Peace Project Water Use Plan

WILLISTON RESERVOIR WETLAND HABITAT MONITORING

Reference: GMSMON-15

Williston Reservoir Wetland Habitat Monitoring

Study Period: 2011 – 2020

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August 4, 2021

EA3901

PEACE PROJECT WATER USE PLAN

Program No. GMSMON-15

Williston Reservoir Wetland Habitat Monitoring




Final Report

Prepared for

BC Hydro

BC Hydro Generation
Water Licence Requirements
6911 Southpoint Drive
Burnaby, BC

BC Hydro Reference #77186 R15

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Suggested Citation:

d'Entremont, M.V., N. Hentze, K. Tuttle, S. Johnson, I. Beveridge, P. Gibeau and J. Novoa. 2021. GMSMON-15: Williston Reservoir Wetland Habitat Monitoring. Final Report. LGL Report EA3901. Unpublished report by LGL Limited environmental research associates, Sidney, B.C for BC Hydro Generations, Water License Requirements, Burnaby, B.C. 56 pp + Appendices.

Cover photos:

From left to right: Airport Lagoon, Western Toad (*Anaxyrus boreas*) tadpoles in Beaver Pond, Habitat diversity, Common Loons (*Gavia immer*). All photos © Guy Monty, LGL Limited.

EXECUTIVE SUMMARY

Under project GMSWORK-17 (Williston Reservoir Trial Wetlands), BC Hydro selected two Wetland Demonstrations Sites (WDS) for detailed design and construction in the Parsnip Arm of the Williston Reservoir to improve foreshore habitat for fisheries, wildlife, and riparian areas. The two sites are identified as Airport Lagoon and Beaver Pond. At Airport Lagoon, two 1200 mm diameter culverts with an invert elevation of approximately 664.5 meters above sea level (masl), along a causeway at the southern end of the lagoon, were replaced with new 1200 mm diameter culverts with staggered invert elevations, starting at 666.99 to 667.05 masl. The objective of this treatment was to create 27 to 34 ha of permanently wetted habitat upstream of the causeway. At Beaver Pond, a water control structure was constructed, approximately 3 m in height with an invert elevation of 667.25 masl, at the inlet to the pond. This created a 0.3 ha inundated area when reservoir levels are below 667.25 masl. Monitoring the effectiveness of these wetland demonstration projects in improving fish and wildlife habitat on the reservoir was completed under GMSMON-15 Williston Reservoir Wetland Habitat Monitoring. GMSMON-15 was a 10-year monitoring program designed to determine the response of selected indicator groups (i.e., waterfowl, songbirds, amphibians, and vegetation) to the wetland enhancements. Pre-construction monitoring at Airport Lagoon occurred from 2011 and 2012; enhancements were constructed in 2013; and post-construction monitoring occurred from 2014 to 2020. Likewise, pre-construction monitoring at Beaver Pond occurred from 2011 and 2013; enhancements were constructed in 2014; and post-construction monitoring occurred from 2014 to 2020.

Four management questions and associated hypotheses were developed at the commencement of GMSMON-15 to direct the study design and monitoring program. This report presents the comprehensive results of the 10-year monitoring program. A summary of the findings for the indicator groups is presented below.

Fish: Fish sampling occurred in May, June and July, from 2011 to 2020 at the Airport Lagoon and the Beaver Pond enhanced sites. At each site, minnow traps and fyke nets were deployed and electrofishing was conducted. Due to COVID-19 restrictions in 2020, angling occurred at the Airport Lagoon as minnow trapping was the only other method that could be used while maintaining social distancing (2 m apart). Each year the study was replicated when water levels would allow. At the Airport Lagoon, six to 12 minnow traps and two fyke nets were deployed and the same reach at the northern end of the lagoon was electrofished. At Beaver Pond, three to six minnow traps and one fyke net were deployed and the same reach was electrofished. During some years water levels at the Beaver Pond were too low to electrofish or to deploy a fyke net or too high to access the site.

Over the ten-year period, 12 fish species from five families were captured in Airport Lagoon. At the Beaver Pond six fish species from five families were captured. In total, 61824 fish, predominantly adults, were captured, with the majority (99%; 59,518) captured in the Airport Lagoon. At the Airport Lagoon, minnows (*Cyprinidae*) dominated catches, followed by suckers (*Catostomidae*), prickly sculpin (*Cottus asper*) and burbot (*Lota lota*). At Beaver Pond, suckers dominated catches, followed by minnows, prickly sculpin, bull trout (*Salvelinus confluentus*) and burbot. Data collected from 2011 to 2020 for the GMSMON-15 project consistently showed that a diverse species of fish were present at both wetland sites.

Waterbirds and shorebirds: Surveys for waterbirds and shorebirds were typically completed in April, May and June during each year of the monitoring program. Five observation stations were set up at Airport Lagoon and only one station was at Beaver Pond. A total of 49 species were observed during the monitoring program, including 35 species of waterbirds and 14 species of shorebirds.

