Wetland Construction Is Not an Effective Strategy to Mitigate the Loss of Biodiversity and Habitat of Canadian Wetlands

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Abstract:

There has been extensive wetland loss in Canada and Canadian wetlands remained threatened by anthropogenic activities. Canada mitigates the loss of wetland biodiversity and wetland habitat through wetland construction. Yet, habitat compensation strategies, like wetland construction, often fail to replicate natural ecosystems, contributing to the loss of biodiversity and habitat. Many Canadian studies have investigated habitat compensation for fish habitat, excluding Canadian wetland construction projects targeting shallow wetlands unsuitable for fish. I investigated whether wetland construction is an effective strategy to mitigate biodiversity and habitat loss of Canadian wetlands. I considered whether wetland construction produces wetland ecosystems comparable to natural Canadian wetlands, in terms of biodiversity and habitat. I conducted a literature review of eight Canadian, peer-reviewed, academic studies comparing habitat use and/or species richness and community assemblages of natural and constructed wetlands. Ultimately, wetland construction fails to mitigate fully the loss of Canadian wetland biodiversity and wetland ecosystem. Wetland construction does compensate for some wetland habitat loss for some species. Ineffective wetland habitat compensation strategies threaten wetland-dependant species that do not benefit from wetland construction. I conclude that wetland construction is not an effective strategy to mitigate biodiversity and habitat loss of Canadian wetlands. Habitat compensation is a relatively new practice in ecology; I identified numerous gaps in knowledge that should be further explored to improve the science of wetland construction. Protecting natural wetlands is the best strategy to conserve Canadian wetland biodiversity and wetland ecosystems. In Canada, wetland conservation policies should prohibit further wetland loss and degradation by new anthropogenic activities. Wetland construction should be limited to activities attempting to alleviate historical wetland habitat loss.

Introduction:

There has been tremendous wetland loss in Canada as wetlands were perceived as wastelands to be drained for other uses. In the early 1990s, the government of Canada estimated that about 20 million ha of wetlands had been lost to other functions since the 1800s (Government of Canada, 1991). This represents a loss of nearly 15% of Canadian wetlands. The degree of wetland loss has not been homogeneous throughout the country. Extreme loss has been experienced in the heavily populated regions of Canada (Canadian Wetlands Roundtable, 2019) such as the east and west coasts, the southern region of Ontario, the St. Lawrence River region, the Prairie Potholes, and the Okanagan and Lower Similkameen valleys (Figure 1.; (Kraus, 2021)).

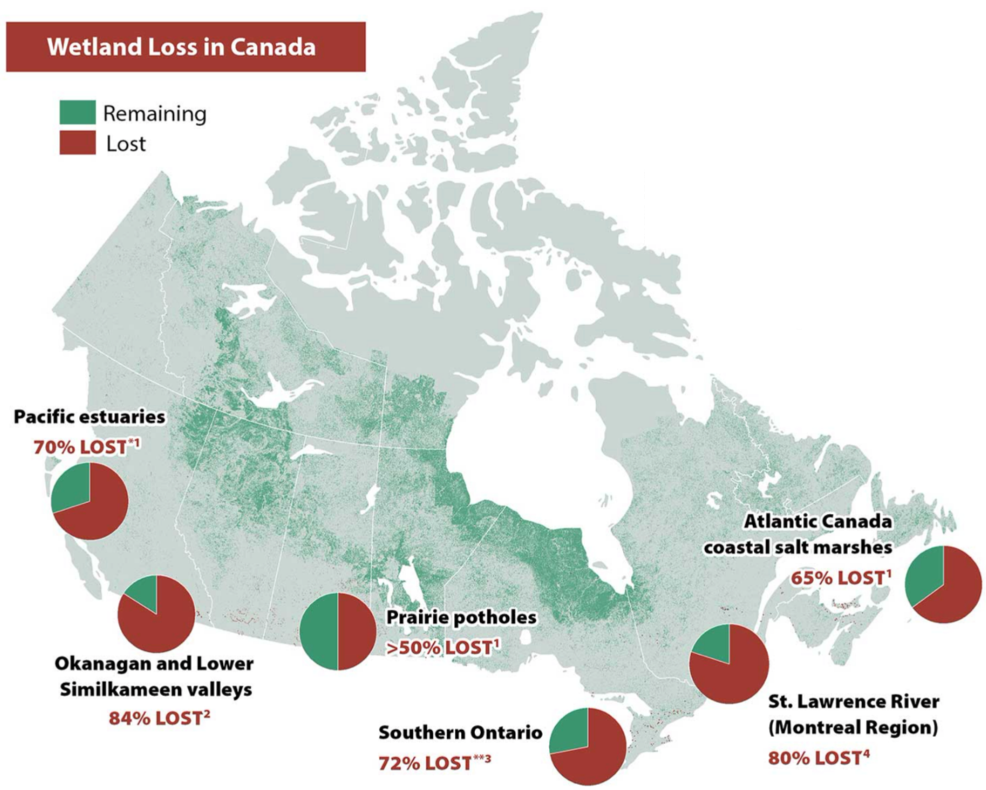

Figure 1. Representation of the percentage of wetland loss in the areas of Canada where loss has been most extensive. Image by Nature Conservation Canada (Kraus, 2021).

