The Contribution of Wetlands Towards a Sustainable Agriculture in Canada

CAPI Doctoral Fellows 2017-2019 Group Paper

By

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Résumé : Les zones humides constituent des milieux de plus en plus vulnérables. Ils ont subi, et continuent de subir, l’impact de l’expansion des activité agricoles et de l’urbanisation. Leur destruction a notamment eu des répercussions importantes sur la qualité, la disponibilité et la distribution de l'eau. Pourtant, les zones humides sont des écosytèmes d’exception. Elles fournissent de nombreuses fonctions écosystémiques qui profitent à la fois aux êtres humains et à la biodiversité. Par exemple, la recherche scientifique a démontré que ces écosystèmes sont reconnus pour leur capacité à contrôler les inondations, à contrôler les éléments nutritifs dans les différentes masses d'eau ou à séquestrer le carbone. Bien que de nombreux projets soient axés sur les zones humides et l'agriculture, il existe un besoin important de recherche interdisciplinaire dans ce domaine. Une telle approche contribuerait à dresser un portrait plus complet et fournirait une analyse pertinente en ce qui concerne les connaissances actuelles et les mécanismes de protection relatifs aux zones humides. C'est pourquoi notre étude vise à fournir un état des lieux interdisciplinaire des terres humides en lien avec l'agriculture, notamment en montrant que la protection de ces écosystèmes peut être perçue comme un atout au profit d’une agriculture canadienne plus durable. Dans ce rapport, nous explorons donc, entre autres, les risques anthropogéniques auxquels les zones humides sont confrontés, les services écosystémiques qu’elles fournissent, les techniques de conservation qui pourraient leur être bénéfiques et les mécanismes juridiques et politiques qui s'y rapportent. Sur la base de cette analyse, un ensemble de recommandations est proposé. Elles dressent, au regard de la recherche, de l'agriculture et des politiques publiques, de l'état actuel de la conservation des zones humides et des possibilités d'actions futures.

Abstract: Wetlands are becoming more and more vulnerable environments. They were, and still are, largely impacted by the expansion of agricultural activities and urbanization. Their substantial loss has had significant repercussions, including on water quality and quantity. Yet, wetlands are remarkable ecosystems. They provide many ecosystem functions that benefit both human beings and biodiversity. For instance, scientific research has shown that wetlands are known to provide flood control, improve water quality, and enhance carbon sequestration. Although many projects focus on wetlands and agriculture, there is a lack of interdisciplinary research in this field. Such an approach would sketch out a more comprehensive portrait and provide a useful analysis with respect to existing knowledge and protection mechanisms relating to wetlands. This is why our report aims at providing an interdisciplinary overview of wetland ecosystems in their relation to agriculture, especially by showing that these ecosystems can be an important asset for a more sustainable Canadian agriculture. We explore, amongst other things, the anthropogenic risks wetlands face, the ecosystem services they provide, the conservation technics that could benefit them and the legal and political mechanisms that relate to them. Based on this analysis, a set of recommendations is suggested. From the perspectives of research, farming, and policy, these recommendations take into consideration the current state of wetland conservation and the potential for future actions.

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1. Introduction

Although often overlooked in international discussions on climate change (Intergovernmental Panel on Climate Change, 2014), wetlands play a crucial role as one of the most diversified ecosystems on the planet (Whittaker & Likens, 1973). Wetlands provide many ecological functions for both plants and animals; they form extraordinary basins of biodiversity (Bartzen, Dufour, Bidwell, Watmough, & Clark, 2017; Shutler, Mullie, & Clark, 2000). In fact, "[w]etlands and wetland functions are inextricably linked to their surroundings, particularly aquatic ecosystems" (Government of Canada, 1991). They also provide benefits to agriculture, including "crop pollination, nutrients for crops from the breakdown of organic matter, contaminant degradation and agricultural pest control" (Statistics Canada, 2015). Wetlands moderate climate change, not only by storing carbon, but also by "protecting communities from the impacts of a changed climate system" (Moonmaw et al., 2018). They also play an essential part in the conservation of both water quality and quantity. In addition, wetlands "buffer water supplies by holding water during droughts, maintain water quality by filtering nutrients and pesticides [and] reduce greenhouse gases by building and storing soil carbon" (Government of Canada, 2016; Wang et al., 2010; Padmanabhan & Bengtson, 2001).

There is a diversity of wetlands across Canada. Fresh and saltwater marshes, wooded swamps, bogs, seasonally flooded forest, and sloughs cover about 14% of the land area of Canada (Ducks Unlimited Canada (DUC), 2019; Government of Canada, 2016). For instance, a substantial proportion of the Canadian Prairies, where agriculture-related activities are prevalent, is made up of wetlands. As such, 43% of land area in Manitoba is covered by wetlands (Halsey, Vitt, & Zoltai, 1997). This natural network of wetlands aid in retaining floods, recharging groundwater and maintaining water quality by trapping nutrients such as phosphorus on the Canadian Prairies (Badiou, Page, & Akinremi, 2018; Haque, Ali, Macrae, Badiou, & Lobb, 2018; Hayashi, van der Kamp, & Rosenberry, 2016). However, the need for more agricultural production and urban development has meant that more wetlands are being drained and levelled across Canada.

Over time, wetlands have become vulnerable areas and one of "the most threatened of natural resources" (Austen & Hanson, 2007). It is estimated that more than 50% of the world's wetlands have been lost (Davidson, 2018). Wetland destruction has been occurring in Canada and is expected to continue in the future. Up to 70% of historic wetlands have been degraded or lost in Canada (DUC, 2019), of which 40% occurred in the twentieth century, mostly due to drainage: 84% of this loss is attributed to drainage for agricultural land (Wheater and al., 2013). Almost 75% of Prairie pothole wetlands and 68% of Ontario wetlands have been drained and converted to agricultural lands. According to DUC, the provinces of Manitoba and Saskatchewan are losing 8 and 6 hectares of wetlands each day, respectively, for this reason. This loss is even more substantial in some intensively cultivated regions like the Red River Valley in Manitoba, where almost 90% of the natural wetlands have been drained and converted to agricultural lands. This has resulted in negative consequences regarding water quality and increased agrochemical loads in surface water bodies, exhaustion of groundwater resources and increased risk of downstream flooding.

The loss of wetlands also has a significant impact on the human environment. Field trials and economic analysis have shown that conservation of wetlands can improve ecosystem functions and save costs associated with flood control, nutrient management in water bodies, carbon sequestration and recreation (Pattison-Williams, Pomeroy, Badiou, & Gabor, 2018). This is why the ecological services and societal values provided by wetlands have been increasingly recognized, and efforts have been made to protect or restore these natural areas. Over the past few years, many legal and political tools have been developed across Canada in support of this cause. As a result of international efforts and national initiatives, a contemporary legal framework was adopted in order to recognize the importance of wetlands and to strengthen their conservation (Rubec & Hanson, 2009). In addition, several initiatives have also been introduced by conservation and research communities. Current research initiatives such as Prairie Waters of Global Water Futures project task the researchers, partner organizations and end-users to work together to increase awareness and understanding of the importance of wetland management and conservation on the Canadian Prairies (Spence et al., 2019). Also, conservation groups such as DUC are working with stakeholders to protect, rehabilitate and manage wetlands (www.ducks.ca). As well, federal wetland conservation programs such as the Canadian Government's *National Wetland Conservation Fund* (2014-2019) have aided in restoring degraded wetlands and in funding research for scientific monitoring of wetland functions.

When it comes to agriculture and its impact on natural ecosystems such as wetlands, much of the current research has only explored a few dimensions of this topic. The lack of perspectives on this issue creates a need for interdisciplinary research. By focusing simultaneously on disciplines such as hydrology, agricultural sciences and law, a more comprehensive portrait can be drawn. In this research paper, we aim to explore the interactions between agriculture and wetlands from various disciplinary perspectives. By providing an interdisciplinary analysis, this paper will propose a transversal vision of how wetlands can be protected and what they can bring to a sustainable agriculture in Canada.

