributing factor. Strategies are then prioritized to identify those strategies that are likely to have the greatest impact on the conservation of the targets and that optimize the overriding interests of stakeholders, thereby limiting potential conflicts or facilitating partner buy-in.

For each of the selected strategies, a set of actions is developed, integrating opportunities and constraints for implementation. An action is a measure taken to implement one of the project strategies. Strategies may include a wide range of actions such as changing government directions and policies, strengthening municipal regulations, habitat restoration, land protection, education and awareness. Each action must correspond to a distinct set of specific and complementary tasks that must be carried out to achieve the desired result. For each of the actions, a clear objective is established; it must be results-oriented, measurable, time-bound, specific and practical.

15.6. Monitoring plan

Since the Open Standards is an adaptive management process, this requires the use of effective monitoring programs designed to integrate the design, management and monitoring of actions so that assumptions explicitly stated prior to implementation can be systematically tested. Monitoring is essential to be able to determine which strategies and actions have succeeded or failed and why. Such evaluations will make it easier to justify the continuation of actions undertaken or to adapt and modify planned actions to improve their effectiveness. Ultimately, the monitoring data should also provide the information needed to assess progress towards achieving the goals set for each target in the conservation plan.

16. Action plans

The development and implementation of an action plan for such a vast territory is an ambitious project. On the other hand, several possibilities are envisaged to create a synergy around the production of the Atlas and to develop implementation tools. In addition to making the data available, the project team plans to conduct an analysis aimed at identifying sub-regions within the St. Lawrence Lowlands where conservation actions are required as a priority. Identifying these areas where the situation is the most critical will make it possible to focus the implementation of conservation strategies. The mapping of the human footprint in the St. Lawrence Lowlands using the methodology proposed by Woolmer et al. (2008) and applied to recent land use mapping is a tool currently under development.

In addition, complementary analyses to characterize the condition of ecosystems in the St. Lawrence Lowlands have been completed or are in the process of being completed. For example, an analysis of structural connectivity to characterize the state of forested areas and surrounding matrices in terms of their propensity to displace forest species was recently completed (Rayfield et al., 2019). The methodology developed by Gonzalez et al. (2013) in Montérégie was therefore applied to detailed land use mapping of the St. Lawrence Lowlands, which made it possible to identify sectors that are critical to terrestrial connectivity. These "nodes" can then be compared to the sites of interest of the conservation targets, including multi-target sites, which will make it possible to add value to certain sectors in the event that some of these sites of conservation interest correspond to connectivity nodes. An analysis of aquatic connectivity is also planned in the coming months. Coupled with the results of the Atlas, this analysis will provide a better understanding of the importance of certain elements of the river system for the conservation of biodiversity and the movement of aquatic species. Reflections are also underway to characterize the resilience of the main terrestrial (forests, wetlands, agriculture) and aquatic ecosystems to anticipated changes due to climate change. The development of criteria to quantify this resilience is being considered, which would also make it possible to link these results to the sites of interest in the Atlas. The addition of these two inputs that characterize the ecosystems of the St. Lawrence Lowlands, namely structural connectivity and resilience to climate change, should thus make it possible to develop regional action plans to plan the conservation of the most integrated, functional and resilient sites of interest.

Other tools also remain to be developed, such as a methodological guide to facilitate the regional application of the Atlas tools, as well as a series of webinars focusing on the use of the data and on the implementation of conservation projects at regional and local scales already carried out or in progress according to the Open Standards. Related topics will also be addressed, including the integration of connectivity, ecological services and climate change adaptation into conservation plans.

A presentation tour is also envisaged, with the objectives of 1) validating the results of the analyses with regional experts, 2) presenting conservation tools, 3) initiating the development of conservation strategies with stakeholders, and 4) identifying geographic entities, sectors or territories where pilot projects could be carried out. Inspired by the conceptual framework proposed by Raymond et al. (2017), the pilot projects could serve as a reference to inform, learn from and refine the implementation of conservation strategies specific to recurring issues. The most effective strategies could then be transposed to the scale of the study area.

17. Publicly available data

In order to guide the development of conservation strategies and future action plans, the information layers and analysis results for identifying sites of interest related to the coarse filter conservation targets (forest fragments, wetland complexes, old fields, aquatic ecological units, topographic complexes) as well as data on the distribution of alvars and bird colonies are publicly available in ther Data Catalogue of the St. Lawrence Global Observatory website (https://catalogue.ogsl.ca/en). Users will thus be able to access this information to visualize more precisely the location of sites of interest. In addition, they will be able to continue the analyses as they wish based on specific objectives related to their interests or regional realities.

However, a request must be made directly to the managers of certain databases whose public dissemination is restricted. These include exceptional forest ecosystems (MFFP), data on threatened and vulnerable species from the CDPNQ (MELCC, MFFP), critical habitats of species at risk (ECCC, DFO), data on fish spawning grounds (MFFP), data on birds at risk from the SOS-POP database (Regroupement QuébecOiseaux) and the Répertoire des sites de conservation volontaire du Québec (RMN). Finally, it is possible to download information on protected areas listed in the Registre des aires protégées au Québec (MELCC) and the Cadre écologique de référence (MELCC) from the Québec government's open data portal (https://www.donneesquebec.ca/fr/).

18. Conclusion and future perspectives

The Atlas of Sites of Conservation Interest in the St. Lawrence Lowlands provides a synthesis of current knowledge on the spatial distribution of areas with a high potential for maintaining biodiversity. Complementary to existing territorial planning, this information enhances current knowledge on the conservation needs of natural environments and biodiversity and will be useful in guiding the conservation actions of organizations active in this area. As this document is a methodological report that aims to explain in detail the data sources and methods used to prioritize the territories to be conserved, an Atlas, in the true sense of the term, will be produced shortly, in which the emphasis will be on the presentation of results and cartographic assemblies. In addition, the results of other complementary analyses will be added, such as the aquatic ecological units of interest, when LIDAR data become available.

Obviously, the determination of the conservation actions required to maintain the ecosystems in place will be modulated by the conservation value of the sites and the threats and pressures they face. The production of regional action plans integrating the needs of the various regional stakeholders will be necessary in order to consider the maintenance of the integrity of the ecosystems, the pressures acting on them and the particular needs of the stakeholders in the area. Thematic action plans are also being considered in order to identify conservation actions associated with global themes or that have been somewhat ignored in the past (e.g., old fields management, conservation of agricultural landscapes). The uniqueness of the Open Standards approach to conservation will therefore be evident here. In addition, because the results and geospatial data associated with the sites of interest in this Atlas are available, regional stakeholders will be able to more accurately view the spatial distribution of sites of interest and the conservation value associated with each habitat patch of the coarse and fine filter conservation targets using geographic information systems (e.g., ArcGIS). Users will also be able to adapt the analysis of these data to their territorial reality and according to their needs. Since this Atlas is intended to be a tool to assist in land use planning, it is hoped that the sites of interest resulting from the analyses can be considered in the context of the revision of metropolitan land use and development plans (PMAD), RCM land use plans and municipal urban plans.

The production of such an atlas depends on existing information on the ecosystems in place as well as on knowledge of the wildlife and plant populations that inhabit them. The detailed mapping of land use (ECCC and MDDELCC, 2018) is, in itself, a major achievement that has made this Atlas possible. A considerable effort was also made to select and sort the databases used for the selection and prioritization of natural environments; expert advice was then of great use in ensuring that only the most accurate, precise and relevant information was considered. Furthermore, consideration of the major types of ecosystems present in the St. Lawrence Lowlands, other than forests and wetlands, responds to a recommendation from the last conservation plan produced for this ecoregion (Gratton, 2010). The integration of aquatic ecosystems and significant wildlife components of the St. Lawrence corridor, as well as the ongoing analysis of terrestrial (and aquatic) connectivity, are all innovative elements of this Atlas that will help guide and complement the planning of priority conservation areas.

19. References

ADSAVAKULCHAI, S., D. MINNS and A. CHAN (2004). « Assessing the interaction of vegetation diversity and land use using remote sensing: An example in Southeastern Ontario, Canada ». *Environmental Informatics Archives* 2, p. 499-508.

AMOROS, C., and G.E. Petts, réd. (1993). *Hydrosystèmes fluviaux*. Paris, Masson, 300 p. (Collection Écologie no 24).

ANDRÉN, H. (1994). « Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review ». *Oikos,* vol. 71, nº 3, p. 355-366.

ÅS, S. (1999). « Invasion of matrix species in small habitat patches ». [En ligne], *Conservation Ecology*, vol. 3, nº 1, article 1, [http://www.consecol.org/vol3/iss1/art1/index.html] (Consulté le 26 octobre 2018).

AVARD, K., M. LAROCQUE and S. PELLERIN (2013). « Perturbations des tourbières de la région de Bécancour, Centre-du-Québec, entre 1966 et 2010 ». *Le Naturaliste canadien*, vol. 137, nº 1, p. 8-15.

BAGNOLD, R. A. (1966). *An approach to the sediment transport problem from general physics*. Geological Survey Professional Paper 422-1, 37 p.

BAZOGE, P., D. LACHANCE and C. VILLENEUVE (2015). *Identification et délimitation des milieux humides du Québec méridional*. Québec, ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, Direction de l'écologie et de la conservation et Direction des politiques de l'eau, 64 p. + annexes.

BEAULIEU, R., 2001. *Historique des travaux de drainage au Québec et état du réseau hydrographique*. Sainte-Marthe, Colloque régional sur les cours d'eau, gouvernement du Québec, ministère de l'Agriculture, des Pêcheries et de l'Alimentation, Direction régionale de la Montérégie, secteur Ouest, 12 p.

BEAULIEU, J., G. DAIGLE, F. GERVAIS, S. MURRAY and C. VILLENEUVE. (2010). *Rapport synthèse de la cartographie détaillée des milieux humides du territoire de la Communauté métropolitaine de Montréal*. Québec, Canards Illimités–Québec et ministère du Développement durable, de l'Environnement et des Parcs, Direction du patrimoine écologique et des parcs, 60 p.

BÉLANGER, L., and M. GRENIER (2002). « Agricuture intensification and forest fragmentation in the St. Lawrence valley, Québec, Canada ». *Landscape Ecology,* vol. 17, nº 6, p. 495-507.

BÉLANGER, L., M. GRENIER and S. DESLANDES (1999). *Bilan des habitats et de l'occupation du sol dans le sud du Québec*. Environnement Canada, Service canadien de la faune, région du Québec.

BELLAVANCE, D., T. LI and F. POISSON (2019). *Le cadre écologique de référence des basses-terres du Saint-Laurent : Cartographie et classification des districts écologiques – Notice explicative*. Québec, ministère de l'Environnement et de la Lutte contre les changements climatiques, Direction de la connaissance écologique, Québec, 59 p.

BENÍTEZ-LÓPEZ, A., R. ALKEMADE and P. A. VERWEIJ (2010). « The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis ». *Biological Conservation*, vol. 143, nº 6, p. 1307-1316.

BENTON, T.G., J.A. VICKERY and J.D. WILSON (2003). « Farmland biodiversity: Is habitat heterogeneity the key? » *Trends in Ecology and Evolution*, vol. 18, nº 4, p. 182-188.

BÉRARD, J., and M. CÔTÉ (1996). Manuel de foresterie. Publié par Les Presses de l'Université Laval en collaboration avec l'Ordre des ingénieurs forestiers du Québec, 1428 p.

BIBEAU, S., and C. ROULEAU, 2007. *Mémoire sur le projet de règlement sur le contrôle des déversements d'eaux usées dans les ouvrages d'assainissement et cours d'eau*. Montréal, Comité de la zone d'intervention prioritaire (ZIP) Jacques-Cartier, 10 p.

BILODEAU, P., B. DUMAS and H. MASSÉ (2004). *Composition et état de santé de la communauté des poissons de la baie Missisquoi, lac Champlain, été 2003*. Québec, ministère des Ressources naturelles et de la Faune, 66 p.

BLAIS, D., M.J. CÔTÉ, J. SUAZO and D. LECLERC. (in preparation). *Méthodologie d'identification des milieux aquatiques : Atlas des territoires d'intérêt pour la conservation dans les Basses-terres du Saint-Laurent*. Québec, ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, Direction de l'expertise en biodiversité, XX p.

BLANCHER, P. (2013). « Estimated number of birds killed by house cats (*Felis catus*) in Canada ». [En ligne], *Avian Conservation and Ecology*, vol. 8, nº 2, article 3, [http://www.ace-eco.org/vol8/iss2/art3/] (Consulté le 26 octobre 2018).

BOIVIN, V., and C. CÔTÉ (2014). *Inventaire de la héronnière de La Grande Île, Archipel du lac Saint-Pierre, 1975 à 2011*. Québec, ministère des Forêts, de la Faune et des Parcs, Direction de la gestion de la faune de Lanaudière et des Laurentides, 40 p.

BOUCHARD, A., and G. DOMON (1997). « The transformations of the natural landscapes of the Haut-Saint-Laurent (Québec) and their implications on future resource management ». *Landscape and Urban Planning*, vol. 37, nºs 1-2, p. 99-107.

BOUCHER, I., and N. FONTAINE (2010). *La biodiversité et l'urbanisation, Guide de bonnes pratiques sur la planification territoriale et le développement durable*. [En ligne], Québec, ministère des Affaires municipales, des Régions et de l'Occupation du territoire, 178 p. [www.mamrot.gouv.qc.ca] (Collection Planification territoriale et développement durable).

BOUTHILLIER, L., P. DUMONT and G. ROY (1993). *Répertoire des habitats du poisson de la région de Montréal*. Montréal, ministère du Loisir de la Chasse et de la Pêche du Québec, Service de l'aménagement et de la Faune, Direction régionale de Montréal, ii + 6 p. + fiches d'habitats + 18 cartes d'habitats à l'échelle 1:50 000.

BOUTIN, C., B. JOBIN and L. BÉLANGER (2003). « Importance of riparian habitats to flora conservation in farming landscapes of southern Québec, Canada ». *Agriculture, Ecosystems and Environment*, vol. 94, nº 1, p. 73-87.

BOYER, C., D. CHAUMONT, I. CHARTIER and A.G. ROY (2010). « Impact of climate change on the hydrology of Saint-Lawrence tributaries ». *Journal of Hydrology*, vol. 384, n[os] 1-2, p. 65-83.

BRAUN-BLANQUET, J. (1964). *Pflanzensoziologie. Grundzüge der Vegetationskunde,* 3[e] édition. Wien-New York, Springer, 865 p.

BRETAGNOLLE, V., B. GAUFFRE, H. MEISS and I. BADENHAUSSER (2011). « The role of grassland areas within arable cropping systems for the conservation of biodiversity at the regional level ». Dans Lemaire, G, J. Hodgson et A. Chabbi (dir.) *Grassland productivity and ecosystem services*, p. 251-270, Wallingford, CAB International, 296 p.

BRINSON, M.M. (1993). *A Hydrogeomorphic Classification for Wetlands*. Wetlands Research Program TR-WRP-DE-4, Washington, D.C., US Army Corps of Engineers, 101 p.

BRISSON, J., Y. BERGERON and A. BOUCHARD (1988). « Les successions secondaires sur sites mésiques dans le Haut-Saint-Laurent, Québec, Canada ». *Revue canadienne de botanique*, vol. 66, n[o] 6, p. 1192-1203.

BUREL, F., A. BUTET, Y.R. DELETTRE, and N. MILLÀN de la PENA (2004). « Differential response of selected taxa to landscape context and agricultural intensification ». *Landscape and Urban Planning*, vol. 67, n[os] 1-4, p. 195-204.