Both the enhanced wetland sites were being used by waterbirds and shorebirds during the migratory and breeding periods. Species richness of waterbirds and shorebirds was generally higher at Airport Lagoon in the post-enhancement period. The occurrence of waterbirds and shorebirds was higher during the migratory period, so it appeared the enhanced habitats at Airport Lagoon were being used by several species as a stopover site. It is also clear that waterbirds and shorebirds were using Beaver Pond, but the occurrence of species within these subgroups was relatively lower compared to what was observed at Airport Lagoon.

Songbirds: Songbird surveys were conducted between May 30 and June 15 each year from 2011 to 2019 and followed provincial standards and established protocols for conducting variable radius point count surveys. Data were collected from 17 stations at Airport Lagoon and three stations at Beaver Pond. Due to transportation restrictions in 2020 because of the COVID-19 pandemic, point counts were not completed. Instead, acoustic autonomous recording units were temporarily set-up at each point count station. A total of 64 songbird species (including hummingbirds and woodpeckers) were observed during the monitoring program including 63 species at Airport Lagoon and 35 species at Beaver Pond. At both locations, it has been demonstrated that songbirds are using the enhancement area, based on observations of birds within the drawdown zone of the reservoir; although, there were no obvious trends in overall species composition or abundance in the pre- and post-enhancement periods for songbirds at Airport Lagoon and Beaver Pond.

Amphibians: Amphibian surveys occurred over two to four sampling intervals (i.e., replicates) between April and June each year to coincide with the active period of amphibians. At Airport Lagoon, 11 transects distributed along the periphery of the inundated area were sampled; whereas, at Beaver Pond the entire site was considered a single transect. The search area along each transect included shallow water (< 1 m deep), the shorelines, and areas within 3 m of the shoreline (ponds, streams, riparian areas). A zig-zag search pattern was applied to areas above the waterline and a linear pattern directly adjacent to the water (i.e., shoreline) to ensure complete coverage of the area. In total ~200,400 amphibians were observed, including 32 egg masses, ~200,000 tadpoles, ~200 metamorphs or juveniles, and 237 adults of the four amphibian species.

Overall, Airport Lagoon had 41% of the species detections and the highest species richness (n = 4). Western Toad was the most abundant species (91% of all detections), with tadpoles, metamorphs and adults observed in multiple years. Breeding was confirmed in Airport Lagoon for all amphibian species. The most productive area for amphibians appeared to be transects the northeastern section of the enhanced wetland area. Despite being a smaller site and having only one survey transect, Beaver Pond had 59% of the individual detections over the 10 years, but only three species were observed. Similar to Airport Lagoon, Western Toad was the most abundant species (78% of all detections), with all life stages observed in multiple years. An increase in abundance for two species (Western Toad and Long-toed Salamander) was noted for the post-enhancement period, suggesting the wetland enhancements improved habitat conditions for amphibians.

Vegetation: Ecological communities were originally delineated and classified at each site in 2011 using a combination of air photo interpretation and terrestrial ecosystem ground sampling. The habitat classifications and their spatial distribution were reassessed in 2012, 2013 and 2018, and the classifications and mapping were refined as additional information was collected. Ground sampling of terrestrial (i.e., riparian) vegetation was typically conducted in June or July along belt-transects. Initially 10 transects were established at Airport Lagoon and five transects at Beaver Pond, but data collection for these varied throughout the program as access to transects changed as a result of water infiltration during the post-enhancement period and as reservoir levels fluctuated. Sampling of aquatic vegetation commenced in 2014 and involved visual observations of plant cover and benthic rake drags to determine density. Twelve and six vegetation communities were identified at Airport Lagoon and Beaver Pond, respectively. The terrestrial vegetation dataset was comprised of 1259 records for 130 individual species. Five aquatic plant communities were documented at Airport Lagoon, whereas none were documented at Beaver Pond. A total of 14 aquatic vegetation species and 2 taxa, identified only to genus, were observed.

At both sites, the general pattern of riparian habitat from the water's edge started with either mineral soil (sand and clay) or mosses and perennials that transitioned into a band of coarse woody debris (driftwood) followed by graminoid-dominated areas and then shrub habitats. Vegetation communities remained relatively stable over time, with little change in species composition; however, the area and coverage of these communities changed. At Airport Lagoon, the biggest changes were a reduction in the area coverage for Basin Moss and Shoreline Driftwood, which were matched with an increase in surface water (i.e., Streams and Ponds habitat class). At Beaver Pond, Basin Cryptantha and Stream Sedge were reduced by about 11% and 7%, respectively. Conversely, Shoreline Clay and the amount of surface water (i.e., Steams and Ponds) increased by approximately 9% and 8%, respectively.