Anthropogenic activities have caused the loss of wetlands in these areas. These activities include agriculture, urban development, industrial expansion, mining, lake-level management, and draining for forestry and peat harvesting (Government of Canada, 1991; Mitsch & Hernandez, 2013).

Canadian wetlands are still facing threats of land-use changes, sedimentation, invasive species, and large-scale water withdrawal (Creed et al., 2017). For instance, the Ford government of Ontario passed Bill 23 in 2022, authorizing urban sprawl into 8,000 km^2 of the protected greenspaces, wetlands, and farmlands of the Toronto Greenbelt. This bill allows housing developers to bypass local planning rules, community consultation procedures, and protective environmental regulations in the name of affordable housing (Bui, 2023).

The historical and current treatment of wetlands does not reflect the importance of these ecosystems to Canadians and Canadian biodiversity. Wetlands offer numerous ecosystem services such as freshwater storage, water filtration, flood control, sinks for atmospheric carbon, and wildlife habitat (Government of Canada, 1991; Kennedy & Mayer, 2002; Mitsch & Hernandez, 2013). Wetland ecosystems support a variety of species, including a third of Canada's species at risk (Environment and Climate Change Canada, 2019), by providing critical nesting, feeding, spawning, and nursery habitat. For instance, the wetlands of the Prairie Potholes constitute a major breeding area for about 50% of North America's duck population (Ducks Unlimited Canada, 2023; Kennedy & Mayer, 2002).

The importance of Canadian wetlands was recognized by governmental jurisdictions and conservation organizations leading to active conservation efforts. Following the Ramsar Convention on Wetlands of 1981, the government of Canada published the *Federal Policy on Wetland Conservation* in 1991. The policy commits the Government of Canada to maintain the wetland functions and values, to ensure no net loss of wetland functions on all federal lands and waters, to enhance and rehabilitate lost and critically degraded wetlands, to secure wetlands of significance, and to use wetlands sustainably (Government of Canada, 1991; Rubec & Hanson, 2009). The federal government does not rely singularly on this policy to protect wetlands. Other federal statutes contribute to wetland conservation. For instance, the *Fisheries Act* protects all waters (including wetlands) that directly or indirectly support fisheries (*Fisheries Act*, 1985; Rubec & Hanson, 2009). Thirty years later, the federal government of Canada continues to prioritize wetland conservation (Environment and Climate Change Canada, 2019). Additionally, many provincial jurisdictions have developed policies and programs to conserve wetlands (Government of Canada, 1991; Rubec & Hanson, 2009). Conservation organizations, such as Ducks Unlimited Canada, have also actively participated in the conservation of natural wetlands. Indeed, Ducks Unlimited Canada has conserved over 2.5 million ha of wetlands since 1938 (Ducks Unlimited Canada, 2022b).

Wetland protection has not been the only conservation effort made by governmental jurisdictions and conservation organizations. Wetland construction practices have been implemented by governmental jurisdictions and organizations to mitigate the loss and degradation of wetlands. In 2000, the Government of Canada published the *Wetland Mitigation in Canada Policy* which provides a framework for the application of wetland mitigation strategies in Canada (Cox & Grose, 2000). The policy states that mitigation is a process for achieving wetland conservation through the application of a hierarchy of decisions that includes avoidance of impacts, minimization of unavoidable impacts, and compensation of impacts that cannot be avoided (Cox & Grose, 2000). When loss or degradation is unavoidable, habitat compensation strategies, such as wetland construction, have been used to compensate for affected wetlands. The federal government established in the *Summary of Canada's 6th National Report to the Convention on Biological Diversity,* that by 2020, wetlands on federal lands would be conserved or enhanced to sustain ecosystem services through management activities including wetland construction (Environment and Climate Change Canada, 2019). While this target was not achieved by Canada, wetland restoration on federal lands continues to be a priority of the federal government (Office of the Auditor General of Canada, 2022) Some Canadian provinces also established strategies to compensate for wetland loss, as Ontario, which published *A Wetland Conservation Strategy for Ontario 2017 – 2030,* indicating that the province will restore wetlands in areas that have experienced great loss (Ontario Ministry of Natural Resources and Forestry, 2017). Additionally, organizations such as Ducks Unlimited Canada have compensated for wetland loss by purchasing private lands and by working with private landowners to re-establish wetlands drained for agriculture. Theoretically, habitat compensation strategies, such as wetland construction, offer the perfect solution to mitigate the adverse effects of human activities.

Habitat compensation strategies often fail to recreate natural ecosystems in terms of biodiversity and ecosystem function (zu Ermgassen et al., 2019). Particularly, studies from the U.S., Canada, and Europe have demonstrated that habitat compensation projects failed to reproduce freshwater ecosystems (Harper & Quigley, 2005; Theis et al., 2020). In the U.S., there is numerous evidence that wetland construction does not replicate natural wetland ecosystems. However, most Canadian studies have investigated compensation projects for fish habitat in streams, rivers, and lakes (Theis et al., 2020). Yet, many Canadian wetland compensation projects target shallow wetlands that are not suited to support fish (Ducks Unlimited Canada, 2022a). This leads to questioning whether wetland construction is an effective strategy to mitigate biodiversity and habitat loss of Canadian wetlands. Ineffective impact mitigation strategies contribute to the loss of wetland biodiversity and habitat by allowing anthropogenic activities to degrade wetlands. Therefore, to answer this research question, I will investigate whether wetland construction produces wetland ecosystems comparable to natural Canadian wetlands in terms of biodiversity and habitat.