CAMPBELL, C., D.H. VITT, L.A. HALSEY, I.D. CAMPBELL, M.N. THORMANN and S.E. BAYLEY (2000). *Net Primary Production and Standing Biomass in Northern Continental Wetlands*. Edmonton, Ressources naturelles Canada, Service canadien des forêts, Centre de foresterie du Nord, 57 p.

CAMPBELL, D., and L. ROCHEFORT (2001). « La végétation : gradients ». Dans Payette, S., et L Rochefort (dir.) *Écologie des tourbières du Québec-Labrador*, p. 129-140. Québec, Presses de l'Université Laval, 644 p.

CARLSON, J.R. (1992). « Selection, production, and use of riparian plant materials for the Western Unites States ». Dans Landis, T.D., *Proceedings, Intermountain Forest Nursery Association 1991, August 12-16, Park City, Utah*. General Technical Report RM-211, Fort Collins, Colorado, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, p. 55-67.

CAYOUETTE, J., A. SABOURIN and D. PAQUETTE (2010). *Les alvars du Québec : caractérisation et floristique avec emphase sur les espèces menacées et vulnérables*. Québec, rapport préparé pour le ministère du Développement durable, de l'Environnement et des Parcs, Direction du patrimoine écologique et des parcs, 151 p. + annexe.

CDPNQ (2017). « Base de données sur les espèces menacées ou vulnérables du Québec ». Québec, Centre de données sur le patrimoine naturel du Québec, gouvernement du Québec, ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, ministère des Forêts, de la Faune et des Parcs et gouvernement du Canada, Environnement et Changement climatique Canada, Service canadien de la faune.

CEDFELDT, P.T., M.C. WATZIN and B. DINGEE RICHARDSON (2000). « Using GIS to identify functionally significant wetlands in the Northeastern United States ». *Environmental Management*, vol. 26, n[o] 1, p. 13-24.

CENTRE SAINT-LAURENT (1996). *Rapport synthèse sur l'état du Saint-Laurent. Volume 1 : L'écosystème du Saint-Laurent*. Montréal, Environnement Canada, région du Québec, Conservation de l'environnement, Éditions Multimondes, 1 v. (en pag. multiple) (Collection BILAN Saint-Laurent).

CEREZO, A., M. CECILIA CONDE and S.L. POGGIO (2011). « Pasture area and landscape heterogeneity are key determinants of bird diversity in intensively managed farmland ». *Biodiversity and Conservation*, vol. 20, n[o] 12, p. 2649-2667.

CHAPDELAINE, G., and J.-F. RAIL (2004*). Quebec's waterbird conservation plan*. Migratory Bird Division, Canadian Wildlife Service, Quebec Region, Environment Canada, Sainte-Foy, Quebec. 99 p.

CHONÉ, G., and P. M. BIRON (2016). « Assessing the relationship between river mobility and habitat ». *River Research and Applications*, vol. 32, n[o] 4, p. 528-539.

CLERC, C. (2009). *Suivi de la nappe, de la recharge et de l'écoulement à l'aide de méthodes in situ afin de comprendre la dynamique de tourbières ombrotrophes de la région de la Baie de James*. Mémoire (M.Sc.), Québec, Université du Québec, Institut national de la recherche scientifique, 240 p.

CMP (2013). *Open Standards – Normes ouvertes pour la pratique de la conservation, Version 3.0*. Conservation Measures Partnership, 52 p.

COMMUNAUTÉ MÉTROPOLITAINE DE MONTRÉAL (2012). *Plan d'action 2012-2017 du plan métropolitain d'aménagement et de développement*. [En ligne], 8 p. [http://cmm.qc.ca/champs-intervention/amenagement/plans/pmad/].

COSEWIC (2003). *COSEWIC assessment and status report on the butternut* Juglans cinerea *in Canada*. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 32 pp.

COSWIC (2006). COSEWIC assessment and status report on the American eel *Anguilla rostrata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 71 pp.

COSEWIC (2015). « Canadian Wildlife Species at Risk ». [On line], Committee on the status of Endangered Wildlife in Canada, [https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/publications/canadian-wildlife-species-risk-2019.html

COSEWIC (2017). *COSEWIC assessment and status report on the Lake Sturgeon* Acipenser fulvescens*, Western Hudson Bay populations, Saskatchewan-Nelson River populations, Southern Hudson Bay-James Bay populations and Great Lakes-Upper St. Lawrence populations in Canada*. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xxx + 153 pp. ((http://www.registrelepsararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1).

COSTANZA, R., H.E. DALY and J.A. BARTHOLOMEW (1991). « Goals, agenda, and policy recommendations for ecological economics ». Dans Costanza, R (dir.) *Ecological economics: the science and management of sustainability*, p. 1-21, New York, Columbia University Press, 525 p.

COUILLARD, L., and P. GRONDIN (1986). *La végétation des milieux humides du Québec*. Québec, Les Publications du Québec, 376 p. et annexes.

CRONK, J.K., and M.S. FENNESSY (2001). *Wetland Plants: Biology and Ecology*. Boca Raton, Lewis Publishers, 462 p.

DAHL, T.E. (1990). *Wetlands Losses in the United States 1780's to 1980's*. Washington, D.C., U.S. Department of the Interior, Fish and Wildlife Service, 13 p.

DAIGLE, C., and J. JUTRAS (2005). « Quantitative evidence of decline in a southern Québec Wood Turtle (*Glyptemys insculpta*) population ». *Journal of Herpetology*, vol. 39, nº 1, p. 130-132.

DAVIS, S.K., R.J. FISHER, S.L. SKINNER, T.L. SHAFFER and R. M. BRIGHAM (2013). « Songbird abundance in native and planted grassland varies with type and amount of grassland in the surrounding landscape ». *Journal of Wildlife Management*, vol. 77, p. 908-919.

DE LA CHENELIÈRE, V., P. BRODEUR and M. MINGELBIER (2014). « Restauration des habitats du lac Saint-Pierre : un prérequis au rétablissement de la perchaude ». *Le Naturaliste canadien*, vol. 138, nº 2, p. 50-61.

DEBINSKI, D.M., and R.D. HOLT (1999). « A survey and overview of habitat fragmentation experiments ». *Conservation Biology*, vol. 14, nº 2, p. 342-355.

DEBUSK, T.A., and W.F. DEBUSK (2001). « Wetlands for Water Treatment ». Dans Kent, D.M. (dir.) *Applied Wetlands Science and Technology*, Second Edition, p. 241-279, Boca Raton, CRC Press LLC, 472 p.

DeGRAAF, R.M., and M. YAMASAKI (2003). « Options for managing early-successional forest and shrubland bird habitats in the northeastern United States ». *Forest Ecology and Management*, vol. 185, nºs 1-2, p. 179-191.

DESGRANGES, J.-L., B. JOBIN, N. PLANTE and C. BOUTIN (1994). « Effets du changement du paysage rural québécois sur les oiseaux champêtres ». Dans Domon G., et J. Falardeau (sous la direction de) *Méthodes et réalisations de l'écologie du paysage pour l'aménagement du territoire : sélection des textes du quatrième congrès de la Société canadienne d'écologie et d'aménagement du paysage*, p. 177-180, Sainte-Foy, Université Laval.

DESPAULT, T.M. (2016). *Dissolved Organic Matter in Subarctic Streams and Rivers: Direct and Proxy Measures of Quantity, Quality, and Mercury*. Electronic Thesis and Dissertation Repository, 3652.

DETTMERS, R. (2003). « Status and conservation of shrubland birds in the northeastern US ». *Forest Ecology and Management*, vol. 185, nº 1, p. 81-93.

DEVITO, K.J., P.J. DILLON and B.D. LAZERTE (1989). « Phosphorous and Nitrogen Retention in Five Precambrian Shield Wetlands ». *Biogeochemistry*, vol. 8, nº 3, p. 185-204.

DFO (2012a). *Recovery Strategy for the beluga whale (*Delphinapterus leucas*) St. Lawrence Estuary population in Canada*. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. 88 pp + X pp.

DFO (2012b). *Recovery Strategy for the Copper Redhorse (*Moxostoma hubbsi*) in Canada*. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. xi+60 pp.

DFO (2014). *Recovery Strategy for the Eastern Sand Darter (*Ammocrypta pellucida*) in Canada, Quebec Populations*. Species at Risk Act Recovery Strategy Series, Fisheries and Oceans Canada, Ottawa. vii + 47 pp.

DONAT, M. (1995). *Bioengineering Techniques for Streambank Restoration. A Review of Central European Practices*. Colombie-Britannique, ministry of Environment, Lands and Parks, and Ministry of Forests, Watershed Restoration Project Report No. 2, 86 p.

DORIOZ, J.M., D. WANG, J. POULENARD and D. TRÉVISAN (2006). « The effet of grass buffer strips on phosphorous dynamics – A critical review and synthesis as a basis for application in agricultural landscapes in France ». *Agriculture, Ecosystems and Environment*, vol. 117, nº 1, p. 4-21.

DOYON, F. (2002). « Quelle est l'importance du rôle écologique du feu dans la forêt méridionale du Québec? » Dans Chabot, M., et S. Gauthier (dir.) *L'aménagement forestier et le feu : actes de colloque*, Chicoutimi, p. 33-42.

DOYON, F. and D. BOUFFARD (2009). *Enjeux écologiques de la forêt feuillue tempérée québécoise*. Québec, ministère des Ressources naturelles et de la Faune, Direction de l'environnement et de la protection des forêts, 63 p.

DUDLEY, N., éd. (2008). *Lignes directrices pour l'application des catégories de gestion aux aires protégées*. Gland, Union internationale pour la conservation de la nature, x + 96 p.

DUPONT-HÉBERT, M. (2017). *Mise à jour du répertoire des plans de conservation des milieux naturels du Québec méridional, 2014-2016*. Bureau d'écologie appliquée pour le Service canadien de la faune d'Environnement et Changement climatique Canada, 14 p.

ECCC and MDDELCC (2018). *Land cover mapping of the St. Lawrence Lowlands, circa 2014*. Environment and Climate Change Canada and Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, St. Lawrence Action Plan, Québec, 49 p.

EKROOS, J., J. HELIÖLÄ and M. KUUSSAARI (2010). « Homogenization of lepidopteran communities in intensively cultivated agricultural landscapes ». *Journal of Applied Ecology*, vol. 47, nº 2, p. 459-46.

ELSON, J.A. (1969). « Late Quaternary marine submergence of Quebec ». *Revue de géographie de Montréal*, vol. 23, nº 3, p. 247-258.

ENVIRONNEMENT CANADA (1986). *Milieux humides le long du fleuve Saint-Laurent 1950-1978*. Ottawa, Service de conservation de l'environnement, Direction générale des terres, document de travail nº 45, 29 p.

ENVIRONNEMENT CANADA (2007). *L'état de l'environnement au Canada*. Ottawa, 833 p.

ENVIRONNEMENT CANADA (2013a). *How much habitat is enough?* 3rd edition, Toronto, Environment Canada, 127 p.

ENVIRONNEMENT CANADA (2013b). *Bird Conservation Strategy for Bird Conservation Region 13 in Quebec Region – Lower Great Lakes/St. Lawrence Plain.* Canadian Wildlife Service, Environment Canada. Quebec, Quebec. 142 pp. + appendices.

ENVIRONMENT AND CLIMATE CHANGE CANADA (2016). *Recovery Strategy for the Golden-winged Warbler (*Vermivora chrysoptera*) in Canada*. Species at Risk Act Recovery Strategy Series. Environment and Climate Change Canada, Ottawa. vii + 59 pp.

ENVIRONNEMENT CANADA and MINISTÈRE DU DÉVELOPPEMENT DURABLE, DE L'ENVIRONNEMENT ET DES PARCS DU QUÉBEC (2007). *Critères pour l'évaluation de la qualité des sédiments au Québec et cadres d'application : prévention, dragage et restauration*. 39 p.

ÉQUIPE DE RÉTABLISSEMENT DE L'ALOSE SAVOUREUSE (2001). *Plan d'action pour le rétablissement de l'alose savoureuse* (Alosa sapidissima Wilson) *au Québec*. Québec, Société de la faune et des parcs du Québec, Direction du développement de la faune, 27 p.

ÉQUIPE DE RÉTABLISSEMENT DU CHEVALIER CUIVRÉ (2004). *Plan de rétablissement pour la survie du chevalier cuivré* (Moxostoma hubbsi) *2004-2008.* Québec, ministère des Ressources naturelles, de la Faune et des Parcs, Direction du développement de la faune, 77 p.

ÉQUITERRE (2009). *Mémoire présenté par Équiterre sur l'avant-projet de Loi sur l'aménagement durable du territoire et l'urbanisme*. Consultation générale et auditions publiques sur l'avant-projet de loi – Loi sur l'aménagement durable du territoire et l'urbanisme, 17 p.

EWERS, R.M., and R.K. DIDHAM (2006). « Confounding factors in the detection of species responses to habitat fragmentation ». *Biological Review* (Cambrige Philosophical Society), vol. 81, p. 117-142.

FAHRIG, L. (1997). « Relative effects of habitat loss and fragmentation on population extinction ». *Journal of Wildlife Management*, vol. 61, no 3, p. 603-610.

FAHRIG, L., J. BAUDRY, L. BROTONS, F.G. BUREL, T.O. CRIST, R.J. FULLER, C. SIRAMI, G.M. SIRIWARDENA and J.-L. MARTIN (2011). « Functional landscape heterogeneity and animal biodiversity in agricultural landscapes ». *Ecology Letters*, vol. 14, no 2, p. 101-112.

FAHRIG, L., J. GIRARD, D. DURO, J. PASHER, A. SMITH, S.K. JAVOREK, D. KING, K.F. LINDSAY, S.W. MITCHLL and L. TISCHENDORF (2015). « Farmlands with smaller crop fields have higher within-field biodiversity ». *Agriculture, Ecosystems and Environment*, vol. 200, p. 219-234.

FAPAQ (2003). *Plan de développement régional associé aux ressources fauniques de la région métropolitaine de Montréal*. Longueuil, Société de la faune et des parcs du Québec, Direction de l'aménagement de la faune de Montréal, de Laval et de la Montérégie, xviii + 158 p.

FILION, L. (1987). « Holocene development of parabolic dune in central St. Lawrence Lowlands, Quebec ». *Quaternary Research*, vol. 28, nº 2, p. 196-209.

FILION, M., J.C. FORTIN, R. LAGASSÉ and R. LAGRANGE (2001). *Histoire du Richelieu Yamaska Rive-Sud. La Montérégie.* Sainte-Foy, Les Presses de l'Université Laval, 557 p. (Collection Les régions du Québec).

FILIPPI-CODACCIONI, O., V. DEVICTOR, Y. BAS, J. CLOBERT and R. JULLIARD (2010). « Specialist response to proportion of arable land and pesticide input in agricultural landscapes ». *Biological Conservation*, vol. 143, nº 4, p. 883-890.

FLORSHEIM, J.L., J.F. MOUNT and A. CHIN (2008). « Bank Erosion as a Desirable Attribute of Rivers ». *BioScience*, vol. 58, p. 519-529.

FORMAN, R.T.T. (1995). *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge, Cambridge University Press, 632 p.

FORMAN, R.T.T., and M. GODRON (1986). *Landscape Ecology*. New York, John Wiley & Sons, 620 p.

FORMAN, R.T.T., B. REINEKING and A.M. HERSPERGER (2002). « Road traffic and nearby grassland bird patterns in a suburbanizing landscape ». *Environmental Management*, vol. 29, nº 6, p. 782-800.

FOUBERT, A. (2017). *Rôles de l'hétérogénéité et de la connectivité du paysage sur les poissons du Saint-Laurent (Canada) : vers de nouvelles unités de gestion écologiques*. Thèse de doctorat en Sciences de l'environnement, Université du Québec à Chicoutimi, 189 p.