At both sites, plant species assemblages identified within habitat classes consisted mostly of herbaceous perennials. Shrub cover were sparse, with the exception of the habitat class located at the edge of the forest cover and tree species were only recorded in the latter years of the monitoring program. On average, herb cover was 3.3 times greater at Airport Lagoon in the post-enhancement period (2014-2020) compared to the pre-enhancement period (2011-2012). At Beaver Pond, the amount of terrestrial vegetation was less than what was recorded at Airport Lagoon; however, the cover of herbaceous vegetation increased significantly during construction and the post-enhancement period. Likewise, species richness was relatively low before the enhancement (e.g., five species) but increased to 15 species in the post-enhancement period.

There was a sharp decline in species richness of aquatic macrophytes over time at Airport Lagoon, with species richness going from a total of 15 in 2018, to nine in 2019, to only three in 2020. Species richness was more stable but much lower in Beaver Pond. Likewise, the density of aquatic vegetation generally declined over time at Airport Lagoon but remained fairly constant at Beaver Pond. There was a clear distinction of species composition at various water depths. Certain species were common at shallower water depths (e.g., <1 m), some of which showed a reduction in abundance over the years; likely as a result of there being more persistent deeper water in the flooded habitat. Conversely, species recorded in deeper water (>2 m) were documented at higher frequencies in the latter years of the monitoring program.

Final status of GMSMON-15

Management Question	Summary of Key Monitoring Results
MQ-1: Are the enhanced (or newly created) wetlands used by fish?	<u>Summary of Findings</u> During the 10-year study period, fish were consistently captured at both the Airport Lagoon and Beaver Pond enhanced wetlands. Fish sampling by electrofishing, minnow trapping, and fyke nets was effective method at both sites and provided additional information on fish populations. The three methods of sampling resulted in the collection of 13 of 22 species known to occur in the Williston Reservoir. <u>Sources of Uncertainties</u> Due to some limitations of the sampling gear (i.e., minnow trap opening) and fish species life histories (i.e., size range, habitat preferences) it is possible that there are biases is species size and composition. <u>Comments</u> Due to high percent gradient, fish access into the Airport Lagoon and Beaver Pond wetlands during low reservoir levels is not possible.

MQ-2: Are the enhanced (or newly created) wetlands used by waterfowl and other wildlife?	<u>Summary of Findings</u> Waterfowl and other wildlife consistently use the newly created wetlands that were monitored under GMSMON-15. Waterbirds and shorebirds – Both the enhanced wetland sites were being used by waterbirds and shorebirds during the migratory and breeding periods. A total of 49 species were observed during the monitoring program, including 35 species of waterbirds and 14 species of shorebirds. Species richness of waterbirds and shorebirds was generally higher at Airport Lagoon in the post-enhancement period. It is clear from the monitoring program that waterbirds and shorebirds are using Beaver Pond, but the occurrence of species within these subgroups was relatively lower compared to what was observed at Airport Lagoon. Songbirds – A total of 64 songbird species (including hummingbirds and woodpeckers) were observed during the monitoring program, including 63 species at Airport Lagoon and 35 species at Beaver Pond. There was no obvious trend in overall species composition or abundance in the pre- and post-enhancement periods for songbirds at both sites. Vegetation characteristics explained only a small amount (9%) of variation in species composition, though species composition of drawdown zone habitats did cluster distinctly from shrub and forest habitats. It is evident that songbirds are using the enhancement areas, based on observations of birds within the drawdown zone. However, wetland enhancement does not seem to have had an impact on overall richness or abundance. Amphibians – Four species of amphibians were detected at the Airport Lagoon, whereas only three species were recorded at Beaver Pond. Western toad was the most abundantly observed species at both sites. At Airport Lagoon, the most productive area for amphibians appeared to be the northeastern section of the enhanced wetland area. Beaver Pond had the highest proportion of overall individual detections over the 10 years, and this site showed greater consistency of species diversity across the years. It was clear that the enhancement at Beaver Pond resulted in an increase in the amount of amphibian breeding habitat available – western toad tadpoles were consistently observed here in the post-enhancement period. <u>Sources of Uncertainties</u> Waterbirds and shorebirds – Observer bias was likely introduced into the monitoring program given the 10-year timeframe; although, this was reduced with the use of standardized survey methods that were consistently followed. Some issues with data consistency and quality control were noted. Songbirds – Annual variation in species richness and total counts were noted, but this is normal and expected over a 10-year monitoring program and was likely a reflection of variability in environmental conditions on the breeding, wintering or migration areas from year to year. Annual survey dates were consistent across the years and selected to be within the breeding bird window, thus migration timing should not have been a major influencer of survey results for the species present. The establishment of consistent observation stations among years allowed for a more precise dataset to be collected. Amphibians – Several assumptions were used in the analysis of the amphibian data; 1) observations were a good representation of the true abundance at each site and that detection rates were not impacted differently across sites or years; 2) animals observed were unique individuals and not double-counted between annual replicates; and 3) all observers over the 10 years had the same level of skill surveying for amphibians. <u>Comments</u> Waterbirds and shorebirds – The data showed higher occurrence of waterbirds and shorebirds during the migratory period, so it appeared the enhanced habitats at Airport Lagoon were being used by several species as a stopover site. More waterbirds and shorebirds appeared to be using Beaver Pond during migration, but there were