The paper is organized in three major sections. Section one provides a literature review of various definitions and interpretations of wetlands, the ecosystem services they provide, the Canadian legal and political framework applicable to their protection and conservation, the impact of agriculture on these ecosystems, and the methods by which wetlands can be restored. The second section analyses the current conditions of wetlands with respect to agriculture from a Canadian perspective. Options to manage wetlands while sustaining agricultural productivity are discussed. The final section proposes recommendations for policymakers, areas for future research and better management practices (BMPs) for farmers.

2. The Diversity of Functions and Interactions of Wetlands: An Interdisciplinary Literature Review

Wetlands serve many functions that can be observed from different disciplinary perspectives. Over the years, a growing literature on wetlands conservation has discussed the diverse impacts suffered by these ecosystems as well as the potential benefits they can provide. From agronomy to law, this section presents an overview of the profoundly interdisciplinary nature of wetlands.

2.1 Wetland Definitions

Wetlands are defined as "land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment" (National Wetlands Working Group (NWWG), 1997). Common inland and coastal wetlands include lakes, lagoons, marshlands, mangroves, estuaries and aquifer systems, through to shallow waters, seagrass beds and coral reefs (Boelee, 2013).

Wetlands are the result of many functional factors such as climate (precipitation, temperature, isolation and wind), hydrology (surface and groundwater), chemistry (water and soil), geomorphology (soil geology and landform), and biology (flora and fauna) that share common characteristics in more than one hierarchical level (NWWG, 1997).

There are two broad types of wetlands: organic and mineral wetlands. Organic wetlands are known as peatlands that contain more than 40 cm of the accumulation of peat on which organic soils could be developed except for Folisols under the Canada Soil Survey Committee (NWWG, 1997). Mineral wetlands are found in areas where the geomorphological structure of the land produces little or no organic peat due to biota, soil, hydrology and climate conditions (NWWG, 1997). Hence, according to the Canadian Wetland Classification System, there are three hierarchical levels depending on the functions and ecological characteristics: (1) class, (2) form, and (3) type. There are five classes organized according to the origin of the wetland ecosystem (bog, fen, swamp, marsh and shallow water). Regarding the form, wetlands are classified with respect to water patterns (surface morphology, surface pattern, water type and morphology of the subjacent soil mineral). Regarding the type, wetlands are classified according to external appearances of vegetation, vertical structure and growth form of the dominant taxa community (NWWG, 1997). On the other hand, depending on their chemical environment, wetlands can be classified by distinctive species, acidity, alkalinity and base cation content (Zoltai & Vitt, 1995). Peatlands with vegetation and chemical differences are primary acid (*Sphagnum*-dominated by bog and poor fens). Then again, wetlands circumneutral to alkaline includes brown moss dominated by fens and others. Wetlands like marshes and swamps, not composed of peat, are dominated by superficial water and are subject to seasonal water level fluctuations.

Additionally, there are constructed wetlands used for human activities such as agriculture, hydroelectric power generation or wastewater treatment. Constructed wetlands become natural functioning wetlands after years of functioning (NWWG, 1997). Thus, wetlands are synonymous with biodiversity that supports a variety of unique species in this unique ecosystem. They are an essential part of the local, regional and national economies, especially in rural areas (Boelee, 2013), as they are deeply connected to agriculture.

2.2 Ecosystem Services of Wetlands and their Interaction with Agriculture

Natural assets that are produced by the environment and utilized by human beings for the improvement of their social and cultural well-being are classified as ecosystem services (Maltby & Acreman, 2011). In this regard, natural wetlands offer various ecosystem services, such as provisioning services (e.g. fisheries support, food production, peat production), regulating services (e.g. water quality improvement, flood mitigation, coastal environment protection, habitat for endangered species, carbon sequestration), cultural services (landscape aesthetics, human recreation, ecology education, ecotourism), and supporting services (hydric soil development, serving sinks for chemical sources, water storage) (Mitsh, Bernal, & Hernandez, 2015). As detailing every one of these ecosystem services is beyond the scope of this paper, we will only describe the wetland ecosystem services that are directly related to agriculture and managing water resources, such as water quality improvement through nutrient reduction, replenishing groundwater resources and reduction of downstream flooding risks.

Agricultural run-off from fertilizers and pesticides are cited as a primary reason for global water quality issues, such as algal blooms and eutrophication (Dupas et al., 2015; Erisman et al., 2013). When surface runoff exits from agricultural fields, it flows through a network of wetlands, riparian zones and streams before reaching the target water body. Natural riparian zones are also often composed of individual or interconnected wetlands (Mitsh et al., 2015). Not only do these wetlands offer valuable ecosystem services such as wildlife habitat and carbon sequestration, but they also reduce agrochemical loads that pass through them as a result of various functions and processes.

2.2.1 Regulating Phosphorus

Wetlands play a critical role in regulating phosphorus (P) concentrations and loads that reach water bodies. However, the potential of wetlands to be P sinks or sources depends on factors such as wetland volume, water level fluctuation, soil texture and human influence (Haque et al., 2018). The immobilization of P by wetlands often occurs via uptake of vegetation, periphyton and microorganisms, sorption processes by soil sediments and chemical precipitation and entrainment (Verhoeven, Arheimer, Yin, & Hefting, 2006; Reddy, Kadlec, Flaig, & Gale, 1999). Retention of P by a natural wetland vegetation largely depends on their age and the season. For example, the capacity of mature vegetation to effectively remove P is low when compared to actively growing vegetation (Nichols, 1983). In addition, P removal efficiency by wetland vegetation is also smaller in non-growing seasons. In Canada, research has shown that removal of P (e.g., cattails (Typha spp.)) can be effective with actively growing vegetation after frequent harvesting in constructed wetlands is done (Gottschall, Boutin, Crolla, Kinsley, & Champagne, 2007; Jeke, Zvomuya, Cicek, Ross, & Badiou, 2018).

Wetlands also function as P sinks due to their higher P sorption capacity and P buffering capabilities (Badiou et al., 2018). However, draining natural wetlands could increase P losses by converting relatively immobile P forms into readily bioavailable forms. A constructed wetland removed about 60% of P from municipal and agro-industrial wastewater in Alberta (White, Bayley, & Curtis, 1999). Another study from Southern Manitoba reported 3.6- and 17-times higher P sorption and P buffering capacities for intact wetlands when compared to artificially drained wetlands (Badiou et al., 2018).

2.2.2 Removing Nitrogen

Wetlands have also been found to effectively remove substantial nitrogen (N) loads from the runoff water that flows through them. Inundation and a higher groundwater table in wetlands often create anaerobic conditions. These conditions favor the removal of nitrogen from input water by denitrification (Verhoeven et al., 2006). In addition, N is used as an electron acceptor by microbial organisms in decomposing organic material in oxygen-poor wetland environments. N is also removed from the system by plant uptake. For example, denitrification was responsible for 47-62% N removal in a constructed wetland in Quebec, whereas plant uptake was responsible for less than 20% of N removal (Maltais-Landry, Maranger, Brisson, & Chazarenc, 2009).

2.2.3 Removal of Pollutants (heavy metals and pesticides)

In addition, wetlands also remove other agricultural pollutants such as heavy metals, herbicides and pesticides through adsorption to clay sediments and microbial mediated biotransformation processes (Kennedy & Mayer, 2002).