FOURNIER, R., M. POULIN, J.-P. RÉVERET, A. ROUSSEAU and J. THÉAU (2013). *Outils d'analyses hydrologique, économique et spatiale des services écologiques procurés par les milieux humides des basses terres du Saint-Laurent : adaptations aux changements climatiques*. [En ligne], Rapport final pour Ouranos. [https://www.ouranos.ca/publication-scientifique/RapportFournier2013_FR.pdf] (Consulté le 26 octobre 2018).

FREI, S., G. LISCHEID and J.H. FLECKENSTEIN (2010). « Effects of micro-topography on surface-subsurface exchange and runoff generation in a virtual riparian wetland – A modeling study ». *Advances in Water Resources*, vol. 33, nº 11, p. 1388-1401.

FRELICH, L. E., and C. G. LORIMER (1991). « A simulation of landscape-level stand dynamics in the northern hardwood region ». *Journal of Ecology*, vol. 79, nº 1, p. 223-233.

FRISSEL, C.A., W.J. LISS, C.E. WARREN and M.D. HURLEY (1986). « A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context ». *Environmental Management*, vol. 10, nº 2, p. 199-214.

GAGNON, D. (2004). *La forêt naturelle du Québec, un survol*. Montréal, Groupe de recherche en écologie forestière interuniversitaire, 74 p

GAGNON, É., and G. GANGBAZO (2007). *Efficacité des bandes riveraines : analyse de la documentation scientifique et perspectives*. Québec, ministère du Développement durable, de l'Environnement et des Parcs, Direction des politiques de l'eau, 17 p.

GAGNON, D., B. TRUAX and S. BARRETTE (2003). *Aménagement et sylviculture du chêne rouge en Estrie via la connaissance des peuplements naturels*. Rapport final 2002-2003 remis à l'Agence de mise en valeur de la forêt privée de l'Estrie. Montréal, Groupe de recherche en écologie forestière interuniversitaire et Sherbrooke, Comité estrien de recherche sur les feuillus, 30 p.

GAGNON-LUPIEN, N., G. GAUTHIER and C. LAVOIE (2015). « Effect of the invasive common reed on the abundance, richness and diversity of birds in freshwater marshes ». *Animal Conservation*, vol. 18, n° 1, p. 32-43.

GAUTHIER, J., and Y. AUBRY (1996). *Atlas of the Breeding Birds of Southern Quebec : The Breeding Birds of Quebec.* Association Québécoise des Groupes d'Ornithologues, Province of Québec Society for the Protection of Birds, and Canadian Wildlife Service. Environment Canada, Québec region, Montréal, Québec.

GAUTHIER, J., I. LESSARD, G. FALARDEAU and J.-P. L. SAVARD (2004). *Stratégie de conservation des oiseaux terrestres du Québec*. Sainte-Foy, Environnement Canada, Service canadien de la faune, Division des oiseaux migrateurs, région du Québec, 26 p.

GAUTHIER, R., and M. GRANDTNER (1975). « Étude phytosociologique des tourbières du Bas Saint-Laurent, Québec ». *Le Naturaliste canadien*, vol. 102, p. 109-153.

GÉOMONT (2018). *Évaluation des pertes et gains de superficies forestières en Montérégie entre 2009 et 2017 – Rapport final*. Projet n° P34045 réalisé pour le compte de la MRC Brome-Missisquoi, 40 p.

GÉRARDIN, V., J.-P. DUCRUC and P. BEAUCHESNE (2002). « Planification du réseau d'aires protégées du Québec ». *VertigO – La revue électronique en sciences de l'environnement sur le WEB*, vol. 3, n° 1, 13 p.

GILPIN, M.E., and J.M. DIAMOND (1980). « Subdivision of nature reserves and the maintenance of species diversity ». *Nature*, vol. 285, p. 567-568.

GONZALEZ, A., C. ALBERT, B. RAYFIELD, M. DUMITRU, A. DABROWSKI, E.M. BENNETT, J. CARDILLE and M.J. LECHOWICZ (2013). *Corridors, biodiversité, et services écologiques : un réseau écologique pour le maintien de la connectivité et une gestion résiliente aux changements climatiques dans l'Ouest des Basses-Terres du Saint-Laurent*. Université McGill et Centre de la science de la biodiversité du Québec, 71 p.

GORHAM, E. (1991). « Northern peatlands: Role in the carbon cycle and probable responses to climatic warming ». *Ecological Applications*, vol. 1, n° 2, p. 182-195.

GOUVERNEMENT DU QUÉBEC (2002). *Loi sur la conservation du patrimoine naturel, L.R.Q., chapitre C-61.01.* Québec, Éditeur officiel du Québec, pag. multiple.

GOUVERNEMENT DU QUÉBEC (2017). « Loi concernant la conservation des milieux humides et hydriques ». *Gazette Officielle du Québec*, Partie 2, 149e année, n° 35, 16 juin 2017, Éditeur officiel du Québec, p. 3787-3824.

GRANDTNER, M. (1960). *La forêt de Beauséjour, comté de Lévis, Québec – Étude phytosociologique.* Contribution au Fonds de recherches forestières de l'Université Laval n° 7, 62 p.

GRATTON, L. (2010). *Plan de conservation pour l'écorégion de la vallée du Saint-Laurent et du lac Champlain.* Montréal, Société canadienne pour la conservation de la nature, région du Québec, 150 p.

GRATTON, L., and P. NANTEL (1999). *Conservation d'aires de faible superficie – Bilan des connaissances applicables aux écosystèmes forestiers exceptionnels du Québec*. Québec, ministère des Ressources naturelles du Québec, Direction de l'environnement forestier, 62 p.

GROUPE DE TRAVAIL SUIVI DE L'ÉTAT DU SAINT-LAURENT (2014). *Portrait global de l'état du Saint-Laurent 2014*. Plan Saint-Laurent, Environnement Canada, ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques du Québec, ministère des Forêts, de la Faune et des Parcs du Québec, Parcs Canada, Pêches et Océans Canada et Stratégie Saint-Laurent, 53 p.

GROUPE DE TRAVAIL SUR LES ÉCOSYSTÈMES FORESTIERS EXCEPTIONNELS (1997). *Les écosystèmes forestiers exceptionnels du Québec, document d'information*. Québec, ministère des Ressources naturelles du Québec, 43 p.

GUERRIER, P., and M. PAUL (2000). *Guide d'intervention en cas de déversement en milieu fluvial pour les directions régionales de santé publique du Québec*. Québec, gouvernement du Québec, ENVIRODOQ ENV/2000/0020, x + 49 p.

GUSTAFSON, E.J., and G.R. PARKER (1992). « Relationships between landcover proportion and indices of landscape spatial pattern ». *Landscape Ecology*, vol. 7, n° 2, p. 101-110.

HAILA, Y., and I.K. HANSKI (1984). « Methodology for studying the effect of habitat fragmentation on land birds ». *Annales Zoologici Fennici*, vol. 21, n° 3, p. 393-397.

HALL, L.S., P.R. KRAUSMAN and M.L. MORRISON (1997). « The habitat concept and a plea for standard terminology ». *Wildlife Society Bulletin*, vol. 25, n° 1, p. 173-182.

HANSKI, I. (1999). *Metapopulation Ecology*. Oxford University Press.

HARMAN, W., R. STARR, M. CARTER, K. TWEEDY, M. CLEMMONS, K. SUGGS and C. MILLER (2012). *A Function-Based Framework for Stream Assessment and Restauration Projects*. United States Environmental Protection Agency, Office of Wetlands, Oceans, and Watershed, Washington, D.C., EPA 843-K-12-006, 344 p.

HARPER, K.A., S.E. MacDONALD, P.J. BURTON, J. CHEN, K.D. BROSOFSKE, S.C. SAUNDERS, E.S. EUSKIRCHEN, D. ROBERTS, M.S. JAITEH. and P-A. ESSEEN (2005). « Edge Influence on Forest Structure and Composition in Fragmented Landscapes ». *Conservation Biology*, vol. 19, n° 3, p. 768-782.

HARRIS, L.D. (1989). « The Faunal Significance of Fragmentation of Southeastern Bottomland Forests ». Dans Hook, D.D., and L. Russ (dir.) *Proceedings of the symposium: The Forested Wetlands of the Southern United States*, p. 126-134. Asheville, United States Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.

HARVEY, C.A., O. KOMAR, R. CHAZDON, B.G. FERGUSON, B. FINEGAN, D.M. GRIFFITH, M. MARTINEZ-RAMOS, H. MORALES, R. NIGH, L. SOTO-PINTO, M. VAN BREUGEL and M. WISHNIE (2008). « Integrating agricultural landscapes with biodiversity conservation in the Mesoamerican hotspot ». *Conservation Biology*, vol. 22, n° 1, p. 8-15.

HELLQUIST, C. B. (1980). « Correlation of alkalinity and the distribution of potamogeton in New England ». *Rhodora*, vol. 82, n° 830, p. 331-344.

HENLE, K., K.F. DAVIES, M. KLEYER, C. MARGULES and J. SETTELE (2004). « Predictors of species sensitivity to fragmentation ». *Biodiversity and Conservation*, vol. 13, n° 1, p. 207-251.

HERZOG, F., K. BALÁZS, P. DENNIS, J. FRIEDEL, I. GEIJZENDORFFER, P. JEANNERET, M. KAINZ, and P. POINTEREAU (2012). *Biodiversity Indicators for European Farming Systems – A Guidebook*. [En ligne] ART-Schriftenreihe 17 [http://www.biobio-indicator.org/deliverables/guidebook.pdf].

HOULAHAN, J.E., and C.S. FINDLAY (2003). « The effects of adjacent land use on wetland amphibian species richness and community composition ». *Journal canadien des sciences halieutiques et aquatiques*, vol. 60, vol. 9, p. 1078-1094.

HOULAHAN, J.E., and C.S. FINDLAY (2004). « Estimating the “critical” distance at which adjacent land-use degrades wetland water and sediment quality ». *Landscape Ecology,* vol. 19, n° 6, p. 677-690.

HRUBY, T., T. GRANGER, K. BRUNNER, S. COOKE, K. DUBLANICA, R. GERSIB, L. REINELT, K. RICHTER, D. SHELDON, E. TEACHOUT, A. WALD and F. WEINMANN (1999). *Methods for Assessing Wetland Functions. Volume I: Riverine and Depressional Wetlands in the Lowlands of Western Washington*. Washington State Department Ecology Publication #99-115, Olympia, 476 p.

HUDON, C. (2005). « Le fleuve Saint-Laurent à l’ère des changements climatiques ». *FrancVert – LeWebzine environnemental*, vol. 2, n° 3, 1.

HYDRO-QUÉBEC TRANSÉNERGIE (2013). *Synthèse des connaissances environnementales pour les lignes et les postes – 1973-2013*. Montréal, Hydro-Québec, Perception des lignes de transport, 25 p.

INSTITUT DE LA STATISTIQUE DU QUÉBEC (ISQ) (2017). « Le bilan démographique du Québec, Édition 2017 ». [En ligne], Québec, Institut de la statistique du Québec, 176 p. [www.stat.gouv.qc.ca/statistiques/population-demographie/ bilan2017.pdf].

IUCN-CMP (2006). *United classification of direct threats.* Union internationale pour la conservation de la nature et Conservation Measures Partnership, 17 p.

JAGER, H.I., J.A. CHANDLER, K.B. LEPLA and W.V. WINKLE (2001). « A theoretical study of river fragmentation by dams and its effects on white sturgeon populations ». *Environmental Biology of Fishes*, vol. 60, n° 4, p. 347-361.

JEAN, M., and G. LÉTOURNEAU (2011). *Changements dans les milieux humides du fleuve Saint-Laurent de 1970 à 2002*. Gatineau, Environnement Canada, Direction générale des sciences et de la technologie, Monitoring et surveillance de la qualité de l'eau au Québec, Rapport technique numéro 511, 302 p.

JEANMOUGIN, M., G. PLATTNER, E. PORCHER, R. JULLIARD, J. TOUROULT and L. PONCET (2014). *Synthèse bibliographique des changements d'échelles cartographiques et des relations écologiques entre les espèces et leurs habitats*. Paris, SPN-CESCO-MNHN, MEDDE, 83 p.

JOBIN, B. (2003). « Cartographie des habitats agricoles dans la région de l'Outaouais : Une région d'intérêt pour la pie-grièche migratrice (*Lanius ludovicianus*) ». *Le Naturaliste canadien*, vol. 127, nº 2, p. 26-35.

JOBIN, B., J.-L. DESGRANGES and C. BOUTIN (1996). « Population trends in selected species of farmland birds in relation to recent developments in agriculture in the St. Lawrence Valley ». *Agriculture, Ecosystems and Environment*, vol. 57, nºs 2-3, p. 103-116.

JOBIN, B., J.-L. DESGRANGES and C. BOUTIN (1998). « Farmland habitat use by breeding birds in southern Québec ». *Canadian Field-Naturalist*, vol. 112, nº 4, p. 611-618.

JOBIN, B., D. RODRIGUE and J.-L. DESGRANGES (2002). Amphibian and Reptile Diversity along the St. Lawrence River. Canadian Field-Naturalist 116: 551-558.

JOBIN, B., J. BEAULIEU, M. GRENIER, L. BÉLANGER, C. MAISONNEUVE, D. BORDAGE and B. FILION (2003). « Landscape changes and ecological studies in agricultural regions, Québec, Canada ». *Landscape Ecology*, vol. 18, nº 6, p. 575-590.

JOBIN, B., C. LATENDRESSE, C. MAISONNEUVE, A. SEBBANE and M. GRENIER (2007). *Changements de l'occupation du sol dans le sud du Québec pour la période 1993-2001*. Sainte-Foy, Environnement Canada, Service canadien de la faune, région du Québec, 112 p. et annexes. (Série de rapports techniques nº 483).

JOBIN, B., R. LANGEVIN, M. ALLARD, S. LABRECQUE, D. DAUPHIN, M. BENOIT and P. AQUIN (2013). *Évaluation d'une approche d'analyse du paysage pour planifier la conservation des habitats des oiseaux migrateurs et des espèces en péril dans l'écozone des Plaines à forêts mixtes : étude de cas au lac Saint-Pierre – Rapport méthodologique*. Québec, Environnement Canada, Service canadien de la faune, région du Québec (rapport non publié), 196 p. et annexes.

JOHNSTON, C.A., N.E. DENTENBECK and G.J. NIEMI (1990). « The Cumulative Effect of Wetlands on Stream Water Quality and Quantity. A Landscape Approach ». *Biogeochemistry*, vol. 10, nº 2, p. 105-141.

JOHNSTON, K. (1991). *Forêts et tourments – 75 ans d'histoire du Service fédéral des forêts, 1899-1974*. Ottawa, Forêts Canada, 208 p.

JOLY, M., S. PRIMEAU, M. SAGER and A. BAZOGE (2008). *Guide d'élaboration d'un plan de conservation des milieux humides*. Québec, ministère du Développement durable, de l'Environnement et des Parcs, 80 p.

JULES, E.S., E.J. FROST, L.S. MILLS and D.A. TALLMON (1999). « Ecological consequences of forest fragmentation in the Klamath region ». *Natural Areas Journal*, vol. 19, nº 4, p. 368-378.

KAREIVA, P., and U. WENNERGREN (1995). « Connecting landscape patterns to ecosystem and population processes ». *Nature*, vol. 373, p. 299-302.

KENT, D.M. (2001). « Evaluating Wetland Functions and Values ». Dans Kent, D.M. (dir.) *Applied Wetlands Science and Technology*, Second Edition, p. 55-80, Boca Raton, CRC Press LLC, 472 p.