Management Question	Summary of Key Monitoring Results
	similarities in the total number of birds observed here between the migratory and breeding periods. Breeding records were limited to 1-3 observations per year, except for 2014, 2015 and 2016 when no breeding observations were recorded. Songbirds – Wetland enhancements were not created with a specific focus on songbirds. As songbird counts included the edge and forest habitats around the enhanced wetland, it is perhaps unsurprising that no obvious trends were observed in the pre- and post-enhancement periods, as forest communities appeared to have remained intact across all years. Although at Beaver Pond a noticeable change in habitat used by songbirds was evident. Here, bird richness appeared to decline post-enhancement while drawdown zone bird richness appeared to increase. However, trends were subject to the vagaries of low sample size as the Beaver Pond area was small enough to only permit three point count stations to be established over all years. Amphibians – Beaver Pond showed a greater consistency of species diversity across the years as three species were typically detected there, whereas Airport Lagoon had several years where only one species was detected. There were increases in amphibian detections immediately following construction of the enhancements, but the overall abundance of amphibians declined in the latter years of the program.

MQ-3: Is there a change in the abundance, diversity, and extent of vegetation in the enhancement area?	<u>Summary of Findings</u> At Airport Lagoon, the general pattern of riparian habitat from the water's edge started with either mineral soil (sand) or mosses and perennials that transitioned into a band of coarse woody debris (driftwood) followed by graminoid-dominated areas and then shrub habitats. At Beaver Pond, as similar gradient was observed, but perennial species were becoming established in the mud and clay present at the water's edge, providing some evidence that a near-shore riparian vegetation may become established over time. These general habitat conditions are typical of reservoir. The wetland enhancements at Airport Lagoon and Beaver Pond created larger areas of permanently flooded habitat and reduced water level changes during reservoir drawdown. Colonization of the drawdown zone by riparian vegetation above the ponds, and the proliferation of aquatic macrophytes within the ponds was evident. Vegetation Communities – Twelve habitat classes were defined at Airport Lagoon, whereas six were identified at Beaver Pond. The habitat classes at both sites have responded to the wetland enhancements and to annual flooding events. The amount of surface water (e.g., pond) increased at both sites leaving a varied shoreline/riparian area. Terrestrial Vegetation – The terrestrial vegetation dataset was the compiled presence/not detected data that was used to measure diversity and abundance of terrestrial vegetation species. The average percent cover of terrestrial species by vegetation layer (e.g., moss, herb, shrub, tree) were compared for each year of the monitoring program. In summary, this dataset was comprised of 1259 records for 130 individual species. The cover of herbaceous vegetation increased slightly on average during construction and immediately after the enhancements at Airport Lagoon (2012 and 2013); however, there was no clear trend in herb cover throughout most of the monitoring program (2014 to 2018), until 2019 and 2020 when cover began to increase. Despite the cover of herbaceous vegetation increasing in the latter years of the monitoring program, overall cover remained relatively low at around 10-20%. At Beaver Pond, the amount of terrestrial vegetation was less than what was recorded at Airport Lagoon; however, some notable changes occurred. The cover of herbaceous vegetation increased significantly during construction and the post-enhancement period. Likewise, species richness was relatively low before the enhancement (e.g., five species) but increased to 15 species in the post-enhancement period. Finally, species composition transitioned over time with distinct changes occurring in the latter years of the program. Aquatic Vegetation – A total of 14 species and 2 taxa, identified only to genus, were included in the dataset for the last three years of the monitoring program. Aquatic macrophytes were relatively well developed in the shallower sections of Airport Lagoon, including areas that are directly influenced by the enhancements. The frequency of species detections were quite variable over the years. The density of aquatic vegetation typically declined with increasing water depth. Aquatic macrophyte development at Beaver Pond was comparatively lower. <u>Sources of Uncertainties</u> The primary challenges with the vegetation datasets were associated with observer bias and data management. Some specific data attributes were missing or not recorded, which only became evident when the full 10-year dataset was compiled and processed. Likewise, observation data on aquatic vegetation from 2017 and spatial data on aquatic vegetation communities was not provided to the report authors; therefore, these components were not discussed in this comprehensive report. The noticeable increase in terrestrial vegetation cover in the later years of the monitoring program may have been influenced by confounding factors, such as later sampling dates, the effect of reservoir operations and the inconsistent sampling of specific transects. The other confounding factor was the fact that different observers collected data each year, potentially adding observer bias to the dataset. <u>Comments</u> Vegetation development and establishment can be a relatively slow ecological process, so the longer time series (i.e., >10 years) is necessary and the conditions under which the vegetation communities persist will become evident in the future. Species richness and cover was highest for herbaceous vegetation across all years of the