2.2.4 Replenishing Groundwater

Besides ecosystem services related to water quality, wetlands also play a crucial role in replenishing groundwater resources in semi-arid regions like the Canadian Prairies. A substantial proportion of the Canadian Prairies is made up of wetlands. Even though they look isolated, many small Prairie pothole wetlands and seasonal freshwater marshes, are hydrologically interconnected through surface and subsurface flow pathways where they function as a fill and spill continuum (Shaw, Vanderkamp, Conly, Pietroniro, & Martz, 2012; Hayashi et al., 2016). Water stored in these pothole wetlands is usually in equilibrium with the nearby surrounding water table (Van der Kamp & Hayashi, The groundwater recharge function of small wetlands in the semi-arid northern prairies, 1998). This water seeps into and replenishes the surrounding groundwater table during high water demand periods.

2.2.5 Flood Control

Wetlands also effectively suppress the magnitude of flooding in coastal and inland areas. For example, in the USA, coastal wetlands from Maine to North Carolina saved a staggering USD 625 million in flood damage costs by reducing flood heights during Hurricane Sandy (Narayan et al., 2017). Another cost-benefit study from Canada reported that the destruction of wetlands in Smith Creek, Saskatchewan would result in the loss of the annual benefits from flood control of CAD 1.83 million (Pattison-Williams et al., 2018). Therefore, destruction or disturbance of this natural system may result in increased flooding in downstream areas and create water quality problems such as algal blooms and subsequent eutrophication. This may require the construction of artificial flood mitigating waterways and structures by the authorities, eventually forcing taxpayers to cover these costs. The fear is that this issue could worsen in a future climate scenario, where frequent extreme precipitation events and floods are projected (Gulbin, Kirilenko, Kharel, & Zhang, 2019).

2.2.6 Biodiversity

Wetlands are temporary or permanent homes for a variety of fauna ranging from birds, amphibians, reptiles and mammals. For example, North American wetlands function as breeding grounds for about 60 waterfowl species (Gray et al., 2013). Aquatic turtles and snakes often utilize semi-permanent and permanent wetlands. In addition, several mammals like coyotes, beavers, river otters and minks also use wetlands in some part of their life cycle (Gray et al., 2013). Wetlands also serve as migration corridors for different animal species (Erwin, 2009).

2.2.7 Carbon Sequestration

Wetlands can store a significant amount of carbon (C) due to the abundance of plant materials. The conversion of these wetlands might result in a negative carbon balance (Byun, Finkelstein, Cowling, & Badiou, 2018). In fact, the result of C losses because of wetland drainage and land cultivation on soil is estimated at an average loss of 0.1Mg of C ha^{-1} (Euliss Jr et al., 2006). Tillage and agriculture disturb the land and the soil structure (soil aggregate degrade, and microbial activity is accelerating), releasing C to the atmosphere. Wetland restoration could be the best option for carbon sequestration. For example, boreal peatlands can sequester between 29 grams of carbon per square meter each year. This C can be stored in the soil between 20 and 200 cm deep (Mitsch et al., 2013). A wetland restoration study was developed in different sites across Alberta, Saskatchewan and Manitoba to learn the amount of total C accumulation in soil, using three different dates since restoration (7 to 11, 4 to 6 and 1 to 4 years). The authors concluded that C concentration (expressed as the total amount of C in the soils) increased by 32% in the old restored area (sandy soils), then by 4 to 6 g (up 23%) and 1 to 3 g (up 17%) relative to the baseline of 107 g, kg^{-1} (Card, Quideau, & Oh, 2010). Peatlands can store twice the amount of carbon than agricultural lands as a result of biomass accumulation and erosional deposition (Euliss Jr et al., 2006). Thus, carbon sequestered in uplands is more stable and contributes more significantly to overall carbon storage (Bedard-Haughn et al., 2006). Carbon stored in wetlands can be used to offset emissions as part of the carbon market, which is increasingly being demanded by governments, private business and non-governments. The carbon market is expected to increase as a result of Canada's contribution to climate change commitments (Settre, Connor, & Wheeler, 2019), and wetlands could play an essential role because of their high storage capacity. This can translate into high economic value for producers (Patton, Bergstrom, Moore, & Covich, 2015).

2.3 Effects of Agriculture on Wetlands: The Challenge of Wetland Drainage

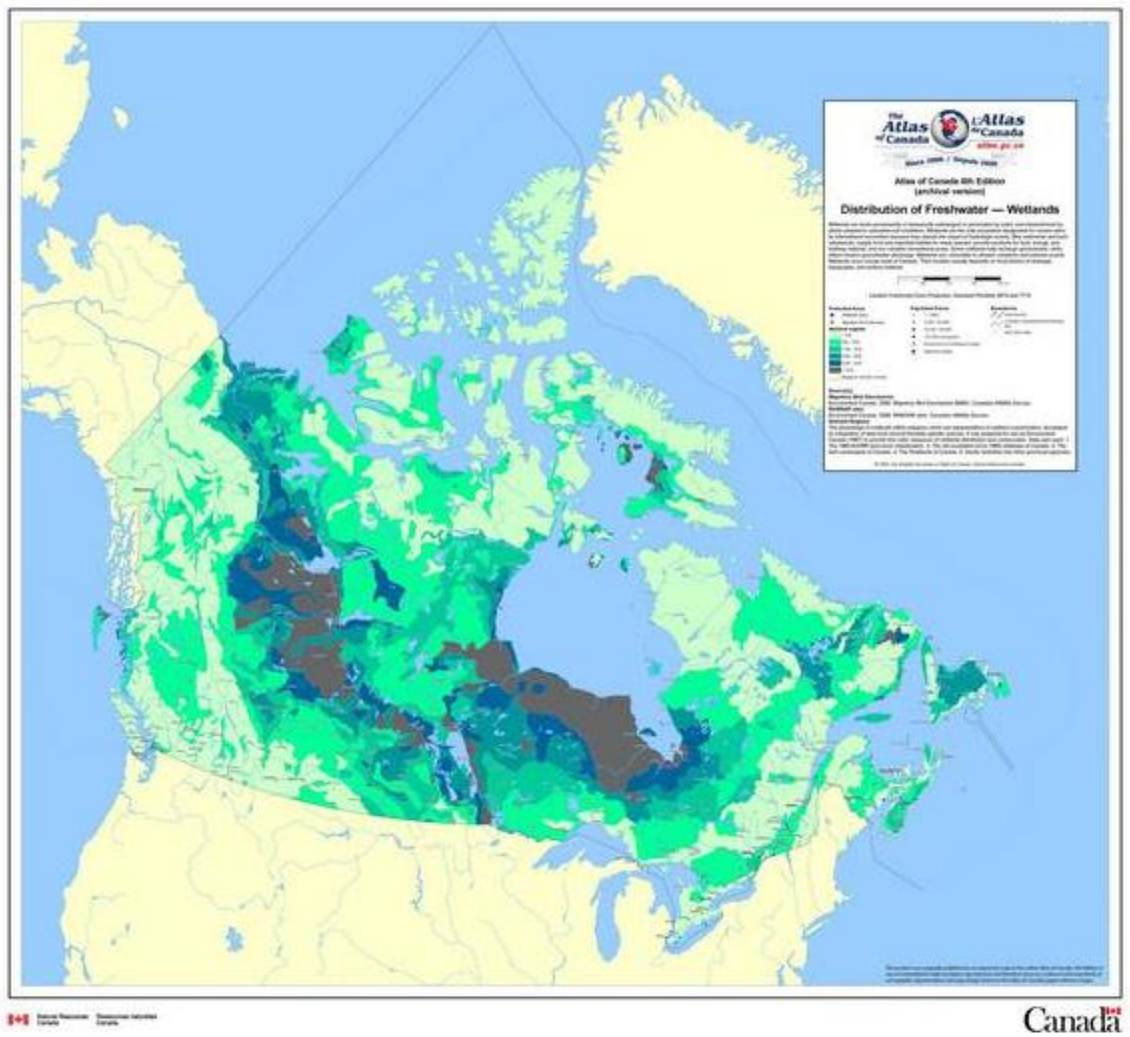
Draining wetlands for future cultivation is a current pattern in agriculture, driven by the necessity for increased crop production and export of agricultural commodities (Spence et al., 2019). Therefore, wetland drainage is still a controversial topic, even though research has clearly shown that it could lead to higher annual streamflow and flood peaks, particularly on the Canadian Prairies (Perez-Valdivia, Cade-Menun, & McMartin, 2017; Yang et al., 2010). Farmers who would like to drain their wetlands often argue they have low economic returns from in-farm wetlands and surrounding areas. To make things more complicated, climate models are now predicting increased frequency in multi-day spring and summer storms. This would potentially exacerbate issues of excess spring moisture issues, especially when there is a pothole wetland within or adjacent to a farm. Expansion of subsurface drainage is already occurring on the Prairies as a solution for excess spring moisture (Kokulan, Macrae, Ali, & Lobb, 2019). The introduction of subsurface drainage systems to drain agricultural and wetlands might add another complex layer to current flooding and water quality issues. In addition, the consequences of wetland drainage during drought years and warm summers (especially on the Prairies) are often downplayed or not discussed thoroughly.