KNAPP, M., and M. REZÁČ (2015). « Even the smallest non-crop habitat islands could be beneficial: Distribution of carabid beetles and spiders in agricultural landscape ». [En ligne], *PLoS ONE*, vol. 10, nº 4. [https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0123052] (Consulté le 26 octobre 2018).

KNICK, S.T., and J.T. ROTENBERRY (1995). « Landscape characteristics of fragmented shrubsteppe habitats and breeding passerine birds ». *Conservation Biology*, vol. 9, nº 5, p. 1059-1071.

KNUD-HANSEN, C.F., T.R. BATTERSON, C.D. McNABB, I.S. HARAHAT, K. SUMANTADINATA and H. MUHAMMED EIDMAN (1991). « Nitrogen input, primary productivity and fish yield in fertilized freshwater ponds in Indonesia ». *Aquaculture*, vol. 94, nº 1, p. 49-63.

KOETSIER, P.G., W. MINSHALL and C.T. ROBINSON (1996). « Benthos and macroinvertebrate drift in six streams differing in alkalinity ». *Hydrobiologia*, vol. 317, nº 1, p. 41-49.

KORFEL, C.A., W.J. MITSCH, T.E. HETHERINGTON and J.J. MACK (2010). « Hydrology, Physiochemistry, and Amphibians in Natural and Created Vernal Pool Wetlands ». *Restoration Ecology*, vol. 18, nº 6, p. 843-854.

LA VIOLETTE, N., D. FOURNIER, P. DUMONT and Y. MAILHOT (2003). *Caractérisation des communautés de poissons et développement d'un indice d'intégrité biotique pour le fleuve Saint-Laurent, 1995-1997*. Québec, Société de la faune et des parcs du Québec, 237 p.

LAMOUREUX, S., and C. DION (2016). *Guide de recommandations – Aménagements et pratiques favorisant la protection des oiseaux champêtres*. Montréal, Regroupement QuébecOiseaux, 198 p.

LANDRY, B., and M. MERCIER (1992). *Notions de géologie,* 3e édition revue et augmentée. Montréal, Modulo, 565 p.

LANDRY, B., J. BEAULIEU, M. GAUTHIER, M. LUCOTTE, S. MOINGT, D.L. OCCHIETTI and M. QUIRION (2013). *Notions de géologie*, 4e édition. Montréal, Modulo, 640 p.

LANGEVIN, R. (1997). *Guide de conservation des boisés en milieu agricole*. Ottawa, Environnement Canada, Service canadien de la faune, 77 p.

LAPOINTE, N.W.R., D.K. KRAUS, E. MEYFARTH, C. LATREMOUILLE and H. BARNA (2015). *Guide de planification de la conservation des aires naturelles de Conservation de la nature Canada*. Toronto, Conservation de la nature Canada, 114 p.

LAROCHELLE, M., P. DUMONT, C. LAVOIE and D. HATIN (2015). « Varying Effects of Common Reed Invasion on Early Life History of Northern Pike ». *Transactions of the American Fisheries Society*, vol. 144, nº 1, p. 196-210.

LATENDRESSE, C., B. JOBIN, C. MAISONNEUVE, A. SEBBANE and M. GRENIER (2008a). « Changements de l'occupation du sol dans le Québec méridional entre 1993 et 2001 ». *Le Naturaliste canadien*, vol. 132, nº 1, p. 14-23.

LATENDRESSE, C., B. JOBIN, A. BARIL, C. MAISONNEUVE, C. BOUTIN and D. CÔTÉ (2008b). *Dynamique spatio-temporelle des habitats fauniques dans l'écorégion des Basses terres du fleuve Saint-Laurent, 1950-1997*. Québec, Environnement Canada, Service canadien de la faune, région du Québec, 83 p. et annexes (Série de rapports techniques nº 494).

LAVOIE, C., M. JEAN, F. DELISLE and G. LÉTOURNEAU (2003). « Exotic plant species of the St Lawrence River wetlands: a spatial and historical analysis ». *Journal of Biogeography*, vol. 30, nº 4, p. 537-549.

LE GROUPE PHRAGMITES (2012). « Le roseau envahisseur : la dynamique, l'impact et le contrôle d'une invasion d'envergure ». *Le Naturaliste canadien*, vol. 136, nº 3, p. 33-39.

LEBEL, A. (2013). *Recensement, portrait et analyse des plans de conservation des habitats dans les Basses-terres du Saint-Laurent*. Rapport préparé par le Bureau d'écologie appliquée et présenté au Service canadien de la faune d'Environnement Canada, Québec, 42 p.

LEBLOND, M., J. FRAIR, D. FORTIN, C. DUSSAULT, J.-P. OUELLET and R. COURTOIS. (2011). « Assessing the influence of resource covariates at multiple spatial scales: an application to forest dwelling caribou faced with intensive human activity ». *Landscape Ecology*, vol. 26, nº 10, p. 1433-1446.

LEGENDRE, P., and L. LEGENDRE (1998). *Numerical Ecology*, 2nd Edition. Amsterdam, Elsevier Science, 852 p.

LEHNEN, S. E. (2008). *An evaluation of survivorship and habitat use of early-successional birds during the breeding season: implications for conservation*. Thèse, Ohio State University, 169 p.

LEMELIN, L.-V., and M. DARVEAU (2006). « Coarse and fine filters, gap analysis, and systematic conservation planning ». *Forestry Chronicle*, vol. 82, nº 6, p. 802-805.

LESMERISES, F., C. DUSSAULT and M.-H. ST-LAURENT (2012). « Réponses du loup gris au réseau routier et à la présence d'un important chantier de construction ». *Le Naturaliste canadien*, vol. 136, nº 2, p. 29-34.

LEVINS, R. (1969). « Some demographic and genetic consequences of environmental heterogeneity for biological control ». *Bulletin of the Entomological Society of America*, vol. 15, nº 3, p. 237-240.

LI, T., and J.-P. DUCRUC (1999). *Les provinces naturelles. Rang 1 du Cadre écologique de référence du Québec*. Québec, ministère de l'Environnement, 90 p.

LI, T., J.-P. DUCRUC, M.-J. CÔTÉ, D. BELLAVANCE and F. POISSON (2014). *Les provinces naturelles : première fenêtre sur l'écologie du Québec.* Québec, ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, Direction de l'expertise en biodiversité, 22 p.

MacARTHUR, R.H., and E.O. WILSON (1967). *The Theory of Island Biogeography*. Princeton, Princeton University Press, 205 p.

MAGURRAN, A.A. (1988). *Ecological Diversity and Its Measurement*. Princeton, Princeton University Press, 179 p.

MAJCEN, Z. (2003). « Raréfaction des espèces compagnes de l'érablière ». Dan Grondin, P., et A. Cimon (coord.), *Les enjeux de biodiversité relatifs à la composition forestière*, p. 93-102, Québec, ministère des Ressources naturelles, de la Faune et des Parcs, Direction de la recherche forestière et Direction de l'environnement forestier, 213 p.

MASSE, D., and M. RAYMOND (1988). « La nidification de la sauvagine dans le marécage de la Rivière-du-Sud et la zone agricole environnante ». *Revue canadienne de zoologie*, vol. 66, n^o^ 5, p. 1160-1167.

MAZEROLLE, M. J., A. PEREZ and J. BRISSON (2014). « Common reed (*Phragmites australis*) invasion and amphibian distribution in freshwater wetlands ». *Wetlands Ecology and Management*, vol. 22, n^o^ 3, p. 325-340.

McCABE, R. A. (1947). « Homing of flying squirrels ». *Journal of Mammalogy*, vol. 28, n^o^ 4, p. 404.

McGARIGAL, K., and B.J. MARKS (1995). « FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure ». [En ligne], Gen. Tech. Report PNW-GTR-351, USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. [http://www.fs.fed.us/pnw/pubs/gtr_351.pdf] (Consulté le 26 octobre 2018).

McLAUGHLIN, A., and P. MINEAU (1995). « The impact of agricultural practices on biodiversity ». *Agriculture, Ecosystems and Environment*, vol. 55, n^o^ 3, p. 201-212.

McMASTER, D. G., J. H. DEVRIES and S. K. DAVIS (2005). « Grassland birds nesting in haylands of southern Saskatchewan: landscape influences and conservation priorities ». *Journal of Wildlife Management*, vol. 69, n^o^ 1, p. 211-221.

McPHERSON, M., C. NIELSEN and K. PROUDLOCK (2009). *The development of Tier 1 generalized habitat-based standards for ecozones in agricultural regions of Canada*. National Agri-Environmental Standards Initiative, Synthesis Report No. 3. Gatineau, Environnement Canada, 137 p.

MDDELCC (2015a). « Cartographie de l'utilisation du territoire du Québec ». Données de SIG (ArcMap, ESRI Canada). Québec, ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques.

MDDELCC (2015b). *Guide d'interprétation, Politique de protection des rives, du littoral et des plaines inondables*. [En ligne], Québec, ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, Direction des politiques de l'eau, 131 p. [http://www.mddelcc.gouv.qc.ca/eau/rives/guide-interpretationPPRLPI.pdf] (Consulté le 26 octobre 2018).

MDDELCC (2013). *Rapport sur l'état de l'eau et des écosystèmes aquatiques au Québec*. [En ligne], Québec, ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques [http://www.mddelcc.gouv.qc.ca/rapportsurleau/Etat-eau-ecosysteme-aquatique.htm] (Consulté le 26 octobre 2018).

MDDEP (2002). « La moule zébrée et autres espèces aquatiques nuisibles au Québec ». [En ligne], Québec, ministère du Développement durable, de l'Environnement et des Parcs [www.mddep.gouv.qc.ca/biodiversite/nuisibles/zebree.htm].

MDDEP (2010). *Portrait du réseau des aires protégées au Québec, période 2002-2009*. Québec, ministère du Développement durable, de l'Environnement et des Parcs, Direction du patrimoine écologique et des parcs, 41 p.

MELCC (2018). « Registre des aires protégées ». [En ligne], Québec, ministère de l'Environnement et de la Lutte contre les changements climatiques. [http://www.mddelcc.gouv.qc.ca/biodiversite/aires_protegees/registre/].

MILLAR, W., and A. OLIVERO-SHELDON (2017). *Stream Classification for the Northern Appalachian – Acadian Region of Canada.* Fredericton, Nature Conservancy of Canada, Atlantic Regional Office, 91 p.

MINGELBIER, M., and J. LECLERC (2001). « Preliminary atlas of fish habitat in the fluvial St. Lawrence River ». Affiche présentée à la 8th Annual International Conference on the St. Lawrence River Ecosystem tenue à Cornwall (Ontario).

MINGELBIER, M., Y. PARADIS, P. BRODEUR, V. de la CHENELIÈRE, F. LECOMTE, D. HATIN and G. VERREAULT (2016). « Gestion des poissons d'eau douce et migrateurs dans le Saint-Laurent : mandats, enjeux et perspectives ». *Le Naturaliste canadien*, vol. 140, nº 2, p. 74-90.

MINGELBIER, M., Y. REYJOL, P. DUMONT, Y. MAILHOT, P. BRODEUR, D. DESCHAMPS and C. CÔTÉ (2008). *Les communautés de poissons d'eau douce dans le Saint-Laurent, fiche synthèse*. Plan Saint-Laurent, 2e édition, Québec, ministère des Ressources naturelles et de la Faune, 8 p.

MITSCH, W.J., and J.G. GOSSELINK (2007). *Wetlands*, Fourth edition. Hoboken, John Wiley & Sons, 582 p.

MITTELBACH, G.G., C.F. STEINER, S.M. SCHEINER, K.L. GROSS, H.L. REYNOLDS, R.B. WAIDE, M.R. WILLIG, S.I. DODSON and L. GOUGH (2001). « What is the observed relationship between species richness and productivity? » *Ecology*, vol. 82, nº 9, p. 2381-2396.

MOISAN, M., and H. LAFLAMME (1999). *Rapport sur la situation de l'esturgeon jaune* (Acipenser fulvescens) *au Québec*. Québec, ministère de la Faune et des Parcs, Direction de la faune et des habitats, 68 p.

MOORE, T.R. (1989). « Growth and net production of Sphagnum at five fen sites, subarctic eastern Canada ». *Revue canadienne de botanique,* vol. 67, nº 4, p. 1203-1207.

MORGAN, M., and M. BURGER (2008). *A Plan for Conserving Grassland Birds in New York: Final Report to the New York State Department of Environmental Conservation*. Ithaca, Audubon New York, 140 p.

MORIN, J., and A. BOUCHARD (2000). *Les bases de la modélisation du tronçon Montréal/Trois-Rivières. Rapport scientifique SMC-Hydrométrie RS-100*. Sainte-Foy, Environnement Canada, 56 p.

MORISSETTE, O., F. LECOMTE, G. VERREAULT, M. LEGAULT and P. SIROIS (2016). « Fully equipped to succeed: Migratory Contingents Seen as an Intrinsic Potential for Striped Bass to Exploit a Heterogeneous Environment Early in Life ». *Estuaries and Coasts*, vol. 39, nº 2, p. 571-582.

NATURE QUÉBEC (2018). « Programme ZICO ». [En ligne]. [https://naturequebec.org/projets/zicos] (Consulté le 17 juin 2019).

NAZARNIA, N., C. SCHWICK and J.A.G. JAEGER (2016). « Accelerated urban sprawl in Montreal, Quebec City, and Zurich: Investigating the differences using time series 1951-2011 ». *Ecological Indicators*, vol. 60, p. 1229-1251.

NCC (2018). *Conservation Assessment for Southern Canada*. Nature Conservancy of Canada, vii + 137 p.

NICHOLS, D.S. (1983). « Capacity of Natural Wetlands to Remove Nutrients from Wastewater ». *Journal of Water Pollution Control Federation*, vol. 55, nº 5, p. 495-505.

NRC (2018). « Emerald ash borer ». [Online], Natural Resources Canada, [https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/wildland-fires-insects-disturban/top-forest-insects-diseases-cana/emerald-ash-borer/13377?_ga=2.148716337.703978336.1598360291-1132479233.1598360291].

OCCHIETTI, S., M. PARENT, P. LAJEUNESSE, F. ROBERT and É. GOVARE (2011). « Late Pleistocene–Early Holocene Decay of the Laurentide Ice Sheet in Québec–Labrador ». *Quaternary Glaciations – Extend and Chronology, Developments in Quaternary Science*, vol. 15, chapitre 47, p. 601-630.

ODUM, E.P. (1963). *Ecology*. New York, Holt, Rinehard and Winston, 152 p. (Modern Biology Series).

ODUM, E.P., and G.W. BARRETT (2004). *Fundamentals of Ecology,* Fifth Edition. Belmont, Brooks Cole, 624 p.

OGAWA, H., and J.W. MALE (1983). *The Flood Mitigation Potential of Inland Wetlands*. Amherst, Water Resources Research Center Publication No. 138, University of Massachussetts, 164 p.

OGAWA, H., and J.W. MALE (1986). « Simulating the flood mitigation role of wetlands ». *Journal of Water Resource Planning and Management*, vol. 112, nº 1, p. 114-128.

ONTARIO MINISTRY OF NATURAL RESOURCES (2014). *Ontario Wetland Evaluation System, Southern Manual,* 3rd Edition, version 3.3. Peterborough, ministère des ressources naturelles de l'Ontario, 283 p.

OSBORN, T.G. (1981). « Stream insect production as a function of alkalinity and detritus processing ». *All Graduate Theses and Dissertations*, 3759.

OSTFELD, R.S., and R.H. MANSON (1996). « Long-distance homing in meadow voles, *Microtus pensylvanicus* ». *Journal of Mammalogy*, vol. 77, nº 3, p. 870-873.