Management Question	Summary of Key Monitoring Results
	monitoring program. The richness and cover of moss and shrub species was relatively low and tree species were only noted in the final years of the monitoring program. Data on aquatic vegetation was only collected in the post-enhancement period and the methods of data collection varied across sampling years. The sampling methods for collecting data on aquatic vegetation differed between 2014 – 2016 and 2018 – 2020 , and no data was provided for 2017). Comparable analysis across all years could not be performed. Although, this was not a major drawback since all data on aquatic vegetation were collected in the post-enhancement period.

Management Question	**Summary of Key Monitoring Results**
MQ-4: Is the area and quality of fish and wildlife habitat created by the wetland enhancement maintained over time?	Summary of Findings The area of aquatic habitat created by the wetland enhancements is clearly being maintained. In 2020 water levels at Airport Lagoon and Beaver Pond appeared to be stable and the enhancement structures were performing as intended. The quality of this habitat varied differently for fish and wildlife species. Fish – During the 10-year study period, fish were consistently captured at Airport Lagoon and Beaver Pond. Both wetland enhancements have resulted in increased habitat available for fish. Based on the results of GMSMON-15, over time, this will benefit fish by providing an increased amount of habitat available for spawning, food sources, or overwintering (for some species). Wildlife – It was clearly evident that waterbirds and shorebirds are using this newly created habitat during the migratory and breeding seasons. At Airport Lagoon, more birds were using habitat in the northern sections of the site. The water depths here were typically shallower and there were likely better foraging opportunities for birds. The occurrence of species within these subgroups was relatively lower at Beaver Pond. This is likely a reflection of the size of the impounded area at Beaver Pond and the lower habitat complexity, compared to Airport Lagoon. Songbirds are utilizing the suite of habitats available at and near the enhanced wetland sites at Airport Lagoon and Beaver Pond. At Airport Lagoon, songbird richness appeared to increase in drawdown zone habitat in the post-enhancement period, while remaining fairly stable in shrub habitats. Forest habitat had an increase in richness in Year 8 relative to other years. Beaver Pond had fewer data points, but richness appeared to increase in drawdown zone and decrease in forest habitats post-enhancement. The wetland enhancement at Beaver Pond resulted in a large increase in the amount of available amphibian breeding habitat, which was evident from the high number of tadpoles observed here. The abundance of amphibians appeared to decline in the latter years of the program. Sources of Uncertainties Sources of uncertainty are presented in the management questions above. Comments No suitable salmonid spawning habitat was observed, and no juvenile Salmonids (<20 cm) were captured. Habitats at Beaver Pond are more susceptible to fluctuations in reservoir elevations, which may affect the suitability of habitats on a seasonal or annual basis. Declines in amphibian abundance at Airport Lagoon could be partially explained by the increases in potential predators (e.g., fish, waterbirds).

ACKNOWLEDGEMENTS

The authors express their appreciation to the following individuals for their assistance in coordinating and conducting this study: Teri Neighbour (BC Hydro) and Kate Froats (BC Hydro). Data from 2011 to 2017 was collected by staff from Cooper Beauchesne and Associates Ltd. Data from 2018 to 2020 was collected by staff from LGL Limited (listed below) and staff from Chu Cho Environmental LLP, including Benita Kaytor, Jeff Strohm, Dillon Hamelin, Caroline Walter, Kristin Marini, Erica Bonderud, Sarah Poole, Nathan French and Marty Izony. Chu Cho Environmental participation was overseen and coordinated by Mike Tilson and Sean Rapai, who also provided logistical and field support. Guy Monty, Julia Burger and Ryan Batten also provided technical support in the field. Lucia Ferreira and Julio Novoa of LGL Limited assisted with GIS analysis.

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1 INTRODUCTION

The annual reservoir cycling in Williston Reservoir created a drawdown zone of approximately 450 km^2 that was unproductive in both the inundated state as aquatic habitat and the drawdown state as terrestrial habitat (BC Hydro 2003). The Peace Water Use Plan Committee (hereafter known as the Committee) recognized that the largely unproductive drawdown zone on Williston Reservoir contributed to low fishery productivity, a lack of riparian and wildlife habitat, and potentially increased predation risk for wildlife. To address this issue, the Committee recommended the Riparian and Wetland Habitat management plan to improve foreshore habitat for fisheries, wildlife, and riparian areas. The components of the plan were an inventory of sites that were potentially suitable for enhancement, selection of sites for implementation of demonstration wetland enhancement projects, and a monitoring program to test their effectiveness in improving riparian and foreshore habitat for wetland species over the life of the project.