Methods:

To answer my research question, I conducted a literature review of Canadian studies comparing habitat use, and/or, species richness and community assemblages, of natural and constructed wetlands. The literature review was the most appropriate research method to provide an answer to the research question. The literature review allowed me to synthesize available information from numerous Canadian studies, on the differences between natural and constructed wetlands in terms of habitat use, species richness and community assemblages. The literature review also allowed me to delineate gaps in knowledge on wetland construction and the probable causes of differences in habitat use, species richness and community assemblages between constructed wetlands and natural wetlands. The gaps in knowledge established following the literature review should guide future research on wetland construction. Literature reviews should be accurately and reliably representative of the current state of knowledge on a current issue (Higgins et al., 2019). To ensure that I presented accurate and reliable information on the current ability of constructed wetlands to replicate natural wetland ecosystems, and to minimize bias and synthesis errors, I established eligibility criteria to select studies on which to base my literature review.

Studies that respected the eligibility criteria for the information source, location, publication date, research objective and reason for wetland construction were selected for the literature review. Due to time constraints and to ensure some scientific rigour to the studies used in the literature review, only academic, peer-reviewed studies were eligible. Additionally, the studies had to be a primary source of information, to eliminate confirmation bias. Therefore, third-party sources such as literature reviews or meta-analyses were excluded. The natural and constructed wetlands used in the studies had to be located in Canada because I am investigating the effectiveness of wetland construction to mitigate the loss of biodiversity and Canadian wetland habitat. There were no restrictions placed on the location of wetlands within Canadian ecozones. The studies had to be published following the publication of the *Wetland Mitigation in Canada Policy*, in the year 2000; as the policy establishes objectives that wetland construction practitioners should achieve for a successful intervention (Cox & Grose, 2000). The research objective of the studies had to be a comparison of habitat use, and/or, species richness and community compositions between natural wetlands and constructed wetlands. There were no restrictions on the class of wetlands or the taxonomic groups used in the studies. The studies were restricted to wetlands constructed as part of mitigation strategies to alleviate wetland loss due to anthropogenic activity. Studies using wetlands constructed to offset the loss of natural wetlands due to agriculture, urban sprawl, and invasive species encroachment were eligible for the literature review. Studies using constructed wetlands that are not usually constructed for mitigation of natural wetland loss, like urban ponds, stormwater ponds and sewage lagoons, were excluded from the literature review. Additionally, wetlands constructed on post-oil-sand mining landscapes were excluded from this study. The mechanism and amendments behind the construction of such wetlands are too different from those of wetlands constructed for wetland habitat.

To extract eligible studies from academic databases, I used combinations of search strings composed of keywords and Boolean operators. I used *Web of Science* to find peer-reviewed, academic studies. Combinations of search strings and Boolean operators were used to extract relevant studies. The keywords used in the search string consisted of key concepts of this study, including any related synonyms, variations or alternate spellings of keywords and key concepts (Table 1.).

Table 1. Search strings used in *Web of Science* to extract the eligible studies for the literature review. The table contains the combinations of keywords, Boolean operators, and filters used in each search string. The number of results obtained by each search strings are also presented. The search strings were used in the database Web of Science between January 09, 2023 and February 15, 2023.

Database: Web of Science	**Search Strings**	**Filters**	**Number of Results**
#1	(wetland compensation) AND (North America)		10
#2	(wetland creation) AND (biodiversity offset)		13
#3	(wetland compensation) AND (biodiversity offset)		35
#4	wetland mitigation		2, 593
#5	wetland AND enhancement* AND restoration AND (biodiversity offset)		3
#6	comparing AND (natural wetland*) AND (restored wetland* OR constructed wetland*) AND Canada		148
#7	restor* AND wetland* AND Canada		825
#8	restor* AND wetland* AND Canada	Not (US OR (United States))	641
#9	(Use OR Usage) AND wildlife AND (artificial* OR construct*) AND wetland* AND Canada		63
#10	(Use OR Usage) AND wildlife AND (artificial* OR construct*) AND wetland* AND Canada	Not (US OR (United States))	49
#11	(Use OR Usage) AND wildlife AND (restor* OR enhanc*) AND wetland* AND Canada		61
#12	(Use OR Usage) AND wildlife AND (restor* OR enhanc*) AND wetland* AND Canada	Not (US OR (United States))	47

Results:

Eight studies, either comparing habitat use, or species richness and assemblages, of natural and constructed wetlands in Canada were selected for the literature review (Table 2). Habitat use comparison between natural and constructed wetlands were established by using the occurrence and abundance of anurans and *Ambystoma* salamander larvae, avian community composition, and breeding pairs and broods of waterfowl. The studies comparing species richness and community assemblages of natural and constructed wetlands were based on a variety of taxonomic groups like birds, vegetation guilds, aquatic macro-invertebrates, plankton, and benthic diatoms. The natural and constructed wetlands were situated in the ecozones of the Mixwood Plains, Prairies, and the Atlantic Maritimes; which range the provinces of Alberta, Saskatchewan, Ontario, and Prince Edward Island. The studies were based on natural and constructed wetlands of comparable area, class, and hydrology. Wetlands in the studies were in two classes: marsh and shallow water wetlands. Natural and constructed wetlands ranged from ephemeral to permanent wetlands.