Wetlands function as natural filters for agricultural nutrients and contaminants. The draining of these wetlands for agricultural production substantially affects the environment's natural tendency for retaining pollutants. For example, drained wetlands were found to function as P sources in Southern Manitoba (Badiou et al., 2018). Another impact of intensive agriculture is the contamination of the wetlands themselves. In the Prairies, agricultural practices were also found to be contaminating the adjacent wetlands with agrochemicals. Traces of insecticides (e.g. neonicotinoids) and herbicides (e.g. glyphosate) were detected in the ephemeral wetlands situated within intensively cultivated agricultural landscapes on the Prairie provinces (Degenhardt, et al., 2012; Main et al., 2014).

Even though natural riparian wetlands tend to retain substantial P and N from agricultural runoff, their effectiveness is affected when their thresholds are breached. When wetland denitrification activity is hampered by contamination of or the addition of excess N, incomplete denitrification may occur. Incomplete denitrification often emits nitrous oxide (N_2O) instead of nitrogen (N_2), where N_2O is a greenhouse gas (Verhoeven et al., 2006). Excess nutrient leaching into natural wetlands can also result in dramatic shifts in the composition of wetland species and the function and biodiversity of the ecosystem (Verhoeven et al., Arheimer, Yin, & Hefting, 2006).

In semi-arid regions such as the Canadian Prairies, wetland drainage could also affect the groundwater balance as a shallow groundwater table may not be recharged. Draining a wetland may affect the surrounding vegetation and nearby shallow water wells (Van der Kamp & Hayashi, 1998). With drier Prairie summers requiring additional water inputs, communities will be forced to exploit water from deep aquifers risking the depletion of deep groundwater reserves in the long run.

Distribution of Freshwater – Wetlands



Source: Government of Canada, NRCAN, 2016.

2.4 The Legal Context Surrounding Wetlands in Canada

As noted, wetlands are important ecosystem service providers. The increasing risks they face served as a rationale for various governments to adopt regulations to manage them. Although a historical approach of law could have been helpful to identify if a legal dynamic supported the degradation of wetlands over the years, a focus on how powers relating to wetlands are divided and used by the various orders of government provides important insights on the state of the legal framework in this field.

2.4.1 Constitutional Framework

The legal framework surrounding wetlands in Canada is shaped by the constitutional division of powers. Based on sections 91 and 92 of the 1867 *Constitution Act*, both the federal and provincial governments hold a legislative jurisdiction concerning wetlands. However, as neither protection nor management of wetlands is mentioned in the *Constitution Act*, it is necessary to identify which powers give orders of government legislative authority over these ecosystems. Through its authority over public property (*Constitution Act*, 91(1A)), the federal government has powers with respect to wetlands. In fact, "[o]ver 9% of all of Canada's wetlands are estimated to be located on federal lands or waters, largely in our northern territories" (Government of Canada, 1991). Although crown ownership is a vast power, provincial authority is usually dominant when it comes to property. Provincial governments have almost uncontested jurisdiction with regards to lands, property and civil rights in the limits of their territories (*Constitution Act*, 92(5) and 92(13)).

The nature of an activity can also determine which level of government has authority over it. Activities such as navigation or fisheries give the federal government a legislative authority while local works and undertakings, or, more broadly, all matters of a merely local or private nature, fall under provincial jurisdiction. Although it might seem ambiguous, such powers grant governments the authority to legislate with respect to wetlands conservation, enhancement and use.

The size of, the impact on, or the activities within wetlands are amongst the many factors that can trigger both federal and provincial policies or legislation (Bailey, 2000). This uncertain constitutional context characterizes the legal framework surrounding wetlands as shared, fragmented and, possibly, conflicting; it also contributes to better understand the fact that "[m]any types of policies may impact wetlands, including agricultural policy" (Austen & Hanson, 2007).

Agriculture is a joint federal-provincial jurisdiction, under the Constitution. Agricultural activities can also be presented as factors that influence wetland management. The jurisdiction over agricultural activities can lead to a different set of powers for both federal and provincial governments. In fact, agriculture is structured around a specific division of powers. If wetlands protection is shared because of the unforeseen circumstances that arose over time, agriculture is the object of a shared jurisdiction by the means of section 95 of the *Constitution Act*. However, this provision remains unclear as to how authority should be divided with regard to agriculture; it only specifies that where two provincial and federal statutes are in conflict, the latter will be granted paramountcy. Therefore, the power to enact laws with respect to agriculture is also linked to the general provisions stated in Sections 91 and 92 of the *Constitution Act*. The federal government can rely, for instance, on the regulation of trade and commerce (section 91(2)) as well as criminal law (section 91(27)) to legislate with regard to agriculture (Buckingham, 2018). Provincial legislatures depend upon powers such as property and civil rights within their territories (section 92(13)) to enact laws relating to agriculture (Buckingham, 2018). Regulation with respect to plants, animals or agricultural products usually fall within federal jurisdiction, by the means of its power over criminal law, whereas agricultural lands are governed by provincial regulations (Hogg, 2018). Although the ability to enact laws relating to agriculture depends upon the nature of agricultural activity, such jurisdiction can give, especially to provinces, an extended authority to modify lands and natural landscapes for agricultural reasons. Thus, this power can positively or negatively affect wetlands, whether it involves the creation or destruction of such ecosystems.

2.4.2 Federal Actions

Because each order of government is given the ability to create regulations concerning wetlands, there are abundant sources of law and policy applicable to such ecosystems. Back in 1991, the central government published the *Federal Policy on Wetland Conservation*. This guiding document does not have a regulatory dimension (Bruneau, 2017a) and applies only “to federal lands and federally regulated development projects” (Poulton & Bell, 2017).

However, it is a non-binding pledge that draws a symbolic orientation for wetland management. The Federal Policy on Wetland Conservation has for objective to “promote the conservation of Canada’s wetlands to sustain their ecological and socio-economic functions, now and in the future” (Government of Canada, 1991). This policy is built around a no net loss of wetland functions (Poulton & Bell, 2017; Government of Canada, 1991). Additional tools were developed by the federal government in order to support its policy on wetlands conservation. For instance, an implementation guide (Lynch-Stewart, Neice, Rubec, & Kessel-Taylor, 1996) was published in 1996 with the purpose to “assist federal land managers when making decisions that may affect wetlands”, as well as to “assist departmental policymakers in developing "customized" departmental plans and directives for implementing the Policy” (Lynch-Stewart et al., 1996).

In 2014, the National Wetland Conservation Fund was created, as part of the National Conservation Plan, with the objective “to support on-the-ground wetland conservation and restoration activities across Canada, with a focus on working landscapes” (Environment and Climate Change Canada, ECCC., 2018). However, this funding opportunity ended in 2018 (Westcott, 2018).