Under GMSWORKS-16 Williston Reservoir Wetlands Inventory, a total of 42 candidate sites in the Parsnip Arm of the Williston Reservoir were surveyed as potential wetland enhancement sites by Golder Associates Ltd. (2010). Candidate sites were assessed based on biological, geotechnical and archaeological considerations as well as factors including cost, feasibility and potential benefits to wildlife. Through this work, the list of candidate sites was narrowed to five Wetland Demonstration Sites (Golder Associates Ltd. 2010). BC Hydro selected two Wetland Demonstrations Sites (WDS) for detailed design and construction: WDS 6-2 (Airport Lagoon) and WDS 34 (Beaver Pond). This phase was completed under GMSWORKS-17 Williston Reservoir Trial Wetland. Monitoring of the effectiveness of the wetland demonstration projects in improving wildlife habitat on the reservoir was completed under GMSMON-15 Williston Reservoir Wetland Habitat Monitoring, which commenced in 2011.

At Airport Lagoon, two 1200 mm diameter culverts with an invert elevation of approximately 664.5 meters above sea level (masl), along a causeway at the southern end of the lagoon, where replaced in 2013 with new 1200 mm diameter culverts with staggered invert elevations, starting at 666.99 to 667.05 masl. The objective of this treatment was to create 27 to 34 ha of permanently wetted habitat upstream of the causeway. At Beaver Pond, a water control structure was constructed in 2014, approximately 3 m in height with an invert elevation of 667.25 masl, at the inlet to the pond. This created a 0.3 ha inundated area when reservoir levels are below 667.25 masl.

This report presents a comprehensive assessment of the monitoring data collected from 2011 to 2020 to assess the effectiveness of wetland enhancement in meeting the objectives of the Riparian and Wetland Habitat management plan. This report is divided into two main sections: the main body and the appendices. The main body of the report provides an overview of the study, summarizes the methods and locations of work, introduces the data that were collected, and provides answers to each of the four management questions. The answers to management questions are supported by the detailed analyses presented in the appendices.

2 STUDY AREA

Williston Reservoir is located in northeastern British Columbia and was created by construction of the W.A.C. Bennett Dam at the head of the Peace River Canyon, about 20 km west of Hudson's Hope, B.C (BC Hydro 2015). The reservoir extends for about 260 km along the Rocky Mountain Trench from the Finlay River in the north to the Parsnip River in the south (Figure 1). The reservoir is generally divided into three geographic regions (from north to south): Finlay Reach, Peace Reach and Parsnip Reach (BC Hydro 2015).

Since 1971, reservoir elevations have ranged between 654 m and 672 m, caused primarily by an operation of seasonal water storage, but with considerable annual variability associated with inflows and system generation needs. Inflows to the reservoir are primarily driven by snowmelt in the Peace River watershed and are much higher in summer than in winter. The reservoir is typically ice covered between the end of January and the beginning of May and generally reaches an annual minimum elevation in April or May, followed by reservoir refilling in the spring freshet. The reservoir usually reaches the maximum elevation in July or August and is then drafted through the winter as power generation is increased to meet peak winter energy demands (Figure 2). The Normal Maximum Reservoir Level (NMRL) is 672 m and BC Hydro normally maintains a minimum elevation of approximately 655 m (BC Hydro 2015).

Figure 1. Location of the Williston Reservoir in northern British Columbia and locations of enhanced wetlands (Airport Lagoon and Beaver Pond) sampled for GMSMON-15.