The constructed wetlands varied in age, the reason for construction, and the method of construction. The age of constructed wetlands varied from 1 to 30 years. The reasons for the construction of the wetlands varied between studies, ranging from waterfowl habitat restoration by Ducks Unlimited Canada, wetland habitat restoration, and removal of invasive plant species. Constructed wetlands were usually located on agricultural lands, which had previously been wetlands. The historical wetland habitats were reinstated by plugging the drainage ditches and/or dredging accumulated sediments, mud and vegetation to form the wetland basin.

Physicochemical and landscape characteristics differed between natural and constructed wetlands. Constructed wetlands tended to have steeper slopes, but no overall trend was observed for differences in water depth between natural and constructed wetlands. Furthermore, natural wetlands tended to have similar environmental and landscape characteristics, while constructed wetlands displayed greater variation. Natural wetlands tended to have a greater proportion of the surrounding landscape consisting of woodland or forest. In comparison, restored wetlands were more likely to be closer to open grassland, agricultural landscapes, and roads. Furthermore, constructed wetlands were more likely to have more open-water areas than natural wetlands, which had more vegetative cover. The water chemistry of older constructed wetlands (7+ years post-construction) was indistinguishable from that of natural wetlands. Younger constructed wetlands (less than 7 years post-construction) had lower pH, higher concentrations of total phosphorus and carbon dioxide, and contained less sediment organic carbon.

Table 2. Presentation of the eight studies selected for the literature review. The table presents the ecozone, a short description of the wetlands used in the studies, the number of natural wetlands, the number of constructed wetlands, the number of years since construction, the study topic and the focus group of each study.

Study	Ecozone	Description of Wetlands	Natural Wetlands	Constructed Wetlands	Years Since Construction	Study Topic	Focus Group
Stevens et al., 2002	Atlantic Maritime	Emergent, temporary and permanent freshwater wetlands	22	22	2 - 7	Habitat	Anurans
Stevens et al., 2003	Atlantic Maritime	Emergent, temporary and permanent freshwater wetlands	22	22	2 - 7	Habitat	Waterfowl
Begley et al., 2012	Prairies	Seasonal, semi-permanent wetlands of fresh to brackish water	39	41	3 - 8	Species richness, community assemblages, habitat	Avian communities
Schummer et al., 2012	Mixedwood Plains	Upland-marsh meadow, emergent marsh, shallow open-water wetlands	22	11	2 - 4	Species richness, community assemblages	Plant, aquatic macroinvertebrate, and avian communities
Bortolotti et al., 2016	Prairies	Semi-permanent and permanent, naturally fishless prairie wetlands	8	16	1 - 14	Species richness, community assemblages	Plant, macroinvertebrates, plankton, and benthic diatoms, communities
Anderson & Rooney, 2019	Prairies	Temporary, seasonal, semi-permanent marshes	36	24	3 - 10	Species richness, community assemblages	Avian Communities
Salaria et al., 2019	Prairies	Temporary and seasonal wetlands	6	18	3 - 30	Species richness, community assemblages	Plant communities
Ward & Hossie, 2020	Mixedwood Plains	Vernal pools, semi-permanent, and permanent freshwater wetlands	8	24	1 - 15	Habitat	*Ambystoma* salamander larvae

Plant Species Richness and Community Assemblages:

Natural wetlands had higher species richness than constructed wetlands, but the difference depended on the age post-construction of the wetlands. The species richness of all vegetative zones was higher in natural wetlands than in older wetlands (7+ years post-construction). However, the species richness of vegetation in younger constructed wetlands (less than 7 years post-construction) was comparable to that of natural wetlands. Species richness represents alpha or gamma diversity but not beta diversity. Therefore, studies also considered community assemblages to see if there were any differences in the composition of the plant communities between natural wetlands and constructed wetlands.

The vegetation community assemblages differed between natural wetlands and constructed wetlands of different age classes. Natural wetlands contained plant communities that significantly differed from plant communities of all age classes of constructed wetlands. However, unlike species richness, the plant communities of older constructed wetlands (7 + years post-construction) were more similar to natural wetlands than younger constructed wetlands (less than 7 years post-construction). The emergent vegetation of natural wetlands contained facultative-wetland and obligate-wetland species, whereas the emergent vegetation of constructed wetlands also included facultative and facultative-upland species. Therefore, the plant communities of constructed wetlands differed significantly from the plant communities of pristine natural wetlands.