Besides the previously discussed tools, a set of legislative instruments has been developed over the years with an indirect impact on wetlands. The *Migratory Bird Convention Act*, the *Species at Risk Act*, the *Canadian Environmental Assessment Act*, the *Fisheries Act*, the *Navigable Waters Protection Act*, and the *Convention on Biological Diversity* might all have a distinct application when it comes to wetlands use, protection or enhancement (Bruneau, 2017b).

2.4.3 Provincial Actions

The constitutional division of powers also enables each Canadian province to act with respect to wetlands. The cases of Alberta, Ontario and Quebec provide a useful overview of the provincial initiatives in this field. In 2013, Alberta adopted a wetland policy as part of the achievement of the provincial “Water for Life” strategy (Water for Life, 2003). The main objective of this tool is to provide “strategic direction to conserve, restore, protect and manage Alberta wetlands” (Government of Alberta, 2013). It is based on a relative wetland value classification, which creates categories of wetlands from low to high based on criteria such as biodiversity, water quality improvement, flood reduction, human value and abundance (Government of Alberta, 2013).

Ontario has a more complex framework with respect to wetland conservation. Three laws mainly regulate the policy and legal context surrounding wetlands: The *Planning Act*, which protects provincially significant wetlands and coastal wetlands from development and site alteration, the *Conservation Authorities Act*, which prohibits certain activities in and around wetlands, and the *Greenbelt Act*, which further protects wetlands in the designated area. In addition, a set of policy tools was more recently adopted: The 2014 Policy Statement, issued under section 3 of the *Planning Act*, the Ontario Wetland Evaluation System, and the Wetland Conservation Strategy for Ontario 2017-2030. This latter document was adopted as "a framework to guide the future of wetland conservation across the province" (Government of Ontario, 2017). Its objective is stated as follows: "Ontario's wetlands and their functions are valued, conserved and restored to sustain biodiversity and to provide ecosystem services for present and future generations" (Government of Ontario, 2017). Ontario's wetland protection framework is based on an evaluation system that designates "provincially significant wetlands" (Government of Ontario, 2014). However, it is to be noted that Ontario's 2017-2030 Wetland Conservation Strategy aims at updating protection mechanisms by adopting, in the future, a no net loss policy (Government of Ontario, 2017).

Wetland conservation in Quebec has a different orientation from that of Alberta and Ontario. With no provincial policies dedicated to wetlands, such ecosystems are protected through the broader regime of water conservation. In 2017, *An Act respecting the conservation of wetlands and bodies of water* (Bill 132) was adopted with the purpose of reforming "the legal framework applicable to wetlands and bodies of water in order to modernize the measures that ensure their conservation" (Bill 132, 2017). With the objective of making the water management legal framework more encompassing, the wetland addition was presented as an effort "to ensure the conservation of such environments, whether to preserve, protect, sustainably use or restore them, or to create new ones" (Bill 132, 2017). In the same way as Ontario, Bill 132 also adopts a no net loss protection mechanism. The Quebec government, besides the general legal framework, also introduced subsidy programs for restoration and creation of wetlands as well as for the development of regional plans dedicated to such ecosystems.

2.4.4 International Actions

The Canadian legal framework surrounding wetlands is also influenced by international initiatives. It is to be noted that, although transboundary and international matters fall under federal jurisdiction, provincial governments are also affected by supra-national norms. The main international tool regarding wetland conservation is the *Ramsar Convention.* Adopted in 1972, its objective is "the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world" (Ramsar Convention Secretariat, 2013). The Ramsar Convention allows each party to designate, within its territory and following nine established criteria, suitable wetlands to be qualified as international importance (Ramsar Handbook, 2016). This status imposes on each party to the treaty an obligation to protect and effectively manage areas designated (Poulton & Bell, 2017). Canada signed this convention in 1983; it has since identified 37 Ramsar sites, including the Mer Bleue Conservation Area in Ontario, the Baie de l'Isle-Verte in Quebec, the Peace-Athabasca Delta in Alberta, the Old Crow Flats in Yukon and the Shepody Bay in New-Brunswick. Other international tools have an influence within the Canadian context. For instance, the North American Waterfowl Management Plan was signed in 1986 and indirectly contributes to protect wetlands as part of its habitat protection program.

An increasing number of legal mechanisms have been developed over the past few decades. Within a Canadian context, a common effort is still conditional on the constitutional division of powers, so a diversity of conservation mechanisms have been proposed and implemented. Legal instruments can therefore be seen as incentives to better protect wetlands. However, they need to be paired with technical restorations methods in order to fully protect such ecosystems.

2.5 Wetlands Restoration Methods

The state of the science and the philosophy in wetland restoration and conservation have evolved tremendously since the 1970s, but challenges continue to arise as the ecosystem services rendered by the wetlands, an understanding of natural habitat conservation growing in the public consideration.

The restoration of wetlands consists of returning a disturbed wetland back to an undisturbed, near-natural state. Unlike rehabilitation or partial or full replacement, restoration implies the ecological restoration of the ecosystem to its pristine condition (Ellison, 2000).

Many schools of thought exist in wetlands restoration objectives and efficiency evaluation. Wetlands are complex ecosystems, and the uniqueness of natural wetlands is also undervalued (Zedler & Kercher, 2005). It is also known that even after years of replanting and burning, a replica of the natural wetland model cannot necessarily be created (Jordan, Gilpin, & Aber, 1987). Some methods accept the impossibility of recreating a natural model and aim for the restoration and replacement of wetlands functions using the conservation of territories offering similar ecosystem services (Gayet et al., 2016). Others think that duplication of ecosystem services is impossible (Zedler & Weller, 1989), and that even if restoration cannot reverse many damages made to wetlands (Zedler & Kercher, 2005), the restoration of a natural wetland, rather than the creation of a new one, should be the primary approach. However, for both wetlands creation or restoration, ecosystem services are listed as important targets and constraints for a project (Zedler & Kercher, 2005). The appropriate selection of sites for restoration is also an important aspect of the success of a restoration project (Zhao et al., 2016).

Ecological restoration of wetlands can be divided into two main methods: passive and active restoration. The passive restoration method consists of the elimination of the factors that have led to the degradation of the wetlands, such as chemical contamination (Wagner, Gallagher, Hayes, Lawrence, & Zedler, 2008). The restoration of degraded wetlands to a healthy state is made under natural conditions and influences. Active restoration implies direct action on the ecosystem itself. It includes, but is not limited to, diverting river streams to their original location, removing drainage tiles to restore natural drainage or replanting of native plant species. Both methods are used in certain circumstances, depending on the nature and the sources of the degradation. Nevertheless, they ultimately both share the same goal: create a self-maintaining, self-organized and functioning natural ecosystem that is resilient to natural disturbances without further anthropogenic support.

The techniques used to restore wetlands are separated into three broad categories: re-establishing or managing wetland hydrology, control or eliminate chemical contaminants affecting the wetlands and re-establishing the native biota (Craft, 2016; National Research Council, 1992; Zhao, et al., 2016).

2.5.1 Re-establishing Wetland Hydrology

Restoration or reestablishment of wetland hydrology is indispensable and a fundamental objective to achieve a lasting restoration (Craft, 2016; Zhao, et al., 2016). Requirements for restoring wetlands depend on the location of the wetlands in the landscape and its topography, whether coastal-estuarine, riverine, depressional or large-scale freshwater setting (National Research Council, 1992). The beginning of the restoration project is the same regardless of the types of wetlands, whether they require removing or disabling a human-made modification (dikes, dams, channels, drainage tiles, crops, restore flood regime, restore topography) or whether the natural landscape is being restored.