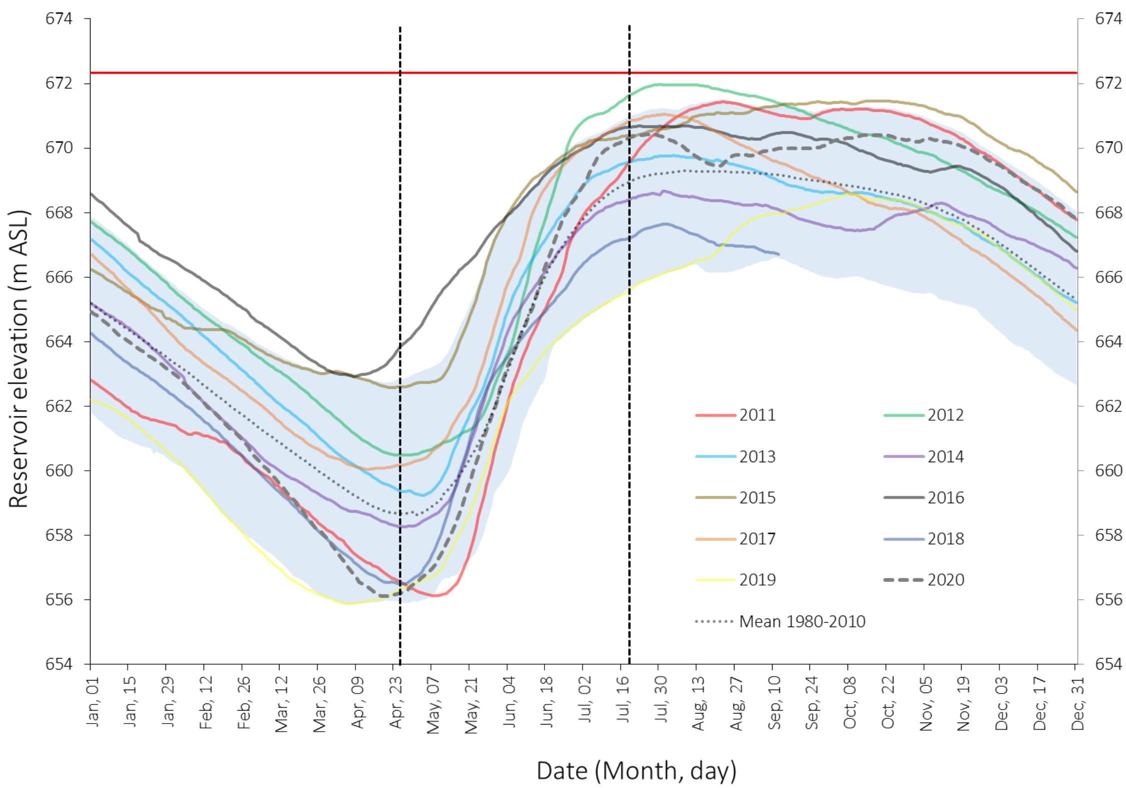

Figure 2. Williston Reservoir elevations from 2011 to 2020. The shaded area represents the 10th and 90th percentile for the period 2011 to 2019; the horizontal red line is the normal operating maximum. Vertical dashed lines indicated the typical start and end dates of field sampling.

2.1 Physiography

The Williston Reservoir is nestled between the Hart Range of the Northern Rocky Mountains on its east and the Omineca Mountains on its west, which lie in a north-northwest to south-southeast orientation. The Finlay and Parsnip Reaches lie within the wide, flat-bottomed Rocky Mountain Trench and the former stream channels are deeply incised. Glacial till is the most abundant surficial deposit in the region.

The reservoir is located within the Sub-Boreal Spruce and Boreal White and Black Spruce biogeoclimatic zones (Meidinger and Pojar 1991). The Sub-Boreal Spruce zone is the dominant zone and occurs as two subzones and variants at lower elevations along most of the reservoir (Meidinger and Pojar 1991). The Boreal White and Black Spruce zone occurs only at the northern end of the reservoir in the Finlay Arm (Meidinger and Pojar 1991). The drawdown zone consists of large areas of mud, sand, and gravel flats with stranded large woody debris. Limited amounts of vegetation occur even following extended periods of drawdown.

2.2 Climatology

Daily weather in the region is influenced by middle-latitude cyclones, which typically move from southwest to northeast British Columbia that respond to large scale features of the Rocky

Mountains (Whiteman 2000, Klock and Mullock 2001). These lows tend to move over mountains and produce a widespread area of precipitation as well as unstable air where bands of clouds and showers develop. The middle-latitude cyclones dominate the weather during the fall through spring, while convection dominates during the summer months. The lows can become very slow moving and result in large amounts of precipitation in one place (Klock and Mullock 2001); combined with moist air that originates over the Pacific Ocean, which makes its way eastward through the narrow and deep valleys that occur through the Rocky Mountains (Vickers et al. 2001). The region experiences long, cold winters and ice formation on the reservoir begins as early as November and can extend into the beginning of May. Annual precipitation ranges between 40 cm to 50 cm with snowfall accounting for 35-45% of the annual precipitation. The Williston Reservoir receives and stores most of its hydrologic input from snowmelt. The large spring runoff typically begins in mid-May and peaks in June (Stockner et al. 2005).

2.3 Physical Works

The two locations identified for the wetland demonstration projects are both located on the east side of the Parsnip Reach (Figure 1). The uniqueness of both sites, along with the completed enhancements, meant there were no associated control or reference sites for this program. As such, pre-construction baseline data were used to assess the post-construction changes associated with each enhancement.

2.3.1 Airport Lagoon

The Airport Lagoon site (WDS 6-2) is located approximately six kilometres south of Mackenzie and is an approximately 75 ha site on the upstream side of a forest service road causeway. Except for two culverts at the base of the causeway, the area is isolated from the main reservoir. Water supply to the lagoon is primarily from two unnamed streams located at the north end of the lagoon. Prior to the enhancements, water levels in the lagoon corresponded to the reservoir level when water levels were >664.5 m. To create a larger area of permanently flooded habitat and reduce water level changes, the existing culverts were removed in May of 2013 and two new culverts were installed at an elevation of 666.99 m for the west culvert and 667.05 m for the east culvert, raising the pond elevation by ~2.5 m (Golder Associates Ltd. 2013).