OUELLET, V., M. MINGELBIER, A. SAINT-HILAIRE and J. MORIN (2010). « Frequency analysis as a tool for assessing adverse conditions during a massive fish kill in the St. Lawrence River, Canada ». *Water Quality Research Journal of Canada*, vol. 45, nº 1, p. 47-57.

OURANOS (2010). *Savoir s'adapter aux chagements climatiques*. Montréal, 128 p.

PARENT, S. (1990). *Dictionnaire des sciences de l'environnement*. Québec, Broquet, 748 p.

PAYETTE, S., and L. ROCHEFORT (sous la dir. de) (2001). *Écologie des tourbières du Québec-Labrador*. Québec, Presse de l'Université Laval, 644 p.

PELLERIN, S. (2003). « Des tourbières et des hommes. L'utilisation des tourbières dans la région de Rivière-du-Loup – L'Isle-Verte ». *Le Naturaliste canadien*, vol. 127, p. 18-23.

PELLERIN, S., and M. POULIN (2013). *Analyse de la situation des milieux humides au Québec et recommandations à des fins de conservation et de gestion durable*. Rapport produit pour le ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques du Québec, 104 p. Également disponible en ligne : http://www.mddelcc.gouv.qc.ca/eau/rives/Analyse-situation-milieux-humides-recommandations.pdf.

PERREAULT, R., and A. PORLIER (2005). *Un projet alternatif au prolongement de l'autoroute 25*. Montréal, Conseil régional de l'environnement de Montréal, 21 p.

POTVIN, F., P. BEAUPRÉ and G. LAPRISE (2003). « The eradication of balsam fir stands by white-tailed deer on Anticosti Island: a 150-year process ». *Écoscience*, vol. 10, nº 4, p. 487-495.

PRICE, J.S. (2001). « L'hydrologie ». Dans Payette, S. et L. Rochefort (dir.) *Écologie des tourbières du Québec-Labrador*, p. 141-158. Québec, Presses de l'Université Laval, 644 p.

PRICE, J.S. (1997). « Soil moisture, water tension, and water table relationships in a managed cutover bog ». *Journal of Hydrology*, vol. 202, nºs 1-4, p. 21-32.

QUENNEVILLE, R. (2007). « Pin blanc d'Amérique : exploitation des peuplements ». [En ligne], *Encyclopédie du patrimoine culturel de l'Amérique française* [http://www.ameriquefrancaise.org/fr/article-54/#.XTchw_nhCt8].

QUESNEL, P.-O., L. TANGUAY and B. ARPIN (2006). *Portrait agricole sommaire et évolutif de la Communauté métropolitaine de Montréal*. Québec, ministère de l'Agriculture des Pêcheries et de l'Alimentation du Québec, 51 p.

RABENI, C.F., and G.W. MINSHALL (1977). « Factors affecting microdistribution of stream benthic insects ». *Oikos*, vol. 29, nº 1, p. 33-43.

RAYFIELD, B., G. LAROQUE, C. DANIEL and A. GONZALEZ, 2019. Une priorisation pour la conservation des milieux naturels pour les Basses-Terres du Saint-Laurent en fonction de leur importance pour la connectivité écologique. Rapport final remis au Ministère de l'Environnement et de la Lutte contre les changements climatiques, Québec, 36 p. et annexes. Disponible en ligne à : https://quebio.ca/fr/rapport_connectivite

RAYMOND, C.M., N. FRANTZESKAKI, N. KABISCH, P. BERRY, M. BREIL, M.R. NITA, D. GENELETTI and C. CALFAPIETRA (2017). « A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas ». *Environmental Science and Policy*, vol. 77, p. 15-24.

REGROUPEMENT QUÉBECOISEAUX (2015). *L'aménagement écosystémique des forêts : projet pilote pour la Paruline à ailes dorées dans la région de la Vallée-du-Haut-Saint-Laurent – Rapport d'activités*. Montréal, Regroupement QuébecOiseaux, 56 p.

REYJOL, Y., P. BRODEUR, Y. MAILHOT, M. MINGELBIER and P. DUMONT (2010). « Do native predators feed on non-native prey? The case of round goby in a fluvial piscivorous fish assemblage ». *Journal of Great Lakes Research*, vol. 36, nº 4, p. 618-624.

RIBIC, C.A., R.R. KOFORD, J.R. HERKERT, D.H. JOHNSON, N.D. NIEMUTH, D.E. NAUGLE, K.K. BAKKER, D.W. SAMPLE and R.B. RENFREW (2009). « Area sensitivity in North American grassland birds: patterns and processes ». *The Auk*, vol. 126, nº 2, p. 233-244.

RICHARDSON, C. (1978). « Primary productivity values in fresh water wetlands. Wetland functions and values: the state of our understanding ». Dans Greeson, P.E, J.R. Clark et J.E. Clark (dir.) *Proceedings of the National Symposium on Wetlands. American Water Resources Association, Minneapolis, Minnesota*, p. 131-145.

RICKETTS, T.H., E. DINERSTEIN, D.M. OLSON, C. J. LOUCKS, W. EICHBAUM, D.A. DELLASALA, K. KAVANAGH, P. HEDAO, P. HURLEY, K. CARNEY, R. ABELL and S. WALTERS (1999). *Terrestrial Ecoregions of North America. A Conservation Assessment*. Washington, D.C., Island Press, 508 p.

RIOUX, S., C. LATENDRESSSE, B. JOBIN, A. BARIL, C. MAISONNEUVE, C. BOUTIN and D. CÔTÉ (2009). « Dynamique des habitats fauniques dans les Basses-terres du Saint-Laurent de 1950 à 1997 ». *Le Naturaliste canadien*, vol. 133, nº 2, p. 20-28.

RMN 2020. *Répertoire des sites de conservation volontaire du Québec*. [En ligne]. Réseau de milieux naturels protégés, [http://www.lerepertoire.org].

ROBITAILLE, J., M. BÉRUBÉ, A. GOSSELIN, M. BARIL, J. BEAUCHAMP, J. BOUCHER, S. DIONNE, M. LEGAULT, Y. MAILHOT, B. OUELLET, P. SIROIS, S. TREMBLAY, G. TRENCIA, G. VERREAULT and D. VILLENEUVE (2011). *Recovery Strategy for the Striped Bass (*Morone saxatilis*), St. Lawrence Estuary Population, Canada*. Species at Risk Act Recovery Strategy Series. Ottawa: Fisheries and Oceans Canada. xi + p. 52.

ROULET, N.T. (1990). « Hydrology of a headwater basin wetland: Groundwater discharge and wetland maintenance ». *Hydrological Processes*, vol. 4, nº 4, p. 387-400.

ROUSSEAU, Y., and P. BIRON (2009). « Geomorphological impacts of channel straightening in an agricultural watershed, Southwestern Québec ». *The Northeast Geographer*, vol. 1, p. 91-113.

RUSSELLE, M.P., M.H. ENTZ and A.J. FRANZLUEBBERS (2007). « Reconsidering integrated crop–livestock systems in North-America ». *Agronomy Journal*, vol. 99, nº 2, p. 325-334.

SAINT-LAURENT VISION 2000 (1999). « Le chevalier cuivré – À la rescousse d'une espèce menacée au Québec ». *Le fleuve : Bulletin d'information Saint-Laurent Vision 2000,* vol. 10, no 3, p. 1-5.

SALA, O.E., F.S. CHAPIN III, J.J. ARMESTO, E. BERLOW, J. BLOOMFIELD, R. DIRZO, E. HUBER-SANWALD, L. F. HUENNEKE, R.B. JACKSON, A. KINZIG, R. LEEMANS, D.M. LODGE, H.A. MOONEY, M. OESTERHELD, N. LEROY POFF, M.T. SYKES, B.H. WALKER, M. WALKER and D.H. WALL (2000). « Global Biodiversity Scenarios for the Year 2100 ». *Science*, vol. 287, nº 5459, p. 1770-1774.

SANDILANDS, A. P., and S. W. HOUNSELL (1994). « The effect of 500 kv transmission facilities on forest birds in two wetland forest systems in southern Ontario – testing for the edge effect ». Dans Snodgrass, W. J. (dir.) *Wetland Impacts Workshop,* p. 12, Cambridge, Grand River Conservation Authority.

SAUMURE, R.A., R.D. TITMAN and T.B. HERMAN (2007). « Effects of haying and agricultural practices on a declining species: the North American wood turtle, *Glyptemys insculpta* ». *Biological Conservation*, vol. 135, nº 4, p. 565-575.

SAUNDERS, D. A., R. J. HOBBS and C. R. MARGULES (1991). « Biological consequences of ecosystem fragmentation: a review ». *Conservation Biology*, vol. 5, nº 1, p. 18-32.

SCHLOSSBERG, S., and D.I. KING (2008). « Are shrubland birds edge-specialists? » *Ecological Applications*, vol. 18, nº 6, p. 1325-1330.

SCHLOSSBERG, S., and D.I. KING (2015). « Measuring the effectiveness of conservation programs for shrubland birds ». *Global Ecology and Conservation*, vol. 4(C), p. 658-665.

SCHMITT, L., M. LAFONT, M. TRÈMOLIÈRES, C. JEZEQUEL, A. VIVIER, P. BREIL, P. NAMOUR, K. VALIN and L. VALETTE (2011). « Using hydro-geomorphological typologies in functional ecology: Preliminary results in contrasted hydrosystems ». *Physics and Chemistry of the Earth*, Parts A/B/C, vol. 36, nº 12, p. 539-548.

SCHWEIGER, E.W., S.G. LWIBOWITZ, J.B. HYMAN, W.E. FOSTER and M.C. DOWNING (2002). « Synoptic assessment of wetland function: a planning tool for protection of wetland species biodiversity ». *Biodiversity and Conservation*, vol. 11, nº 3, p. 379-406.

SECRETARIAT OF THE CONVENTION ON BIOLOGIVAL DIVERSITY (2007). *Biodiversity and Climate Change*. 48 p.

SEMLITSCH, R.D., and J.R. BODIE (1998). « Are small, isolated wetlands expendable? » *Conservation Biology*, vol. 12, nº 5, p. 1129-1133.

SHUSTACK, D.P., A.M. STRONG and T.M. DONOVAN (2010). « Habitat use patterns of Bobolinks and Savannah Sparrows in the northeastern United States ». [En ligne], *Avian Conservation and Ecology*, vol. 5, nº 2, article 11 [http://www.ace-eco.org/vol5/iss2/art11/] (Consulté le 26 octobre 2018).

SIMARD, H., and A. BOUCHARD (1996). « The precolonial 19th century forest of the Upper St.Lawrence region of Quebec : a record of its exploitation and transformation through notary deeds of wood sales ». *Revue canadienne de recherche forestière,* vol. 26, no 9, p. 1670-1676.

SIRON, R. (2010). « Écosystèmes, biodiversité et changements climatiques : des enjeux indissociables ». *Vecteur Environnement,* vol. 43, nº 5, p. 10-13.

SLAP (2018a). The Canada-Quebec Agreement on the St. Lawrence: Working Together Since 1988. [Online]. [http://planstlaurent.qc.ca/en/home/about_us.html].

SLAP (2018b). « Aquatic invasive animal species in the freshwater section of the St.Lawrence River, 2018 ». [Online], Monitoring Changes in the State of the St. Lawrence [http://planstlaurent.qc.ca/en/state_monitoring/monitoring_sheets.html].

SLAP (2018c). « Water Quality in the Fluvial sectionl ». [Online], Lawrence [http://planstlaurent.qc.ca/en/state_monitoring/monitoring_sheets.html].

TARDIF, B., G. LAVOIE and Y. LACHANCE (2005). *Atlas de la biodiversité du Québec – Les espèces menacées ou vulnérables*. Québec, ministère du Développement durable, de l'Environnement et des Parcs, Direction du développement durable, du patrimoine écologique et des parcs, 60 p.

TARDIF, B., B. TREMBLAY, G. JOLICOEUR and J. LABRECQUE. 2016. Les plantes vasculaires en situation précaire au Québec. Centre de données sur le patrimoine naturel du Québec (CDPNQ). Gouvernement du Québec, ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques (MDDELCC), Direction de l'expertise en biodiversité, Québec, 420 p.

TEFFT, B.C. (2006). « Managing shrublands and old fields ». Dans The Northeast Upland Habitat Technical Committee, *Managing Grasslands, Shrublands, and Young Forest Habitats for Wildlife: A Guide for the Northeast*, chapitre 4. [En ligne]. [http://www.ct.gov/deep/cwp/view.asp?a=2723&q=325732] (Consulté le 26 octobre 2018).

TEWS, J. (2008). *Population viability and sensitivity analysis for Marsh Wren, Ovenbird, Red-Shouldered Hawk, and Bobolink in the Quebec Pilot Study area in support of NAESI habitat-based biodiversity standards*. National Agri-Environmental Standards Initiative Technical Report No. 4-12, 81 p.

THE NORTHEAST UPLAND HABITAT TECHNICAL COMMITTEE (2006). *Managing grasslands, shrublands, and young forest habitats for wildlife: A guide for the Northeast*. [En ligne]. [http://www.ct.gov/deep/cwp/view.asp?a=2723&q=325732] (Consulté le 26 octobre 2018).

THÉRIAULT, M., and R. QUENNEVILLE (1998). *Cadre pour la restauration écologique du pin blanc au parc national de la Mauricie*. Québec, Parcs Canada, Service de la conservation des ressources naturelles, 39 p.

THORMANN, M.N., et S.E. BAYLEY (1997). « Aboveground net primary production along a bog-fen-marsh gradient in southern boreal Alberta, Canada ». *Écoscience*, vol. 4, nº 3, p. 374-384.

TINER, R.W. (1999). *Wetland Indicators: A Guide to Wetland Identification, Delineation, Classification, and Mapping*. Boca Raton, Lewis Publishers, 392 p.

TITTLER, R., M.-A. VILLARD and L. FAHRIG (2009). « How far do songbirds disperse? » *Ecography*, vol. 32, nº 6, p. 1051-1061.

TROMBULAK, S.C., and C.A. FRISSELL (2000). « Review of ecological effects of roads on terrestrial and aquatic communities ». *Conservation Biology*, vol. 14, nº 1, p. 18-30.

TSCHARNTKE, T., A.M. KLEIN, A. KRUESS, I. STEFFAN-DEWENTER and C. THIES (2005). « Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management ». *Ecology Letters*, vol. 8, nº 8, p. 857-874.

UNITED STATES DEPARTMENT OF AGRICULTURE (2008). *Hydrogeomorphic wetland classification system: An overview and modification to better meet the needs of the Natural Resources Conservation Service*. Washington, D.C., Natural Resources Conservation Service, Technical Note No. 190-8-76, 8 p.

VANDER VORSTE, R., P. McELMURRAY, S. BELL, K.M. ELIASON and B.L. BROWN ((2017). « Does stream size really explain biodiversity patterns in lotic systems? A call for mechanistic explanations ». *Diversity,* vol. 9, nº 3, article 26.

VANNOTE, R.L., G.W. MINSHALL, K.W. CUMMINS, J.R. SEDELL and E. GUSHING (1980). « The river continuum concept ». *Journal canadien des sciences halieutiques et aquatiques,* vol. 37, nº 1, p. 130-137.

VILLENEUVE, N., O. PFISTER, J. GOSSELIN, L. GRATTON and L. COUILLARD (in preparation). « Exercice de regroupement de types écologiques/groupements d'essences au sein des communautés forestières cartographiées des régions 1A et 2B ».

VIVIAN-SMITH, G. (1997). « Microtopographic heterogeneity and floristic diversity in experimental wetland communities ». *Journal of Ecology*, vol. 85, nº 1, p. 71-82.