Macroinvertebrates, Plankton, and Benthic Diatoms:

Different factors explained the variance in abundance and community assemblages of macroinvertebrates, phytoplankton, and zooplankton. The number of years post-construction and environmental characteristics best explained the variance in abundance and community assemblages of macroinvertebrates. Macroinvertebrate abundance was higher in recently constructed wetlands. The communities of macroinvertebrates of older constructed wetlands were more similar to the macroinvertebrate communities of natural wetlands. In comparison, the communities of macroinvertebrates of young constructed wetlands were quite dissimilar to older constructed wetlands and natural wetlands. The composition of macroinvertebrate communities was also highly associated with environmental characteristics such as seasonal succession; advanced summer conditions and greater algal abundances favoured gastropods and leeches over aquatic insects. Moreover, phytoplankton community compositions were more varied in constructed wetlands than in natural wetlands. Communities of cyanobacteria, chlorophytes, and picocyanobacteria were less distinct in natural wetlands. Environmental characteristics best explained the variation in the composition of zooplankton communities across natural wetlands and constructed wetlands. The community assemblages of zooplankton were best predicted by the concentration of dissolved organic carbon and the presence of fish within a wetland. There was no observed trend in the composition of the communities of benthic diatoms across natural wetlands and constructed wetlands.

Avian Species Richness and Community Assemblages:

Overall, avian species richness did not differ between natural and constructed wetlands. However, bird abundance and avian community composition differed significantly between the two types of wetlands. Species richness rarely differed between constructed wetlands and natural wetlands. Total wetland-dependant bird abundance was higher in constructed wetlands than in natural wetlands. Furthermore, when investigating only wetland-dependant bird species, there were no differences in community assemblages between natural and restored wetlands. However, the overall avian community, which includes bird species that are not wetland-dependent, differed significantly between natural and constructed wetlands. Notably, other than wetland-dependent birds, natural wetlands were associated with the presence of woodland species and diving birds. In comparison, avian community assemblages on constructed wetlands were associated with the presence of open grassland species and shorebirds.

Habitat Use of Natural and Constructed Wetlands:

Both natural wetlands and constructed wetlands provide habitat to various species. The abundance of anurans and waterfowl was higher in constructed wetlands. Recently constructed wetlands offer very productive feeding habitats for these two groups. In comparison, constructed wetlands offered less suitable habitats for salamander larvae than natural wetlands. Constructed wetlands lacked forested landscapes, which affected the quantity of leaf litter in the substrate; the environmental characteristic which was highly correlated to the occurrence of salamander larvae.

Discussion:

In Canada and other parts of the world, wetland construction fails to replicate natural wetland ecosystems (Harper & Quigley, 2005; Theis et al., 2020; zu Ermgassen et al., 2019). For instance, wetland construction does not reproduce the relationships between wetlands and landscapes. Constructed wetlands were not surrounded by woodlands like natural wetlands. Constructed wetlands did not support woodland-associated bird species characteristic of natural wetlands. The lack of surrounding woodland also potentially affected other biotic communities of constructed wetlands. The phytoplankton communities and macroinvertebrates communities in constructed wetlands were more diverse than in natural wetlands. This disparity could be due to the differences in surrounding woodlands. Decreases in canopy cover increase the diversity of algal communities due to increased sunlight and warmer water temperatures (Plenzler & Michaels, 2015). The constructed wetlands had little canopy cover to reduce sunlight and regulate the water temperature. Therefore, it is likely that the absence of canopy cover resulted in phytoplankton communities proliferating in constructed wetlands. Whereas the extensive canopy cover in natural wetlands limited the diversification of phytoplankton communities by restricting access to sunlight and limiting water temperatures. Canopy cover regulates macroinvertebrate communities by regulating primary productivity and algal communities that are food sources of macroinvertebrates (Plenzler & Michaels, 2015). The macroinvertebrate communities in the wetlands were also associated with seasonal succession. The macroinvertebrate communities progressively change following changes in phytoplankton communities. Seasonal succession is another example of how phytoplankton communities affect macroinvertebrate communities.

Land-use change effects contribute to the inability of constructed wetlands to replicate natural wetlands. The plant communities of constructed wetlands differ from the plant communities of natural wetlands. This pattern is not limited to Canadian wetlands and has been observed in the United States (Yepsen et al., 2014) and Europe (Rojo et al., 2013). Land-use changes potentially affect the seedbank of the constructed wetlands, disrupting the establishment of the wetland plant community (Peralta et al., 2017; Wang et al., 2016). Additionally, the seedbank is replaced by the species that occupy the modified landscape (Ficken & Menges, 2013). Therefore, the seedbank of constructed wetlands is potentially impaired, thus resulting in the lack of native wetland species and the presence of facultative and facultative-upland species observed in the communities of the constructed wetlands. The full impact of the seedbank in the establishment of plant communities in constructed wetlands remains to be explored (Ficken & Menges, 2013; Wang et al., 2016). While physicochemical effects of land-use changes on the establishment of wetland communities were not explored in this paper, land-use changes can affect soil quality (Bruland et al., 2003; Delelegn et al., 2017), contributing to the disruption of the biotic communities in constructed wetlands.