2.5.2 Controlling Chemical Contaminants

Water fluxes originating from agricultural or urban areas usually contain large amounts of contaminants, ranging from nutrients like nitrate and phosphorus that stimulate algal growth in water (Zedler & Kercher, 2005), to sediments and pesticides that cause water turbidity and toxicity (Kusler & Kentula, 1989).

Controlling contaminants input in wetlands can be made by good upstream management practices. Creation of a riparian herbaceous buffer zone is one of the main ways to reduce contamination of waterways, as buffer zones between 3 to 9 meters can reduce between 87-100% of sediments, 22-89% of dissolved phosphorus, 47-100% of nitrate and 44-100% of atrazine a pesticides found in water in agricultural area (Patty et al., 1997). Drainage ditches can also act as preferential paths to waterways for contaminants. The adoption of point and non-point source pollution controls for drainage ditches reduce contamination inflow in wetlands, as they can also act as preferential paths to waterways for contaminants (Kusler & Kentula, 1989). Finally, precision agriculture techniques like variable rate fertilizer, reduction in pesticide usage or in-farm conservation practices (low-tillage and perennial crop), can reduce the output of contaminants from agriculture (Capmourteres, et al., 2018; Basso, et al., 2016a; Basso, Fiorentino, Cammarano, & Schulthess, 2016b).

2.5.3 Re-establishing Native Biota

Following the restoration of wetland hydrology, the reestablishment of the biota can begin. This can be done through an active (planting and introduction of fauna) or passive (natural immigration) method. For the restoring vegetation, both methods are used. For the fauna, passive reintroduction is the most common. However, the passive method will only work if there are adequate corridors to allow movement between the existing populations and the restoration site (Willard, Finn, & Klarquist, 1989). Despite the cost associated with the active restoration of wetlands, it has been demonstrated to be an economically viable solution to limit the financial, social and environmental damages of flooding (Pattison-Williams et al., 2018).

The success of a wetland restoration project is also a challenge. A majority of the projects labeled as successful were judged on a strictly vegetation establishment basis (Kusler & Kentula, 1989). A reason stated for the lack of representation of the other functional capacity of the wetlands (hydrologic functions, water quality improvement) or the wildlife present was that data were unavailable (National research council, 1992). This problem may be an old one, but it is not yet resolved as a recent review stated that diagnosing the success of a restoration project is difficult because of the lack of uniform success indicators or long-term monitoring data (Zhao, et al., 2016). Determining global and long-term indicators and developing large-scale wetland restoration projects would allow for better evaluations of the success of a restoration project (Zhao al., 2016; Wagner et al., 2008).

Other factors to consider for the success of future restoration projects are climatic oscillations and climate change. Climatic oscillations are known as short-term, periodic and repeated weather phenomena that can be observed, monitored and to some extent predictable. El Niño is an example of a climatic oscillation. Wetland restoration could benefit from the consideration and a better understanding of the effect of periodic oscillation on habitats and wildlife. For example, planting native species during the wet phase of the cycle could allow for a stronger and more resilient community in the drought phase (Erwin, 2009). Climate change should also be taken into account for wetland restoration projects. A change in the range of a species' natural habitat and migration of a species are some of the projected effects of climate change that could be assessed from now. For example, the placement of conservation areas on a north-south axis in fragmented habitats could ease the migration of wildlife by providing migration corridors (Erwin, 2009). Also, efforts to conserve specific species could be concentrated in the northern portions of their natural habitat range where the potential future climate is more likely to be sustained (Craft, 2016; Erwin, 2009). Considering the impact of climate change on rising sea levels and wetland migration, as a result, would also allow for resilient and sustainable wetland conservation (Craft, 2016).

2.6 Conclusions from Multidisciplinary Literature Review

The literature review undertaken in this section provides an interdisciplinary overview of the state of wetlands in the context of Canadian agriculture. Based on this review, a specific problem related to wetlands has been made evident. Not only wetlands are essential ecosystem service providers from an environmental, ecological and hydrological perspective, they also contribute to various societal values. In the Canadian context, the diversity of wetlands varies across the country and is well documented. But a significant amount of them are still being lost to agriculture and urbanization. Although restoration methods are well known, the importance of increasing agricultural productivity is negatively affecting these ecosystems and often results in their conversion to agricultural lands. Moreover, even if wetlands are not lost to agriculture expansion, they are being threatened by agricultural practices. As a result, wetlands are qualified as vulnerable ecosystems. Indeed, a growing legal framework attempts to implement conservation and restoration objectives. However, the division of legislative powers leads to various dynamics and inconsistent actions. Not only do we require a strategy toward wetland conservation, there is a need to monetize or place a value on the benefits of these ecosystems. In fact, we will see in the following section that research shows that a set of disciplinary orientations co-exist toward this goal.

3. From Conservation to Value: The Contribution of Wetlands to a More Sustainable Canadian Agriculture

Placing a value on wetlands goes beyond ecosystem conservation. It is an effort to recognize the importance of wetlands and the way in which they can actually contribute to making Canadian agriculture more sustainable, from an environmental, economic and social perspective. Interdisciplinary research provides a set of orientations that can concurrently, legitimate wetland valorization. In this section, we will see how intergovernmental cooperation, best management practices (BMPs) and innovative methods can all contribute to this objective.

3.1 The Need for Intergovernmental Cooperation

The legal context surrounding wetland management in Canada can easily be characterized as being fragmented (Ducks Unlimited Canada, Earthroots, Ecojustice and Ontario Nature, 2012). In a similar way as environmental (Cairns, Turan, & Amos, 2011) and water management (Bakker & Cook, 2011), conservation, enhancement and use of wetlands is a responsibility divided between various government actors. Whether this division is based on territorial or ecosystem considerations, this context can be qualified as fundamentally interjurisdictional.

In addition to the powers granted to each level of government, non-governmental actors have an ever-growing involvement in managing issues related to environmental governance (Arthur & Rhodes, 1996). In the broader field of environmental protection, actors such as citizen groups, the business/economic sector, indigenous communities, recreational and tourism groups and research institutions can be directly or indirectly involved in the management and governance process. In the context of wetlands, agricultural groups and organizations as well as non-governmental organizations are more and more engaged in matters about these ecosystems.

In an interjurisdictional context, reinforced by the progressive implications of non-governmental actors, the preservation and management of wetlands require coordinated efforts and intergovernmental cooperation. From a legal perspective, two streams could lead to cooperative action. On the one hand, the role that wetlands can play in the context of climate change can trigger collaborative strategies. In the recent provincial cases regarding the federal carbon tax, the courts emphasized that the regulatory charge provided by the federal *Greenhouse Gas Pollution Pricing Act* was an answer to provincial inaction. In other words, "[t]he *Act* supports existing provincial [greenhouse gas] emissions pricing schemes and responds to provincial inaction" (Greenhouse Gas Pollution Pricing Act, 2019). What these cases come to show is that intergovernmental mechanisms to tackle a common issue can take different shapes and do not have to be concomitant. The inaction of one government does not necessarily prevent another one to (re)act to a shared pressing matter. On the other hand, the connection to agriculture, as a divided matter between federal and provincial orders of government, and the role wetlands can play toward a sustainable Canadian agriculture, can also be linked to cooperative action in this field. Intergovernmental initiatives, such as the federal-provincial-territorial and provincial-territorial conferences, are necessary tools to establish common directions in the field of agri-food.

Although protection mechanisms and restorations initiatives could be more stringent, the Canadian legal framework surrounding wetlands offers a useful diversity of experience as each government is allowed, under certain conditions, to build its strategy. Moreover, international case studies and academic research could also provide useful insight concerning wetland management and conservation. For instance, the Rights of Nature doctrine is a growing movement that can create unique alternatives for the protection of wetlands (Boyd, 2017). However, there is a persistent lack of cooperation with regard to wetland conservation, especially in relation to agriculture. Intergovernmental conversations regarding agricultural practices need to concentrate on environmental and sustainable dimensions as well as trade matters. Cooperation mechanisms essentially convene governmental actors without sufficiently recognizing the importance of non-state protagonists. Therefore, a substantial effort is necessary, not only to strengthen the legal framework surrounding wetlands but also to reshape our mindset concerning these crucial ecosystems. Doing so will provide the legal and political foundations necessary for making BMPs and innovative methods efficient in restoring and conserving wetlands.