VOULIGNY, C., and S. GARIÉPY (2008). *Les friches agricoles au Québec : état des lieux et approches de valorisation*. Rédigé pour Agriculture et Agroalimentaire Canada, 66 p.

WAIDE, R.B., M.R. WILLIG, C.F. STEINER, G. MITTELBACH, L. GOUGH, S.I. DODSON, G.P. JUDAY and R. PARMENTER (1999). « The relationship between productivity and species richness ». *Annual Review of Ecology and Systematics*, vol. 30, nº 1, p. 257-300.

WEIBULL, A.-C., Ö. ÖSTMAN and A. GRANQVIST (2003). « Species richness in agroecosystems: the effect of landscape, habitat and farm management ». *Biodiversity and Conservation*, vol. 12, nº 7, p. 1335-1355.

WETZEL, R.G. (2001). *Limnology: Lake and River Ecosystems*, 3rd ed. New York, Academic Press, 1006 p.

WILBY, R. L., and G. L. W. PERRY (2006). « Climate change, biodiversity and the urban environment: a critical review based on London, UK ». *Progress in Physical Geography: Earth and Environment*, vol. 30, nº 1, p. 73-98. doi : 10.1191/0309133306pp470ra.

WILCOVE, D.S., C.H. McLELLAN and A.P. DOBSON (1986). « Habitat fragmentation in the temperate zone ». Dans Soulé, M.E (dir.) *Conservation Biology: The Science of Scarcity and Diversity*, p. 237-256, Sunderland, Sinauer Associates, Inc.

WILSON, C.V. (1971). *Le climat du Québec, partie 1 : Atlas climatique*. Ottawa, Service météorologique du Canada, Études climatologiques nº 11, 44 figures.

WILSON, E.O., and E.O. WILLIS (1975). « Applied biogeography ». Dans Cody, M.L., et J.M. Diamond (dir.) *Ecology and Evolution of Communities*, p. 523-534, Cambridge, Harvard University Press.

WOO, M.-K., and J. VALVERDE (1981). « Summer Streamflow and Water Level in a Midlatitude Forested Swamp ». *Forest Science*, vol. 27, nº 1, p. 177-189.

WOO, M.-K., and T.C. WINTER (1993). « The role of permafrost and seasonal frost in the hydrology of northern wetlands in North America ». *Journal of Hydrology*, vol. 141, nºs 1-4, p. 5-31.

WOODS, M., R. A. MCDONALD and S. HARRIS (2003). « Predation of wildlife by domestic cats *Felis catus* in Great Britain ». *Mammal Review*, vol. 33, nº 2, p. 174-188.

WOOLMER, G., S.C. TROMBULAK, J.C. RAY, P.J. DORAN, M.G. ANDERSON, R.F. BALDWIN, A. MORGAN and E.W. SANDERSON (2008). « Rescaling the Human Footprint: A tool for conservation planning at an ecoregional scale ». *Landscape and Urban Planning*, vol. 87, nº 1, p. 42-53.

YOUNG, A., T. BOYLE and T. BROWN (1996). « The population genetic consequences of habitat fragmentation for plants ». *Trends in Ecology and Evolution,* vol. 11, nº 10, p. 413-418.

20. Metadata for maps

Sources

1:1,000,000 Geographic and Administrative Database, (AMDB 1M), MERN,
1:20,000 SYSTÈME SUR LES DÉCOUPAGES ADMINISTRATIFS (SDA 20k)

Coordinate system

Albers equivalent conic projection for Quebec (NAD83)

Appendix A. Terrestrial species at risk that have been documented in the the St. Lawrence Lowlands

(only federally endangered or threatened or provincially threatened or vulnerable species are listed)

Common name	Scientific name	Status	
		Federal	Provincial
Lichen			
Flooded jellyskin	*Leptogium rivulare*	Threatened	None
Vascular plants			
Wild Leek	*Allium tricoccum*	None	Vulnerable
Putty Root	*Aplectrum hyemale*	None	Threatened
Green dragon	*Arisaema dracontium*	None	Threatened
Forked threeaw n	*Aristida basiramea*	Endangered	Threatened
Butterfly milkw eed	*Asclepias tuberosa* var. *interior*	None	Threatened
Flax-leaved stiff-aster	*Ionactis linariifolia*	None	Vulnerable
White w ood aster	*Eurybia divaricate*	Threatened	Threatened
Slender w oodland sedge	*Carex digitalis* var. *digitalis*	None	Threatened
False hop sedge	*Carex lupuliformis*	Endangered	Threatened
American w ater-willow	*Justicia Americana*	Threatened	Threatened
Victorin's w ater-hemlock	*Cicuta maculata* var. *victorinii*	Concerned	Threatened
American cancer-root	*Conopholis Americana*	None	Vulnerable
Autumn coralroot	*Corallorhiza odontorhiza* var. *odontorhiza*	None	Threatened
Ram's head lady's slipper	*Cypripedium arietinum*	None	Vulnerable
Wallrue spleenw ort	*Asplenium ruta-muraria* var. *cryptolepis*	None	Threatened
Black maple	*Acer nigrum*	None	Vulnerable
Estuary pipew ort	*Eriocaulon parkeri*	None	Threatened
False mermaid	*Floerkea proserpinacoides*	None	Vulnerable
Victorin's gentian	*Gentianopsis virgata* ssp. *victorinii*	Threatened	Threatened
American ginseng	*Panax quinquefolius*	Endangered	Threatened
Dow ny rattlesnake plantain	*Goodyera pubescens*	None	Vulnerable
Woodland sunflow er	*Helianthus divaricatus*	None	Vulnerable
Sharp-fruited rush	*Juncus acuminatus*	None	Threatened
Lizard's tail	*Saururus cernuus*	None	Threatened
Purple tw ayblade	*Liparis liliifolia*	Threatened	Susceptible
Southern tw ayblade	*Listera australis*	None	Threatened
Spotted beebalm	*Monarda punctata* var. *villicaulis*	None	Threatened
Slender muhly	*Muhlenbergia tenuiflora*	None	Threatened
Spring scorpion grass	*Myosotis verna*	None	Threatened
Butternut	*Juglans cinereal*	Endangered	Susceptible
Eastern prairie marbleseed	*Lithospermum parviflorum*	None	Threatened
Rock elm	*Ulmus thomasii*	None	Threatened
Purple-stem cliffbrake	*Pellaea atropurpurea*	None	Threatened
Broad beech fern	*Phegopteris hexagonoptera*	None	Threatened
Pitch pine	*Pinus rigida*	None	Threatened

		Status	
Common name	**Scientific name**	**Federal**	**Provincial**
Mayapple	*Podophyllum peltatum*	None	Threatened
Woodland pinedrops	*Pterospora andromedea*	None	Threatened
Douglas' knotweed	*Polygonum douglasii*	None	Vulnerable
Blunt-scale bulrush	*Schoenoplectiella purshiana* var. *purshiana*	None	Threatened
Roundleaf ragwort	*Packera obovate*	None	Threatened
Fragrant sumac	*Rhus aromatica* var. *aromatica*	None	Vulnerable
Jewelled maiden fern	*Thelypteris simulate*	None	Threatened
Provancher's fleebane	*Erigeron philadelphicus* var. *provancheri*	None	Threatened
Narrowleaf vervain	*Verbena simplex*	None	Threatened
Blunt-lobed woodsia	*Woodsia obtusa*	Threatened	Threatened
Arthropod			
Rusty patched bumble bee	*Bombus affinis*	Endangered	None
Northern barrens tiger beetle	*Cicindela patruela*	Endangered	None
Fish			
Common shad	*Alosa sapidissima*	None	Vulnerable
Striped bass	*Morone saxatilis*	Endangered	None
Copper redhorse	*Moxostoma hubbsi*	Endangered	Threatened
River redhorse	*Moxostoma carinatum*	Concerned	Vulnerable
Northern cisco	*Coregonus artedi*	Endangered	Susceptible
Eastern sand darter	*Ammocrypta pellucida*	Threatened	Threatened
Rainbow smelt	*Osmerus mordax*	None	Vulnerable
Channel darter	*Percina copelandi*	Threatened	Vulnerable
Northern brook lamprey	*Ichthyomyzon fossor*	Concerned	Threatened
Bridle shiner	*Notropis bifrenatus*	Concerned	Vulnerable
Amphibian			
Western chorus frog	*Pseudacris triseriata*	Threatened	Vulnerable
Spring salamander	*Gyrinophilus porphyriticus*	Concerned	Vulnerable
Allegheny mountain dusky salamander	*Desmognathus ochrophaeus*	Threatened	Threatened
Reptile			
Wood turtle	*Glyptemys insculpta*	Threatened	Vulnerable
Northern map turtle	*Graptemys geographica*	Concerned	Vulnerable
Spiny softshell	*Apalone spinifera*	Threatened	Threatened
Blanding's turtle	*Emydoidea blandingii*	Threatened	Threatened
Common musk turtle	*Sternotherus odoratus*	Threatened	Threatened
Bird			
Henslow's sparrow	*Ammodramus henslowii*	Endangered	None
Whip-poor-will	*Antrostomus vociferus*	Threatened	None
Common nighthawk	*Chordeiles minor*	Threatened	None
Peregine falcon	*Falco peregrinus anatum/tundrius*	Concerned	Vulnerable
Chimney swift	*Chaetura pelagica*	Threatened	None
Olive-sided flycatcher	*Contopus cooperi*	Threatened	None
Golden-winged warbler	*Vermivora chrysoptera*	Endangered	None

Common name	Scientific name	Status Federal	 Provincial
Cerulean warbler	*Setophaga cerulea*	Concerned	Threatened
Kirtland's warbler	*Setophaga kirtlandii*	Endangered	None
Canada warbler	*Cardellina canadensis*	Threatened	None
Least bittern	*Ixobrychus exilis*	Threatened	Vulnerable
Red-headed woodpecker	*Melanerpes erythrocephalus*	Threatened	Threatened
Loggerhead shrike	*Lanius ludovicianus migrans*	Endangered	Threatened
Bald eagle	*Haliaeetus leucocephalus*	None	Vulnerable
Yellow rail	*Coturnicops noveboracensis*	Concerned	Threatened
Mammal			
Northern long-eared bat	*Myotis septentrionalis*	Endangered	None
Little brown bat	*Myotis lucifugus*	Endangered	None
Tricolored bat	*Perimyotis subflavus*	Endangered	None
Gray fox	*Urocyon cinereoargenteus*	Threatened	None

Appendix B. Protected Areas in the St. Lawrence Lowlands extracted from the Registre des aires protégées au Québec

(Excluding designated wildlife habitats)

Responsible	Type of protected area	Site name	Administrative region*	Number of sites
Federal government	National wildlife area	Cap-Tourmente	03	1
	National wildlife area	Îles-de-la-Paix	16	1
	National wildlife area	Lac-Saint-François	16	1
	National wildlife area	Îles-de-Contrecoeur	14	1
	Migratory bird santuary	Mont-Saint-Hilaire	16	1
	Migratory bird santuary	Îles-de-la-Paix	16	1
	Migratory bird santuary	Trois-Saumons	12	1
	Migratory bird santuary	Philipsburg	16	1
	Migratory bird santuary	Cap-Saint-Ignace	12	1
	Migratory bird santuary	Saint-Vallier	12	1
	Migratory bird santuary	Islet	12	1
	Migratory bird santuary	Nicolet	17	1
	Migratory bird santuary	Montmagny	12	1
	Migratory bird santuary	Île-aux-Hérons	16	1
	Migratory bird santuary	Île-de-Carillon	15	1
	Migratory bird santuary	Île-de-la-Couvée	16	1
	Park of the National Capital Commission	Gatineau	07	1
Provincial government	National park	Oka	15	1
	National park	Mont-Saint-Bruno	16	1
	National park	Îles-de-Boucherville	16	1
	National park	Plaisance	07	1
	Ecological reserve	Boisé-des-Muir	16	1
	Ecological reserve	Chênaie-des-Îles-Finlay	07	1
	Ecological reserve	Île-Garth	15	1
	Ecological reserve	Îles-Avelle-Wight-et-Hiam	16	1
	Ecological reserve	Jules-Carpentier	03	1
	Ecological reserve	Lac-à-la-Tortue	04	1
	Ecological reserve	Léon-Provancher	17	1
	Ecological reserve	Lionel-Cinq-Mars	12	1
	Ecological reserve	Marcel-Léger	04	1
	Ecological reserve	Marcel-Raymond	16	1
	Ecological reserve	Micocoulier	16	1
	Ecological reserve	Pin-Rigide	16	1
	Ecological reserve	Pointe-Platon	12	1
	Ecological reserve	Presqu'île-Robillard	15	1
	Ecological reserve	Rivière-aux-Brochets	16	1
	Ecological reserve	Rivière-du-Moulin	12	1

Responsible	Type of protected area	Site name	Administrative region*	Number of sites
	Ecological reserve	Tourbières-de-Lanoraie	14	1
	Biodiversity reserve	Samuel-De Champlain	16	1
	Wildlife refuge	Rivière-des-Mille-Îles	15	1
	Wildlife refuge	Grande-Île	14	1
	Wildlife refuge	Deux-Montagnes	15	1
	Wildlife refuge	Pointe-du-Lac	04	1
	HTVPS**	Alvar-de-l'Île-de-Pierre	13	1
	HTVPS	Baie-des-Anglais	16	1
	HTVPS	Chenal-Proulx	16	1
	HTVPS	Hêtraie-du-Calvaire-d'Oka	15	1
	HTVPS	Île-Beauregard	16	1
	HTVPS	Île-Rock	06	1
	HTVPS	Îles-Arthur-et-Bienville	16	1
	HTVPS	Marais-de-l'Anse-du-Cap	12	1
	HTVPS	Marais-de-l'Anse-Verte	12	1
	HTVPS	Marais-de-la-Pointe-de-La Durantaye	12	1
	HTVPS	Marais-de-l'Île-Avelle	16	1
	HTVPS	Marais-de-l'Île-des-Juifs	15	1
	HTVPS	Marécage-de-la-Grande-Île	14	1
	HTVPS	Marécage-de-l'Île-Bouchard	14	1
	HTVPS	Marécage-de-l'Île-Lacroix	17	1
	HTVPS	Marécage-de-l'Île-Marie	16	1
	HTVPS	Ormes-Lièges-du-Canton-de-Chatham	15	1
	HTVPS	Parc-du-Mont-Royal	06	1
Private	Natural reserve	Abbaye-Cistercienne-de-Rougemont	16	1
	Natural reserve	Alvar-d'Aylmer	07	1
	Natural reserve	Annedda	05	1
	Natural reserve	Anse-Ross	12	1
	Natural reserve	Archipel-du-Mitan	13	1
	Natural reserve	Baie-des-Brises	16	1
	Natural reserve	Battures-de-Saint-Augustin-de-Desmaures	03	1
	Natural reserve	Bois-de-Brossard	16	1
	Natural reserve	Bois-Angell	06	1
	Natural reserve	Bois-Barré-de-Villieu	12	1
	Natural reserve	Bois-des-Patriotes	16	1
	Natural reserve	Boisé-des-Blouin	16	1
	Natural reserve	Boisé-des-Douze	16	1
	Natural reserve	Boisé-des-Soeurs-de-l'Assomption	17	1
	Natural reserve	Boisé-Du Tremblay	16	1