The different establishment of the plant community potentially affects biotic interactions which would regulate phytoplankton communities. Some submergent aquatic macrophytes have allelopathic abilities that inhibit phytoplankton growth (Rojo et al., 2013). Submergent aquatic macrophytes such as *Myriophyllum* spp. inhibit the growth of cyanobacteria. Constructed wetlands that have impaired plant communities have more cyanobacteria. The relationship between macrophyte allelopathy and phytoplankton communities remains to be explored in Canadian wetlands. This potential relationship demonstrates how intricate wetland ecosystems are, and how little we truly understand the relationships and interactions that structure the establishment of biotic communities within wetlands.

Evidently, constructed wetlands fail to mitigate fully the loss of wetland biodiversity and natural wetland ecosystem. However, wetland construction provides wetland habitat for some wetland-dependant species, thus compensating for the loss of some wetland habitat. Sandercock & Gratto-Trevor, (2023), found that constructed wetlands provide important breeding habitats for declining shorebirds in the Prairie Potholes region of Alberta. Additionally, wetland construction can alleviate adverse effects associated with anthropogenic activities. Wetland construction can alleviate the effects of habitat fragmentation by improving interconnectivity between water systems (Ashpole et al., 2018). Additionally, wetland construction can transform by-products of human activity into habitats for some wetland species. For instance, Kuczynski et al., (2012), observed that, in Alberta, ponds formed by borrow pits (used in the construction of a highway) provided quality breeding and brood-rearing habitat to Horned Grebes (*Podiceps auritus*). Therefore, wetland construction can be a useful strategy to compensate for some wetland habitat loss and to support some wetland-dependant species.

Additionally, literature should carefully choose the terminology that concerns constructed wetlands. In the literature used for the analysis (Table 2.), constructed wetlands were described as *restored* wetlands, which referred to the restoration of wetlands in areas that lost natural wetlands to land-use changes. In light of the findings of this literature review, using *restoration* is misleading as it insinuates that constructed wetlands replicate natural wetland ecosystems. Hence, I have used *constructed wetlands* and *wetland construction* to refer to wetlands manufactured by humans.

Protecting natural wetlands is the best strategy to conserve Canadian wetland biodiversity and wetland ecosystems. In Canada, all jurisdictions should establish wetland conservation policies that prohibit further wetland degradation since the mitigation strategy of wetland construction does not mitigate biodiversity loss. This prohibition appears extreme considering that practitioners apply the hierarchy of decisions established in the *Wetland Mitigation in Canada Policy,* which should eliminate unnecessary impacts on wetlands (Cox & Grose, 2000). However, the mitigation hierarchy of federal and provincial wetland mitigation policies has been criticized for being seldom effective in prioritizing avoidance and minimization above compensation (Clare et al., 2011; Poulin et al., 2016). Ineffective compensation strategies threaten wetland-dependant species that do not benefit from wetland habitat compensation. Those species are extremely vulnerable to further degradation and loss of natural wetland habitat. Since wetland construction and current wetland policies fail to mitigate the loss of biodiversity and wetland ecosystems, activities that would cause degradation or loss of natural wetlands should be prohibited.

Wetland construction does provide habitat to some wetland-dependant species and remains a strategy to alleviate historical wetland loss. Practitioners should implement strategies to increase the ability of wetland construction to replicate natural ecosystems. Gutrich et al., (2009), found that strong initial restoration efforts improved the success of the establishment of native plant communities in constructed wetlands. Planting or seeding native wetland plants could lessen difficulties associated with plant colonization in recently constructed wetlands. The practice of planting submergent aquatic plants and emergent plants from the start could potentially help to establish the plant communities in constructed wetlands. Ducks Unlimited Canada uses seeds, plugs or plants of native species, in constructed wetlands, to accelerate the establishment of emergent plants (Ducks Unlimited Canada, 2022a). Practitioners in Spain even inoculate constructed wetlands with native submergent aquatic vegetation (Rojo et al., 2013). Planting strategies should include native trees to reduce differences in landscape characteristics between natural and constructed wetlands. Yepsen et al., (2014) found that there was no correlation between time since wetland construction and the cover of woody species in constructed wetlands. The effect of planting native trees to increase canopy cover and woodland landscapes at constructed wetlands remains to be explored in Canada.

To ensure the best possible outcome following wetland construction, practitioners should plan for continuous assessment and management of constructed wetlands. Following the construction of a wetland, practitioners should assess the need for additional seeding, planting and weed removal, to ensure that the plant community in established wetlands mirrors natural wetland plant communities as close as possible. Constructed wetlands might require regular assessment to ensure that water-level regulating structures are not impaired by debris and beaver activity.

Additionally, continued monitoring of constructed wetlands will improve knowledge of wetland construction. Habitat compensation is a relatively new practice in ecology; I have outlined numerous areas of research in wetland construction that remain to be explored. Continuous monitoring of constructed wetlands would allow practitioners to understand the abiotic and biotic successions that take place in those wetlands. Most constructed wetlands are monitored for approximately 5 years post-construction (Van den Bosch & Matthews, 2017) and long-term assessments of constructed wetlands are rare (Gutrich et al., 2009; Van den Bosch & Matthews, 2017). It has been proposed that the structure and function of constructed wetlands should increase in similarity to natural wetlands within the hundred years following construction (Moreno-Mateos et al., 2012). However, anecdotal observations by wetland managers have indicated that biodiversity gradually decreases in constructed wetlands, approximately 7 to 10 years following construction (Loder, 2017; Loder, Mallory, Spooner, McLellan, et al., 2018; Loder, Mallory, Spooner, Turner, et al., 2018). This phenomenon has been described as wetland senescence and has been attributed to a decline in productivity, but the exact process remains to be formally identified (Loder, 2017; Loder, Mallory, Spooner, McLellan, et al., 2018; Loder, Mallory, Spooner, Turner, et al., 2018). Knowledge of wetland construction must improve before reconsidering the practice of wetland construction to mitigate the loss of biodiversity and wetland ecosystems caused by new anthropogenic activities.