3.2 Best Management Practices Applied to Agriculture for Wetland Conservation

The most efficient and logical solution to reduce the impacts of agriculture on the environment is through the use of BMPs. The objective of BMPs is to reduce the losses of ecosystem services and maximize the net benefits of food and fiber that society receives (Tilman, Cassman, Matson, Naylor, & Polasky, 2002). BMPs are a combination of practices that reduce or prevent non-point sources of pollution like N and P inputs that leach into wetlands (Fund & Hilliard, 2002). Therefore, agro-practices that promote soil conservation, water sources protection and farm resilience are considered BMPs (Akkari & Robin Bryant, 2017). This analysis will attempt to describe the most important BMPs applied for improving farm management practices on wetland ecosystems by looking at BMPs that: a) Create multi-functional ecosystems, b) restore wetlands functions, and c) reduce the impact on wetlands.

3.2.1 Multi-Functional-Ecosystems as a Farming Asset

Biodiversity is an imperative element of the multifunctional resilience in wetland ecosystems, where species, habitat, and ecosystem services are improved (Gordon, Finlayson, & Falkenmark, 2010; Falkenmark & Lannerstad, 2004). Multifunctional ecosystems in agriculture are systems designed to provide multiple ecosystem services that increase synergies between ecosystem services and the requirement for trade-offs (Landis, Wratten, & Gurr, 2000).

Agriculture can be qualified as a system if it provides more than one ecosystem good or service. Ecosystem goods and services (EG&S) include: provision (cultivation of crops, meat and wood), regulation (pollination, water balance, pest control), cultural benefits (tourism and recreation) instead of simplified systems where monocultures are favored (Benton, Vickery, & Wilson, 2003). By increasing biodiversity, natural enemies (predators) increase; as a result, fewer pesticides are needed for crop production (Letourneau, et al., 2011). Having non-crop habitats create a favorable environment for pollinators resulting in an abundance of species due to the complex landscape (Shackelford et al., 2013). Fahrig et al. (2011) suggests that a complex and heterogeneous agricultural landscape could be an important mechanism for conservation. Perennial habitats including woodlots, forests, hedgerows, windbreaks and perennial grasslands, as well as crop rotation support high levels of biodiversity (Landis, Wratten, & Gurr, 2000), that can increase food security and nutrient cycling and overall ecological services at farm level (Goldman et al., 2007).

3.2.2 Reduce the Impact on Wetlands

Best farming practices include reduced tillage, no-tillage, cover vegetation (cover crops), crop rotation, buffer strips, hedge crops and organic farming (Rasouli, Whalen, & Madramootoo, 2014). For example, under no-till, overall soil health and soil function have been shown to increase (Acton & Gregorich, 1995). Cover crops increase the nutrient cycle, enhance the carbon retention and the fixation of nitrogen (Vukicevich, Lowery, Bowen, Úrbez-Torres, & Hart, 2016). Crop rotation increases yields and reduces synthetic input (Davis, Hill, Chase, Johanns, & Liebman, 2012), and intercropping improves pest control and nutrient cycling

(Tilman, et al., 2002). Also, it is useful to combine production systems (crop and livestock) to reduce fertilizer input by having manure as part of natural fertilizer (RAMSAR, 2014). It is also necessary to protect wetlands and riparian zones (i.e. areas next to water bodies) by providing offsite watering systems (Haak, 2019), and buffer strips through the adoption of controlled grazing and rotational grazing systems (Fitch, Barry Adams, & O'Shaughnessy, 2003). Farming practices that promote sustainability and conservation will increase the benefits of the farm's provision of ecosystem services (Kulshreshtha & Kort, 2009).

The purpose of buffer strips is to separate remnant or wetland habitat from incompatible land uses to promote natural vegetation and maintain its healthiness and functionalities if possible. Moreover, buffer strips act as natural corridors for wildlife species to reduce disturbances associated with agricultural practices like seeding, harvesting and fertilizing (Weston, Antos, & Glover, 2009). Buffer strips along with riparian zones help to reduce N and P leaching into waterways (Wagena & Easton, 2018; Styles, et al., 2016). They also reduce sedimentation by retaining soil and preventing erosion into waterways, which helps maintain water quality at the watershed level (Stang, et al., 2016). (Delgado, et al., 2011). In addition to buffer strips, there are Critical Function Zones (CFZ), which extend and expand the areas around wetlands. CFZ help in the conservation of waterfowl nesting habitat, as well as offering habitat to amphibians and insects (Bruneau, 2017b).

Moreover, a relatively new conservation practice called "prairie strips", which integrates strips of prairie vegetation within crop production areas (S.T.R.I.P.S team), has been shown to provide ecosystem services at the farm level. This practice is part of conservation practices applied in Iowa, USA that has been shown to provide the following positive results in experimental multi-year projects in 2014: provision (crop production), regulation (water infiltration, pollution control), and support (soil quality, biodiversity preservation, pollination, pest regulation) services over 10 % (0.5-3.2 ha) of the watershed. There was a 95% increase in soil retention, a 90% and 84% increase in P and N retention respectively and a 63% increase in water infiltration (Zhou, et al., 2014; Helmers, et al., 2012; Hernandez-Santana, et al., 2013). In addition, crop production (corn or soybean) led to an increase in biomass in the range of 6.9 Mg/ha. Plant diversity increased 3.9 times, native bird abundance increased 1.6 times and beneficial insects increased 1.9 times in comparison with watersheds that did not make use of these strips (Hirsh, Mabry, Schulte, & Liebman, 2013; Cox, O'Neal, Hessel, Schulte, & Helmers, 2014).

Soil erosion and sedimentation in wetland areas are two major factors that affect water quality (Stang, et al., 2016), with hedgerows and buffer strips two farming practices used to fight against soil degradation. Hedgerows have the following benefits: 1) carbon storage (Welsch, 2016); 2) crop performance due to water stress reduction (Nasielski, et al., 2015); 3) retaining soil moisture (Kort, Bank, Pomeroy, & Fang, 2012); and 4) soil erosion diminution (Nasielski, et al., 2015).

In addition to the previous BMP, Agriculture and Agri-Food Canada (AAFC) defined other practices that can be used for sustainable agricultural land management around wetlands. For example, perennial forages and salt-tolerant forage are more tolerant to flooding, and the impact of salinity, respectively (Haak, 2019). Grassy waterways ensure that flows remain in the waterway without sedimentation and erosion into wetlands. Trees and shrubs are common on prairie wetlands, which are tolerant to flooding and can help to restore and generate new trees. Also, trees and shrubs create habits for waterfowl and migration songbirds, adding biodiversity to wetlands (Haak, 2019).

It is necessary to understand that wetlands are complex habitats and each one is a complete and unique entity. Maintaining local wetlands requires regionally focused best management practices for conservation and to maintain local habitat and preserve their hydrological and ecological connectivity (Amezaga, Santamaría, & Green, 2002).

3.2 New and Innovative Methods to Manage Land and Agriculture for Wetland Preservation

In recent years, new technologies have been introduced in agriculture, allowing better control of the environment and preventing environmental degradation caused by agriculture. Drones, satellites, intelligent devices, low-cost sensors, yield maps, robots, wired sensor networks are some of the recent examples of the technological innovations used in agriculture today, and for the future. These innovations allow for agriculture to become more efficient and precise. These new agriculture technologies can prevent agriculture's negative environmental impacts by reducing leaching, erosion, compaction and pesticide contaminants. The implementation of highly efficient precision agriculture leads to a combination of a more economically viable and sustainable agriculture.