Responsible	Type of protected area	Site name	Administrative region*	Number of sites
	Natural reserve	Boisé-du-Séminaire	17	1
	Natural reserve	Boisé-Papineau	13	3
	Natural reserve	Boisé-Roger-Lemoine	15	1
	Natural reserve	Chemin-Saint-Georges	16	1
	Natural reserve	Coteau-de-la-Rivière-La Guerre	16	1
	Natural reserve	Coulée-à-Biron	16	1
	Natural reserve	Coulée-des-Érables	16	1
	Natural reserve	Edgar-Morier	16	1
	Natural reserve	Forêt-de-Senneville	06	1
	Natural reserve	Forêt-du-Grand-Coteau	15	1
	Natural reserve	Gault-de-l'Université-McGill	16	1
	Natural reserve	Grande-Tourbière-de-Villeroy	17	6
	Natural reserve	Île Bonfoin	06	1
	Natural reserve	Île-Beauregard	16	1
	Natural reserve	Île-de-Grâce	16	1
	Natural reserve	Île-Jeannotte	16	1
	Natural reserve	Île-Kettle	07	2
	Natural reserve	Îlet-du-Moulin-à-Vent-de-Contrecoeur	16	1
	Natural reserve	Marais-Léon-Provancher	03	1
	Natural reserve	Marais-Trépanier	07	1
	Natural reserve	Marécage-des-Chenaux-de-Vaudreuil	16	1
	Natural reserve	Méandre-de-la-Rivière-Vincelotte	12	1
	Natural reserve	Milieux-Humides-du-Lac-Lichtfield	07	1
	Natural reserve	Montagne-de-Rigaud	16	1
	Natural reserve	Mont-Rougemont	16	6
	Natural reserve	Mont-Saint-Bruno	16	1
	Natural reserve	Mont-Saint-Grégoire	16	2
	Natural reserve	Mont-Yamaska	16	2
	Natural reserve	Namasté	16	1
	Natural reserve	North River Farm	15	1
	Natural reserve	Patrimoine-des-Hébert	17	1
	Natural reserve	Père-Louis-Trempe	06	1
	Natural reserve	Petit-Canal-à-Salaberry-de-Valleyfield	16	1
	Natural reserve	Piémont-du-Mont-Saint-Hilaire	16	3
	Natural reserve	Pointe-de-la-Croix	03	1
	Natural reserve	Pointe-Fontaine	16	1

Responsible	Type of protected area	Site name	Administrative region*	Number of sites
	Natural reserve	Pointes	04	1
	Natural reserve	Polatouche-de-Villieu	12	1
	Natural reserve	Rapides-de-Lachine	06	1
	Natural reserve	Rocher	16	1
	Natural reserve	Ruisseau-Bleury	16	1
	Natural reserve	Ruisseau-Robert	16	1
	Natural reserve	Sault-à-la-Puce	03	1
	Natural reserve	Station-Agronomique-de-l'Université-Laval	03	1
	Natural reserve	Tourbière-de-Venise-Ouest	16	2
	Natural reserve	Tourbière-du-Lac-à-la-Tortue	04	2
	Voluntary natural conservation environment***	Various names to be specified	All	93

* 03: Capitale-Nationale; 04: Mauricie; 05: Estrie; 06: Montréal; 07: Outaouais; 12: Chaudière-Appalaches; 13: Laval; 14: Lanaudière; 15: Laurentides; 16: Montérégie; 17: Centre-du-Québec

** HTVPS: Habitat of a threatened or vulnerable plant species

*** 93 sites in the registre des aires protégées du Québec (MELCC, 2018)

Appendix C. Determination of priority ranks of floristic occurrences extracted from the CDPNQ to guide the selection of sites of conservation interest in the St. Lawrence Lowlands

The selection of conservation targets (forest fragments/wetland complexs/wetland/ aquatic ecological units) for threatened or vulnerable plant species is based on an objectives approach. These targets have been defined in terms of the "conservation value" of the occurrences of these species. The following text presents the general crite ria used to select occurrences for consideration, as well as those used to rank these occurrences according to their conservation value. Statistics have been prepared to determine the number of occurrences and species that meet these different criteria.

The data used for this purpose comes from the Centre de données sur le patrimoine naturel du Québec (CDPNQ) as of January 2016. The concepts of priority rank (for species) and the degree of precision, viability rating and biodiversity index (for occurrences) referred to below are explained in a document produced by the CDPNQ (Tardif et al., 2016).

GENERAL OCCURRENCES SELECTION CRITERIA

Accuracy and viability of occurrences

In general, only occurrences of S precision and viability "A", "B", "C" (deemed viable) were selected. However, in a few specific cases, this rule was not applied and all or almost all occurrences were considered. In addition, historical occurrences (viability "H") were not considered even though they were originally considered because of the risk of "escaping" "false historical occurrences" (i.e., occurrences that are classified as historical because of the time elapsed since the last observation, but are most likely still existing). This decision is based on the analysis of the CDPNQ data, which revealed the following:

- 372 historical occurrences of precision S, representing 109 species, are present in the St. Lawrence Lowlands;
- The majority of these 109 species are represented by fewer than four historical occurrences and frequently two, or even one, occurrence;
- The addition of historical occurrences could be beneficial for only six species, namely *Acer nigrum, Cardamine bulbosa, Carex typhina, Ceanothus americanus, Cyperus odoratus and Quercus bicolor*;
- A large proportion of the historical occurrences of these six species is along the shores of the Ottawa or Thousand Islands River, where other recent occurrences are present.

In light of this information, the risk of "missing" "false historical occurrences" was found to be relatively low. In the end, therefore, the abandonment of historical occurrences was not considered problematic. Historical occurrences were, however, taken into account in the case of unique occurrences across Quebec and in the analysis to identify species with the majority of occurrences (more than 50%) within the St. Lawrence Lowlands (SLL).

Representativeness of S3 priority occurrences within SLL

In this analysis, the question of whether or not to include occurrences of precision S3 and viability A and B in the conservation objectives has arisen. Because of their lower conservation value, the selection of such occurrences was considered relevant only for "preferred" species in the SLL. In order to avoid including S3 species whose main range was outside the SLL, only species with the majority of occurrences (more than 50%) within the SLL were therefore selected. To determine this percentage, all occurrences of these species were considered, regardless of their degree of precision (S, M, or G) or viability rating (A, B, C, D, E, F, H, or X). A total of 807 occurrences were retained to guide the selection of areas of conservation interest.

OCCURRENCES RATING CRITERIA

1. Unicity (unique occurrence in Quebec)

Outstanding conservation value

Overall priority rank = 1
Detailed Priority Rank = 1: All occurrences within the SLL and unique to Quebec were considered regardless of their S, M or G precision and their A, B, C, D, E, F or H viability rating.

Number of occurrences: 9
Number of species: 9

2. Biodiversity Index (combination of species priority rank and occurrence viability rating)

Very high conservation value*

Overall priority rank = 2

Detailed priority rank = 2: occurrences of species of rank G2 and viability A and B (index B2.02)

Number of occurrences: 15
Number of species: 2

Detailed priority rank = 3: occurrences of species of rank G3 and viability A (index B2.03)

Number of occurrences: 38
Number of species: 10

Detailed priority rank = 4: occurrences of species of rank S1 and viability A (index B2.04)
Number of occurrences: 8
Number of species: 5

High conservation value*

Overall priority rank = 3

Detailed Priority Rank = 5: occurrences of species of rank G3 and viability B (index B3.02)
Number of occurrences: 7
Number of species: 2

Detailed priority rank = 6: occurrences of species of rank G2 and viability C (index B3.01)
Number of occurrences: 62
Number of species: 12

Detailed priority rank = 7: occurrences of species of rank S1 and viability B (index B3.03)
Number of occurrences: 18
Number of species: 14

Detailed priority rank = 8: occurrences of species of rank S2 and viability A (index B3.05)
Number of occurrences: 75
Number of species: 46

Detailed priority rank = 9: occurrences of species of rank S2 and viability B (index B3.11)
Number of occurrences: 126
Number of species: 56

Moderate conservation value*

Overall priority rank = 4

Detailed priority rank = 10: occurrences of species of rank G3 and viability C (index B4.01)
Number of occurrences: 50
Number of species: 13

Detailed priority rank = 11: occurrences of species of rank S1 and viability C (index B4.02)
Number of occurrences: 39
Number of species: 26

Detailed priority rank = 12: occurrences of species of rank S3 and viability A, considered representative of SLL according to the method defined above (index B4.03)
Number of occurrences: 51
Number of species: 18

Detailed priority rank = 13: occurrences of species of rank S3 and viability B, considered representative of SLL according to the method defined above (index B4.07)

Number of occurrences: 62

Number of species: 19

3. Rarity in the SLL

The rarity of a species in the SLL area is another selection criterion that has been added in order to cover the maximum number of species that may be of particular conservation importance for this area. The table below shows the number of species associated with a particular number of occurrences (from 1 to 10) of A, B or C viability within the SLL. For the evaluation of this rarity criterion, all occurrences of precision S and of viability A, B or C of all species present in the SLL, whether or not they are considered representative of this territory, have been selected.

Note, however, that there was a significant number of cross-references to occurrences with exceptional, very high, high or moderate conservation values based on the criteria presented in the previous sections. In cases where occurrences qualified on the basis of both the criteria for outstanding, very high, high or moderate conservation values and the criteria for rarity, only the highest general and detailed priority rankings were retained.

Overall priority ranking	5	5	5	5	5	5	5	5	5	5
Detailed priority ranking	14	15	16	17	18	19	20	21	22	23
Number of occurrences	1	2	3	4	5	6	7	8	9	10
Total number of occurrences corresponding to this rarity criterion	12	12	36	34	37	29	28	27	16	16
Total number of species meeting this rarity criterion	12	8	18	14	11	8	6	7	3	3

According to Table 5.6 in Tardif, B., et al. (2016).

Note: the criterion of geographical distribution with respect to the SLL is not part of the criteria used in Table 5.6 of Tardif et al (2016).

Writing, analysis and technical review: Olivier Pfister (Protected Areas Directorate, MELCC), Line Couillard, Vincent Piché, Jacques Labrecque, Guy Jolicoeur (Biodiversity Expertise Directorate, MELCC), Benoît Jobin (Canadian Wildlife Service, Environment and Climate Change Canada) and David Leclair (Applied Ecology Bureau).

Appendix D. Number of occurrences of plant species selected for the selection of sites of interest

Latin name	Common name	Number of occurrences	Latin name	Common name	Number of occurrences
Acer nigrum	Black maple	7	*Isoetes tuckermanii*	Tuckerman's quillwort	2
Adlumia fungosa	Allegheny vine	5	*Juglans cinerea*	Butternut	1
Agastache nepetoides	Yellow giant hyssop	1	*Justicia americana*	American water-willow	5
Ambrosia psilostachya	Perennial ragweed	1	*Lactuca hirsuta*	Hairy lettuce	5
Amelanchier amabilis	Red-twigged shadbush	3	*Liparis liliifolia*	Purple twayblade	1
Aplectrum hyemale	Putty root	1	*Lithospermum parviflorum*	Eastern Prairie Marbleseed	1
Arisaema dracontium	Dragon root	12	*Lycopus asper*	Rough bugleweed	4
Aristida basiramea	Forked threeawn	6	*Lycopus laurentianus*	St. Lawrence waterhorehound	13
Asclepias tuberosa var. *interior*	Butterfly milkweed	1	*Lycopus virginicus*	Virginia water horehound	5
Asplenium platyneuron	Ebony spleenwort	3	*Lysimachia hybrida*	Lowland yellow-loosestrife	7
Asplenium rhizophyllum	Walking fern	9	*Lysimachia quadrifolia*	Whorled yellow loosestrife	4
Asplenium trichomanes subsp. *quadrivalens*	Maidenhair spleenwort	1	*Monarda punctata* var. *villicaulis*	Spotted beebalm	3
Bartonia virginica	Yellow screwtem	2	*Myosotis verna*	Spring scorpion grass	1
Bidens eatonii	Eaton's beggarticks	15	*Myriophyllum heterophyllum*	Various-leaved water-milfoil	2
Boechera retrofracta	Holboell's rockcress	1	*Neottia bifolia*	Southern twayblade	1
Borodinia laevigata	Smooth rock cress	8	*Oenothera pilosella* subsp. *pilosella*	Meadow evening primrose	2
Botrychium mormo	Little goblin moonwort	1	*Panax quinquefolius*	American ginseng	19
Bromus pubescens	Hairy woodland brome	1	*Panicum flexile*	Wiry panicgrass	10
Cardamine bulbosa	Bulbous bittercress	4	*Panicum philadelphicum* subsp. *philadelphicum*	Philadelphia panicgrass	5
Carex argyrantha	Hay sedge	3	*Panicum virgatum*	Switchgrass	6
Carex atherodes	Wheat sedge	3	*Pellaea atropurpurea*	Purple-stem cliffbrake	1
Carex cephalophora	Oval-leaf sedge	7	*Peltandra virginica*	Green arrow arum	1
Carex cumulata	Clustered sedge	1	*Penstemon hirsutus*	Hairy beard-tongue	3
Carex digitalis var. *digitalis*	Slender woodland sedge	1	*Persicaria arifolia*	Halberd-leaved tearthumb	2
Carex formosa	Handsome sedge	3	*Persicaria robustior*	Stout dotted smartweed	3

Latin name	Common name	Number of occurrences	Latin name	Common name	Number of occurrences
Carex laxiculmis var. *laxiculmis*	Spreading sedge	1	*Phegopteris hexagonoptera*	Broad beech fern	8
Carex lupuliformis	False hop sedge	2	*Physostegia virginiana* subsp. *virginiana*	Obedient plant	1
Carex molesta	Troublesome sedge	1	*Pinus rigida*	Pitch pine	1
Carex muehlenbergii var. *muehlenbergii*	Muhlenberg's sedge	1	*Platanthera flava* var. *herbiola*	Palegreen orchid	5
Carex sartwellii	Sartwell's sedge	3	*Platanus occidentalis*	Sycamore	1
Carex siccata	Dry-spike sedge	5	*Podophyllum peltatum*	Mayapple	3
Carex swanii	Swan's sedge	1	*Podostemum ceratophyllum*	Horn-leaved riverweed	4
Carex trichocarpa	Hairyfruit sedge	1	*Polygala polygama*	Racemed milkwort	1
Carex typhina	Cattail sedge	4	*Polygala senega*	Seneca snakeroot	5
Carex virescens	Ribbed sedge	1	*Polygonum douglasii*	Douglas' knotweed	1
Ceanothus americanus	New Jersey tea	4	*Potamogeton illinoensis*	Illinois pondweed	1
Ceanothus herbaceus	Inland New Jersey tea	5	*Potamogeton strictifolius*	Straight-leaved pondweed	1
Cerastium nutans var. *nutans*	Nodding chickweed	5	*Potamogeton vaseyi*	Vasey's pondweed	1
Cicuta maculata var. *victorinii*	Victorin's water-hemlock	11	*Proserpinaca palustris*	Marsh mermaidweed	3
Claytonia virginica	Virginia spring beauty	7	*Prunus pumila* var. *susquehanae*	Sesquehana sandcherry	4
Conopholis americana	American cancer-root	1	*Pterospora andromedea*	Wood pinedrops	3
Corydalis aurea subsp. *aurea*	Golden corydalis	4	*Pycnanthemum virginianum*	Virginia mountainmint	3
Crataegus brainerdii	Brainerd's hawthorn	1	*Quercus bicolor*	Swamp white oak	1
Crataegus crus-galli var. *crus-galli*	Cockspur hawthorn	1	*Rhus aromatica* var. *aromatica*	Fragrant sumac	2
Crataegus schuettei var. *schuettei*	Royal hawthorn	1	*Rhynchospora capillacea*	Needle beaksedge	1
Crataegus suborbiculata	Caughuawaga hawthorn	1	*Rhynchospora capitellata*	Brownish beaksedge	6
Cyperus dentatus	Toothed flatsedge	1	*Rorippa aquatica*	Lake cress	2
Cyperus erythrorhizos	Redroot flatsedge	1	*Rubus flagellaris*	Northern dewberry	5
Cyperus odoratus	Fragrant flatsedge	6	*Sabulina michauxii*	Rock sandwort	3
Cypripedium arietinum	Ram's head lady's slipper	6	*Sanicula canadensis* var. *canadensis*	Canadian blacksnakeroot	1
Cypripedium reginae	Showy lady's slipper	4	*Saururus cernuus*	Lizard's tail	7
Descurainia pinnata subsp. *brachycarpa*	Green tansymustard	2	*Sceptridium rugulosum*	Ternate grape-fern	2
Eleocharis aestuum	Intertidal spike rush	1	*Schoenoplectiella purshiana* var. *purshiana*	Weak-stalked bulrush	2
Eleocharis compressa var. *compressa*	Flatstem spikerush	1	*Schoenoplectus heterochaetus*	Slender bulrush	3
Eleocharis diandra	Wright's spikerush	2	*Sisyrinchium angustifolium*	Narrow-leaf blue-eyed-grass	7