The findings of this study should be considered in light of the limitations imposed by the small sample size. Due to time constraints, I limited the scope of the literature review to peer-reviewed studies which limited the sample size of eligible literature to review. Additionally, I found few peer-reviewed studies that respected the set objective of comparing habitat use and/or species richness and community assemblages of natural wetlands to constructed wetlands. Many Canadian studies did not compare constructed wetlands to natural wetlands, and therefore, were not eligible for the analysis. Hence, the small sample size limits the accuracy of the generalization of my findings on wetland construction. Yet, my findings were corroborated by studies in the United States of America and in Europe that studied differences in habitat use and/or species richness and community assemblages of natural and constructed wetlands(Harper & Quigley, 2005; Theis et al., 2020).

The findings of this study should also be considered in light of the limitations imposed by the ecozones, class of wetlands, age of constructed wetlands, management of constructed wetlands and the subset of Canadian species used in the studies. The eight studies selected for this literature review did not cover wetlands from all Canadian ecozones. The Canadian ecozones are ecologically distinctive from one another due to the interaction of abiotic and biotic factors (Marshall et al., 1999); which could impact the success of wetland construction efforts in the different ecozones (Table 2.). This literature review applies to small, shallow, fresh to moderately brackish, wetlands. Other wetland classes, such as fens and peatlands, differ in terms of hydrology and structure, which could impact construction and the establishment of these constructed ecosystems. Similarly, the constructed wetlands in this study ranged from 1 to 30 years of age and applying the findings to older constructed wetlands could be erroneous. As mentioned earlier, Moreno-Mateos et al., (2012) proposed that the structure and function of constructed wetlands should increase in similarity to natural wetlands within the hundred years following construction. Yet, as of now, there is no way to know if the function of shallow constructed wetlands improves or deteriorates after more than 30 to 50 years (Gutrich et al., 2009; Van den Bosch & Matthews, 2017). Future research should include long-term assessment studies of constructed wetlands to understand the trajectory of constructed wetlands. With this in mind, the constructed wetlands used in this study had not been subjected to seeding and weeding practices; therefore, it is unsure how differently the establishment of plant communities succeeds in constructed wetlands subjected to those practices. Finally, this study reflected the habitat use and preferences of a subset of Canadian wetland-dependant species and might not be representative of all Canadian wetland-dependant species. Future research on shallow constructed wetlands should look to overcome the limitations due to age and ecozones, while other research should focus on the other classes of wetlands in Canada.

Conclusion:

In this literature review, I investigated whether wetland construction is an effective strategy to mitigate biodiversity and habitat loss of Canadian wetlands. To answer this research question, I considered whether wetland construction produced wetland ecosystems comparable to natural Canadian wetlands in terms of biodiversity and habitat. I reviewed eight Canadian studies comparing habitat use, and/or species richness and community assemblages, of shallow water, natural and constructed wetlands, situated in the ecozones of the Mixwood Plains, Prairies, and the Atlantic Maritimes. Ultimately, wetland construction fails to mitigate fully the loss of Canadian wetland biodiversity and wetland ecosystem. Wetland construction does compensate for some wetland habitat loss for some species. Still, ineffective wetland mitigation strategies threaten wetland-dependant species that do not benefit from wetland habitat construction. Those species are extremely vulnerable to further degradation and loss of natural wetland habitat. Therefore, I conclude that wetland construction is not an effective strategy to mitigate biodiversity and habitat loss of Canadian wetlands. Additionally, I identified numerous gaps in knowledge that should be further explored to improve the science of wetland construction. In Canada, the current wetland mitigation policies do not effectively prioritize avoidance and minimization of impacts over impact mitigation. In light of the findings of this literature review, protecting natural wetlands is the best strategy to conserve Canadian wetland biodiversity and wetland ecosystems. In Canada, wetland conservation policies should prohibit further wetland loss and degradation from new anthropogenic activities. Wetland construction should be limited to activities attempting to alleviate historical wetland habitat loss.

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Appendix 1:

Table 3. The substantive concerns raised by the second reader on the research proposal and how these comments have been addressed in the final version of the research project. The comment column refers to the numbered comments left by the second reader, Dr. Scott Findlay, attached to the research proposal Word document.