Robots and drones, used with image recognition algorithms, can be used independently in the field to spot crop pests, apply chemicals precisely, and even control weeds manually (King, 2017) leading to a decrease in the quantity of pesticides used in agriculture. A reduction in pesticides used as well as the better placement and minimal application will reduce contamination of agrochemicals, serving to passively restore contaminated wetlands by suppressing a source of contamination. The use of autonomous robots is also a way to allow for economically viable reductions in farm size and machinery size (King, 2017) as well as allow farmers the ability to reduce their working hours and focus. This idea challenges a widely accepted myth in agriculture that economies of scale, large farm machinery and monoculture of crops is the most efficient and economically viable farming practice. Reducing the size of farm machinery is a way to lower CO_2 emissions and reduce soil compaction and erosion. In this way, P contamination of wetlands would be reduced, since the primary source of P from agriculture is erosion. Autonomous robots could also be used together with precision mapping of the soil and hydraulic properties of a field to differentiate seeding varieties in a field (Capmourteres, et al., 2018; King, 2017). Growing multiple crops in a field offers many advantages. Examples include: enhancing biodiversity by diversification of the habitats, allowing migration corridors (Capmourteres, et al., 2018) or growing plant diversity for pollinators.

New technologies and precision agriculture also increase agricultural productivity. One of the main drivers of new technology adoption on-farm is the financial aspect (Pierpaoli, Carli, Pignatti, & Canavari, 2013). The cost of technology is often an obstacle to the adoption, but if farm productivity, crop quality and efficiency gains increase profit margins, then adoption of the technologies will be quicker (Daccache, Knox, Weatherhead, Daneshkah, & Hess, 2015; Pierpaoli, Carli, Pignatti, & Canavari, 2013). Precision irrigation has also been shown to reduce variability in crop quality (Daccache et al., 2015), which leads to higher crop prices, less water use and less nutrient leaching. Reducing nutrient leaching leads to less nitrate pollution and fewer algae blooming and eutrophication of waterways (Dupas, et al., 2015; Erisman, et al., 2013). This leads to higher water quality as well as less surcharge and contamination of nutrients in riparian and buffer zones like wetlands. Sub-irrigation, which is irrigation from the drainage system, has also been identified, in specific field crops like cranberries, as a reliable method of growing high-quality plants with minimal environmental impact, as yield can be maintained with lower fertilization rates and environmental loss (Ferrarezi, Weaver, Van Iersel, & Testezlaf, 2015). The use of variable fertilization rates has also been demonstrated to lead to higher net revenues and lower nitrate leaching (Basso, et al., 2016a; Basso, Fiorentino, Cammarano, & Schulthess, 2016b). Basso et al. (2016a) showed how it was possible to identify optimal rates of nitrogen fertilization that provide the highest economic returns and the lowest environmental impacts using crop simulation of site-specific fertilization.

Better profit margins can also be achieved by reducing investments in fields that have lower yields and minimal profit margins (i.e. which are unproductive) (Capmourteres et al., 2018). The change in paradigm proposed by this study recommends using crop yield data to develop high-resolution maps of the farm in implementing conservation practices. This leads to reducing investments in the unproductive fields and focusing on investing in productive fields. Crop intensification on the productive parts of the field combined with the conservative strategies on the unproductive parts were economically viable even without subsidies for ecosystem services or conservation practices by optimizing the investment in the farm and increasing the profit margin (Capmourteres, et al., 2018). The conservation practices tested, like seeding multiple perennial plants and legumes, would be beneficial for wetlands conservation by supporting pollinator populations, reducing nitrate leaching, preventing erosion and phosphorus leaching into wetlands and enhancing wildlife biodiversity by providing more varied habitats. Also, this new paradigm of reducing investments in less productive fields argues against the draining of in-farm wetlands as the investment may yield high returns.

The environmental benefits of new technologies and precision agriculture could help conserve wetlands and increase agricultural productivity. Wetlands are impacted by intensive agriculture from agrochemical contamination (herbicides, insecticides, fungicide) and excessive leaching of nutrients (nitrate and phosphorus). The role of farmers in using new and innovative ways to manage land and adopt BMPs in agriculture can provide potential solutions to protect and help restore existing wetlands.

4. Suggestions for Research, Farming and Policy Options

Not only could wetland conservation a greener agriculture, but valuing wetlands could lead to a more productive sector. Healthy wetlands are indeed a driver of more sustainable agriculture, both from an environmental, economic and social point of view. The benefits include protection against floods; provision of water reservoirs by replenishing groundwater; maintenance of biodiversity; enhancement of pollination; and they act as P and C sinks and N scrubs.

As discussed, various methods, ranging from land and BMPs to legal considerations and technological tools could be factors in protecting and valuing wetland health. These are the benefits of the interdisciplinary approach of this paper. The identification of the various ways wetlands provide value also leads to a set of recommendations, based on an interdisciplinary vision to target research needs and to recommend farming practices from a policy perspective.

Research Suggestions - There is a need to...
Better understand how wetlands can act as a tool toward more economical sustainability for farmers. In fact, providing “a credible assessment of the monetary value of agriculture’s net impact on wetlands” (CAPI, 2019) remains a challenge due to the lack of information.
Provide a historical approach of law and how it has influenced the destruction of wetlands: what legal tools and incentives led to the loss of wetlands.
Produce additional research on recycling water and agrochemicals through in-farm wetlands.
Find ways to minimize crop loss due to flooding from in-farm wetlands during high moisture periods.
Come up with more research on the potential of constructed wetlands serving as riparian buffers in agricultural landscapes.
Create real-time GIS techniques and novel landscape design. Agro-biodiversity requires the collaborative efforts of stakeholders, scientists and geo-designers for using real-time GIS techniques to generate biogeochemical models and novel landscapes design. Models where stakeholders and scientists can work together knowing how ecosystem services and disservices flow in real-time (Slotterback et al., 2016).
Better understand the effects of climate variation and climate change on wetland restoration methods and efficiency to create new models of wetland restoration adapted to each climate reality.
Develop uniform and long-term wetland restoration success indices.

Suggestions for Farmers - Tools / techniques available
Provide and transmit demonstration of the financial benefits of restoring wetlands and on-farm conservation methods leading to passive restorations of wetlands.
Education to present wetlands as a tool toward sustainable agriculture.
Best management practices that promote biodiversity and ecosystem services. Farmers, as stakeholders, should understand that wetlands provide benefits in the longterm due to the advantages of having multiple ecosystems on their lands: Multi-Ecosystem and the positive trade-offs between crop production and biodiversity.
New technologies available in agriculture should be promoted as they provide financial benefits for farmers and environmental benefits for society, therefore allowing for the passive restoration of wetlands.

Policy Recommendations - General orientations
Intergovernmental cooperation and policies are needed to set common objectives, targets and means in the fields of sustainable agriculture and wetland conservation.
Sustainable development goals are required with respect to wetlands.
Better protection mechanisms for significant wetlands are necessary, especially through legally recognizing both the socio-cultural and environmental benefits they provide.
Reinstate subsidy programs could create a positive dynamic to protect or restore endangered wetlands.
Encourage adaptive management of wetlands that allow for a more flexible approach.
Provide an incentive for farming practices that promote biodiversity and ecosystem services. Measures should be designed to provide a vision and incentives required for achieving environmentally sustainable agriculture where programs not only look at innovation, competitiveness and growth in the industry but also encourage small, medium and large farmers to adopt BMPs as part of their incentives.
There is a need to promote vertical and horizontal integration. A link between federal and provincial programs could be used to connect business, research and environmental stewardship programs. Models such as the Canadian Agricultural Partnership (CAP) could be a source of funding and support for environmental stewardship.

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