Latin name	Common name	Number of occurrences	Latin name	Common name	Number of occurrences
Eleocharis robbinsii	Robbins' spikerush	6	*Sparganium androcladum*	Branched bur-reed	6
Elymus villosus	Hairy wildrye	3	*Spiranthes casei* var. *casei*	Case's lady's tresses	2
Epilobium ciliatum subsp. *ciliatum* var. *ecomosum*	Fringed willowherb	8	*Spiranthes lucida*	Shining lady's tresses	1
Erigeron philadelphicus var. *provancheri*	Philadelphia fleabane	7	*Sporobolus compositus* var. *compositus*	Composite dropseed	3
Eriocaulon parkeri	Estuary pipewort	7	*Sporobolus heterolepis*	Prairie dropseed	2
Eurybia divaricata	White wood aster	3	*Sporobolus vaginiflorus* var. *vaginiflorus*	Poverty dropseed	10
Fimbristylis autumnalis	Slender fimbry	4	*Staphylea trifolia*	American bladdernut	5
Floerkea proserpinacoides	False mermaid	3	*Strophostyles helvola*	Amberique-bean	1
Galearis spectabilis	Showy orchid	2	*Thalictrum dasycarpum*	Purple meadow-rue	1
Galium circaezans	Licorice bedstraw	6	*Thelypteris simulata*	Bog fern	2
Gaylussacia bigeloviana	Dwarf huckleberry	1	*Toxicodendron vernix*	Poison sumac	4
Gentiana clausa	Bottle gentian	1	*Trichostema brachiatum*	Fluxweed	6
Gentianopsis crinita	Fringed gentian	8	*Trichostema dichotomum*	Forked bluecurls	1
Gentianopsis virgata subsp. *victorinii*	Victorin's gentian	20	*Ulmus thomasii*	Rock elm	3
Goodyera pubescens	Downy rattlesnake plantain	10	*Utricularia geminiscapa*	Hiddenfruit bladderwort	5
Gratiola aurea	Golden hedgehyssop	1	*Utricularia gibba*	Humped bladderwort	5
Hedeoma hispida	Rough false pennyroyal	2	*Valeriana uliginosa*	Mountain valerian	3
Helianthus divaricatus	Woodland sunflower	3	*Verbena simplex*	Narrowleaf vervain	2
Homalosorus pycnocarpos	Narrow-leaved glade fern	4	*Veronica anagallis-aquatica*	Water speedwell	8
Hudsonia tomentosa	Woolly beachheather	2	*Viburnum recognitum*	Smooth arrowwood	1
Hylodesmum nudiflorum	Naked tick-trefoil	3	*Vicia americana* var. *americana*	American wetch	1
Hypericum ascyron subsp. *pyramidatum*	Great St. John's wort	4	*Viola rostrata*	Longspur violet	7
Hypericum kalmianum	Kalm's St. Johnswort	1	*Viola sagittata* var. *sagittata*	Arrowleaf violet	2
Hypericum virginicum	Virginia marsh-St. John's-wort	1	*Viola sororia var. affinis*	Common blue violet	4
Ionactis linariifolia	Flax-leaved stiff-aster	5	*Zizania aquatica* var. *aquatica*	Annual wildrice	8
Iris virginica var. *shrevei*	Shreve's iris	7	*Zizania aquatica var. brevis*	Annual wildrice	10

Appendix E. Description of depositional contexts in the St. Lawrence Lowlands

(MELCC, 2018)

The depositional contexts in the St. Lawrence Lowlands are taken from the classification of Level 4 ecological districts in Quebec's Ecological Reference Framework. They represent the first level of territorial analysis based on Quaternary events, particularly during the Late Wisconsinan (between 23,000 and 10,000 years ago). These contexts are closely associated with dominant surficial deposits, a key variable in ecosystem analysis of this vast territory.

Rugged glacial context (1A_a): The rugged glacial context is associated with a predominance of reworked till. Below the marine limit, this type of deposit can be distinguished by the surface sand and gravel that were added through littoral processes and currents in the Champlain Sea. This reworking is mainly superficial, in the order of 50 cm or less. In the area bordering the Appalachians, the fine particles were leached from the reworked till during subsequent littoral action. They are concentrated mainly in the Châteauguay, west Huntingdon, Covey Hill, Hemmingford and Acton Vale areas. On the north shore of the St. Lawrence, this type of depositional context is found north of Saint-Jacques and west of Saint-Basile.

The flat glacial context (1A_p): originating from the Laurentide Ice Sheet that once covered Quebec, is associated with deposits left behind by the glacier's passage and its retreat in the St. Lawrence Lowlands. Glaciation deposited a layer of till whose matrix consists primarily of weakly carbonated silty sands and clayey silt; however, some regional textural variations exist. The surficial till deposits, whether thick or thin, form scattered mounds that break through the clay layer, as well as undulating terrain and morainal plains. Significant glacial accumulations are found in the regions of Montreal, south-east Châteauguay, Hemmingford and the Appalachian/Piedmont (Granby, Acton Vale, Victoriaville, Laurierville).

Deltaic context (3DB): The melting of the Laurentide Ice Sheet generated significant inputs of water and sediments to the river systems. Large deltas formed at the mouths of the main rivers in connection with the accumulation of these sediments in the Champlain Sea following land emergence (between 10,000 and 6,900 years ago). The largest deltaic deposits are located on the edge of the Laurentian Plateau (north shore of the St. Lawrence River) in the valleys of the Jacques-Cartier, Sainte-Anne, Portneuf, Batiscan, Saint-Maurice and L'Assomption rivers. The sediments are identifiable mainly in the high terraces composed of stratified, well-sorted and inclined sands with relatively small amounts of gravel.

Recent fluvial context (3FA): The recent fluvial context is associated with the present-day river systems. The deposits therefore include the alluvial beds, terraces and overflow plains of present-day watercourses and their cut in previous Quaternary formations. They also form the terraces adjacent to Lake Saint-Louis and Deux Montagnes. These sediments, which are still stratified, have different sedimentary facies with lamination of dense minerals, and may contain plant fragments.

Subrecent fluvial context (3FB): This fluvial context is associated with the former levels of terraces along the present-day river system, resulting from the change in the river's course and the gouging of the valley by running water. It can be observed on either side of Lake Saint-Pierre and the St. Lawrence River in the Sainte-Anne-de-la-Pérade and Bécancour regions. There are also some subrecent fluvial terraces along the Ottawa River. These sediments, which are still stratified, have different sedimentary facies with lamination of dense minerals, and may contain plant fragments.

Fluviomarine context (3M): This fluviomarine context is associated with fluviomarine alluvia, which were subjected to fluvial currents and deposited during the estuarine period of the St. Lawrence River as ancient terraces. These deposits are often separated by drainage channels. They are confined within terraces at elevations ranging from 60 m (Rigaud phase, between 10,000 and 9,000 years ago) to 15 m (Montreal - Saint-Barthélemy phase, between 9,000 and 8,000 years ago) associated with Lampsilis Lake, the precursor of Lake Saint-Pierre. The sediments, ranging from fine to very fine silty sand to silty loam < 1 m on clay, form high terraces downstream of Mont Saint-Bruno (Bois de Verchères) and Mont Saint-Hilaire, as well as on the north shore of the St. Lawrence, that is, the Achigan-Ouareau terraces north of L'Assomption, Sainte-Sophie and Blainville.

Calm water context (5A): The calm water context relates to the deposition of material on the bottom of the Champlain Sea basin (between 13,000 and 11,000 years ago). The plains on the south shore of the St. Lawrence Lowlands (Saint-Hyacinthe region and along the Yamaska and Richelieu rivers, southwest of Châteauguay, west of Vaudreuil-Dorion) are characterized primarily by marine clay. On the north shore, clay is exposed in outcrops on the terraces of the Lower Laurentians, Mirabel, the high terraces of Lake Saint-Pierre, north of Saint-Narcisse and in the Saint-Thuribe region. Sediment composition ranges from clay loam to silty clay with an appreciable amount of very fine sand.

Turbulent water context (5S): The turbulent water context is associated with deposition on the edge of the Champlain Sea basin during the relative drop in water levels following deglaciation. In general, these dewatering facies consist of fine- to medium-grained sands, with gravel locally, resulting from the reworking of glacial and glaciofluvial materials or from sediment-laden rivers. They are concentrated mainly on the south shore between Drummondville and the Etchemin River, and form extensive sandy plains. Peat deposits, eolian sands and beach ridges are frequently found in association with marine sands. In the Notre-Dame-du-Bon-Conseil region, till is found with these marine sands.

Littoral context (6D): This context corresponds to littoral and pre-littoral marine sediments from the Champlain Sea. These deposits formed in turbulent waters under the combined action of tides, currents and the retreating sea and, to a lesser extent, floating ice. The Quebec City region, Île d'Orléans, the Lévis and Pintendre regions, Saint-Gervais and the area along the Rivière du Sud are associated with this depositional context. In the St. Lawrence Lowlands, these heterogeneous deposits show regional textural discontinuities (alternating fine/coarse/fine) or discontinuities due to stoniness. They are composed of stratified sands and/or gravels, sometimes fossiliferous material, with some boulders. They lie unconformably on hills, lower slopes and high terraces, and in several places collectively form a succession of elongated, parallel ridges.

Appendix F. Descriptive variables for the 48 aquatic habitat types (exemplars) of the St. Lawrence Lowlands

Aquatic type	Watershed area (km²)	Raw specific power (Q2575)	Raw specific power (Q50)	Substrate	Alluvial form	River channel patterns	Alkalinity mod (Q50)	COD mod (Q50)	Max Temp 30J mod (Q50)
1	147,3	41,8	29,5	Alluvial	n/a	Meander	1 546,9	7,4	23,8
2	720,6	227,6	530,5	Rocky	n/a	Ind	619,0	7,7	22,2
3	92,4	23,7	16,3	Alluvial	n/a	Dynamic meanders	1 640,3	8,2	22,5
4	92,9	24,0	19,5	Alluvial	n/a	Corrected	703,1	8,5	24,5
5	177,8	38,9	24,7	Alluvial	n/a	Linear	1 071,1	9,7	21,8
6	289,7	2,6	3,4	Alluvial	n/a	Meanders	916,9	6,5	22,5
7	1 462,7	114,4	213,1	Semi-alluvial	n/a	Linear	734,5	6,5	21,8
8	54,8	9,2	8,1	Alluvial	n/a	Corrected	2 089,0	8,1	24,1
9	2 552,6	1,5	0,8	Alluvial	Delta	Multiple channels	1 653,4	8,7	24,2
10	1 203,8	2,8	1,2	Alluvial	n/a	Linear	918,9	7,1	23,1
11	1 239,1	42,4	29,4	Alluvial	n/a	Multiple channels	918,2	6,4	22,7
12	755,6	109,9	94,9	Alluvial	n/a	Seuil-mouille	829,8	6,3	22,4
13	103,4	6,5	28,9	Ind	n/a	Ind	921,1	7,4	21,1
14	60,3	0,0	0,0	Alluvial	Delta	Linear	2 045,6	5,5	24,4
15	1 464,4	69,6	29,9	Semi-alluvial	n/a	Multiple channels	799,8	6,0	21,7
16	103,2	57,5	32,9	Alluvial	n/a	Meanders	1 692,3	15,5	24,0
17	39,4	34,6	23,8	Ind	n/a	Meanders	788,5	6,5	21,1
18	8,7	72,1	96,9	Ind	n/a	Linear	191,7	4,5	22,3
19	786,5	356,1	467,5	Alluvial	n/a	Divagant	432,2	8,8	21,5
20	15,1	0,4	1,2	Ind	n/a	Linear	1 962,6	5,2	24,1
21	17,9	15,5	20,3	Ind	n/a	Meanders	2 415,0	5,6	23,9
22	4 787,3	0,2	0,2	Alluvial	Delta	Anastomosis	1 594,7	6,6	25,6
23	10,5	8,8	7,2	Ind	n/a	Linear	1 205,9	13,2	28,3
24	11,9	10,2	10,4	Ind	n/a	Linear	751,0	5,6	24,3
25	8,4	34,8	42,9	Ind	n/a	Linear	2 334,3	6,5	23,4
26	8,1	28,2	32,6	Ind	n/a	Linear	794,1	18,6	33,5
27	15,9	8,5	8,0	Ind	n/a	Linear	2 455,5	6,2	24,2
28	19,2	35,4	32,5	Ind	n/a	Linear	1 654,7	17,3	23,5
29	18,4	38,0	32,4	Ind	n/a	Meanders	2 237,3	8,9	22,0
30	11,8	9,8	8,8	Ind	n/a	Linear	1 259,9	26,4	40,4
31	2 060,2	77,5	6,9	Semi-alluvial	n/a	Linear	390,3	5,2	23,9
32	167,0	10,7	4,1	Alluvial	n/a	Linear	1 700,7	9,7	25,2
33	208,9	145,8	154,8	Alluvial	n/a	Seuil-mouille	437,2	4,1	23,6
34	367,8	74,1	129,6	Alluvial	n/a	Linear	320,2	5,1	22,3
35	365,5	50,5	52,4	Alluvial	n/a	Mutiple channels	304,1	5,1	22,3
36	80,5	4,6	3,9	Alluvial	n/a	Dynamic meanders	211,8	5,2	22,8
37	50,2	10,9	5,1	Alluvial	n/a	Meanders	541,6	5,7	23,3
38	337,8	5,3	9,0	Alluvial	n/a	Linear	241,3	4,5	23,1
39	26 449,3	0,6	3,8	Alluvial	n/a	Linear	408,2	6,3	29,1
40	10,1	0,0	276,0	Ind	n/a	Ind	345,2	5,5	25,6
41	10,3	90,7	108,7	Ind	n/a	Linear	492,3	4,6	23,9
42	150,9	140,4	196,4	Alluvial	n/a	Divagant	295,9	7,2	24,1
43	1 980,3	680,2	1 537,9	Rock	n/a	Ind	191,7	4,7	20,4

44	25,4	28,8	25,7	Ind	n/a	Meanders	1 026,1	14,3	25,0
45	10,6	16,5	15,6	Ind	n/a	Linear	2 000,5	6,2	25,6
46	17,0	42,4	47,2	Ind	n/a	Meanders	650,4	5,3	24,1
47	32,1	14,2	36,7	Ind	n/a	Meanders	205,6	30,8	25,7
48	136,7	6,1	15,4	Ind	n/a	Wetlands	1 157,7	9,8	24,8

n/a: not applicable
ind: indefinite

Environment and
Climate Change Canada

Environnement et
Changement climatique Canada

Environnement
et Lutte contre
les changements
climatiques

Québec