Comment	Concerns raised by Second Reader	Addressing the concerns
3	Citing the *Federal Policy on Wetland Conservation* of 1991 as to give an estimate of the total wetland loss in Canada, as the estimate is over 30 years old.	I agree that the estimate is outdated. I have found more recent estimates of wetland loss in Canada, but the estimates only applied to the settled areas of Canada (See Figure 1). I have not found a more recent estimate of the total loss of Canadian wetlands, in academic papers or grey literature. I am certain that the estimate of 1991 is far too low considering the urban development and population growth that occurred in Canada within the last 30 years.
4	The introduction summarizes the values of wetlands but does not provide enough: 1) information on what consists habitat compensation, 2) the statutory or policy framework for habitat conservation in Canada, not just the wetland context, 3) Concerns with habitat compensation as a conservation strategy, specifically concerning the effectiveness The readers will probably know the ecological values of wetlands.	I have reduced the section of the introduction on the values of wetlands as I agreed that knowledge of the importance of wetlands is widespread. I have included a short description of what consists habitat compensation and its role in the mitigation hierarchy. I have included more information on the framework for wetland mitigation in Canada, but I kept the introduction concise and limited the information to wetlands. I also included concerns on wetland construction to compensate for biodiversity and habitat loss of wetlands explaining how ineffective mitigation contributes to the loss and degradation of wetlands.
5	The only evidence that I presented to support the claim that wetlands are a conservation priority in Canada is the *Federal Policy on Wetland Conservation* from 1991.	I included some more recent evidence of wetlands being a conservation priority in Canada, not limited to the federal government.
9	The second reader questioned the statement that habitat compensation was used as a conservation measure in existing wetland conservation/ protection policies.	The second reader was right to question the statement. No, habitat compensation is not used as a conservation measure. Habitat compensation is used to replicate lost or degraded natural habitat.
10	The second reader questioned the word use of repair in the sentence, asking if habitat compensation strategies are designed to repair degraded habitat.	The second reader is correct that habitat compensation is not designed to repair degraded habitat. It was a poor word choice. In the final version of the research project, I clarify that habitat compensation strategies

		construct/manufacture habitat/ecosystems to mitigate the loss and degradation of similar, natural habitats/ecosystems.
11	The research question was confusing; the second reader could not establish that the research question defined the scope of my research as assessing the effectiveness of habitat compensation strategies. The research question in the proposal was quite vague: "*I will be assessing the state of habitat compensation strategies in Canadian wetlands* […]."	In the final version of the research paper, I clearly defined the objective of the research question and how I was going to answer the research question: "[…] *whether wetland construction is an effective strategy to mitigate biodiversity and habitat loss of Canadian wetlands.* Ineffective impact mitigation strategies contribute to the loss of wetland biodiversity and habitat by allowing anthropogenic activities to degrade wetlands. *Therefore, to answer this research question, I will investigate whether wetland construction produces wetland ecosystems comparable to natural Canadian wetlands in terms of biodiversity and habitat."*
16	In the proposal, there was not enough information on what data/information would be extracted from the studies selected for the literature review.	In the final version of the research paper, I synthesized information on habitat use between natural and constructed wetlands. I used the occurrence and the presence of organisms/species to determine trends in differences in habitat use between the two types of wetlands. I synthesized information on differences in biodiversity between natural and constructed wetlands. I used species richness (alpha/gamma diversity) and community assemblages (beta diversity) to determine trends in differences in biodiversity between the two types of wetlands.
17	I should include an assessment of the "quality" of each study selected as it is done for a systemic review or meta-analysis. The second reader suggests that I follow the protocols set for systemic reviews by the Cochrane Handbook (see Higgins, 2019).	I followed the Cochrane Handbook and established very clear objectives for the research question: whether wetland construction is effective to mitigate the loss of biodiversity and habitat of Canadian wetlands. I also established the two questions that my synthesis aimed to answer: Does wetland construction replicate natural wetland biodiversity? Does wetland construction replicate natural wetland habitat? If not, how or why does wetland construction fail to replicate natural wetland ecosystems? Establishing those goals helped me to establish the eligibility criteria for the studies used in the literature review. Then, the studies first selected for the literature review were inspected for quality. I verified that the

		interventions could answer their research question and that the variables and analyses were reasonable for the research objectives of their studies.
20	The second reader stated concerns that I would have difficulties finding enough studies to provide an empirical estimate of the effectiveness of habitat compensation for wetland loss. The second reader provided different research avenues to explore instead of the selected topic.	My inexperience and enthusiasm for the topic lead me to pursue the research question. The second reader was not wrong that there are very few studies on the subject at hand. In my preliminary research, I found numerous articles on the subject of the effectiveness of wetland construction to mitigate the loss of wetland biodiversity and habitat in the United States of America and Europe. I also know that wetland construction is a common practice in Canada, having volunteered at a marsh constructed by Ducks Unlimited Canada. I made the assumption that there would be a relatively good number of Canadian studies to use for my literature review. Unfortunately, I was wrong and my sample size is the most important limitation of my literature review. In hindsight, I should have conducted a quick search before the beginning of the semester dedicated to the MRP, filtering out American studies to see if there were enough studies to pursue the topic. Due to time constraints, I decided to pursue the topic. While the sample size is a strong limitation of my study, I do not regret pursuing the topic. The findings of my literature review are very similar to the findings of American literature reviews on the topic. Additionally, my literature review highlighted how long-term assessments of wetland construction, in academia, and in Canada are lacking and how wetland construction efforts are not monitored. Including grey literature could have increased the sample size but grey literature was omitted due to time constraints.