2.3.2 Beaver Pond

The Beaver Pond site (WDS 34) is located approximately 22 km northwest of Mackenzie at the end of a narrow inlet on Heather Point. At this site there were two beaver ponds located at the head of the inlet with a small stream draining the ponds. In 2014, a berm was constructed part way up the inlet at an elevation of 667.25 m, which created a wetland of approximately 0.3 ha (Golder Associates Ltd. 2015). When reservoir levels are above this measure, the wetland is directly connected to the reservoir; however, more stable water levels remain in the enhanced area as the reservoir levels recede (Golder Associates Ltd. 2015).

3 METHODS

The sampling methods for each of the indicator groups are described below, along with any adjustments that were required due to reservoir elevation or weather conditions at the time of sampling. This effectiveness monitoring program was designed to determine the response of selected indicator groups to the wetland enhancements and to increase knowledge of wildlife use in the enhanced area for the selected groups, particularly birds and amphibians. To provide some indication of wildlife response to the wetland enhancement BC Hydro (2008) identified waterfowl, songbirds, amphibians, and vegetation as the wildlife indicator groups to be used for monitoring in GMSMON-15. Fish populations were also identified for monitoring as fish were observed at both of the selected demonstration sites (Golder Associates Ltd. 2010, 2011). While improving fish habitat was not one of the goals of the wetland enhancement projects, little was known about the fish species composition and distribution at the selected locations (BC Hydro 2008).

3.1 Fish Surveys

Data on fish species were collected to address the following management questions:

> MQ-1: Are the enhanced (or newly created) wetlands used by fish?
>
> MQ-4: Is the area and quality of fish and wildlife habitat created by the wetland enhancement maintained over time?

Fish survey methods and effort were consistent with the Terms of Reference (BC Hydro 2008), previous years of the project (MacInnis et al. 2017, d'Entremont et al. 2019 and d'Entremont et al. 2020), and provincial standards (RIC 2001). Fish sampling sessions were completed one or two times between May and July each year from 2011 to 2020. A combination of methods were used to capture and sample both large and small fish. This included electrofishing, and the deployment of minnow traps and fyke nets (Table 1). In 2020, angling was added as a sampling method at the Airport Lagoon since electrofishing and deployment of fyke nets was not possible because field staff were instructed to follow COVID-19 physical distancing restrictions.

At Airport Lagoon, between six and 12 minnow traps were deployed, one reach was electrofished, and two fyke nets were set each year (Figure 3). At Beaver Pond, between three and six minnow traps were deployed, one reach was electrofished from 2011 to 2016, and one or two fyke nets were set (Figure 3). Given the size of the Beaver Pond, insufficient water levels prevented effective electrofishing or the deployment of a fyke net in some years (Table 1). During some sampling years, high water inundated the Beaver Pond site and sampling could not occur.

Fish sampling was conducted under Scientific Fish Collection Permits issued by the Ministry of Forest, Lands and Natural Resource Operations and Rural Development. All captured salmonids, cyprinids, gadidaes, and suckers were measured for fork length whereas total length was recorded for sculpins. When catches were high for a species and method, the first 50 fish were measured for length (mm) and the remainder were enumerated without measurement.

Using a YSI 556 (2011 to 2015) and Pro Plus multi-parameter meters (2016 to 2020; YSI Inc., Ohio) water quality measurements were taken during sampling events each year. These parameters included water temperature, water depth, water clarity (relative turbidity or Secchi depth), pH, dissolved oxygen (DO), and conductivity. Water temperature, pH, DO, and conductivity were recorded at the surface. Relative turbidity was recorded for each electrofishing reach according to RIC (2001) standards. Secchi depth (20 cm diameter disk) was used as a measure of turbidity for the inundated areas.

Table 1. Number of wetland site visits to Airport Lagoon and Beaver Pond in Williston Reservoir as part of the fish surveys for GMSMON-15, 2011 to 2020.

Site	Year	Phase	Electrofishing			Minnow trap			Fyke net			Angling	
			May	June	July	May	June	July	May	June	July	May	July
Airport Lagoon	2011	Pre	2	1	0	1	1	1	1	1	1	0	0
	2012	Pre	1	1	0	1	0	1	1	0	1	0	0
	2013	Construction	1	0	0	1	0	1	0	0	1	0	0
	2014	Post	1	0	0	1	0	1	1	0	1	0	0
	2015	Post	1	0	0	1	0	1	1	0	1	0	0
	2016	Post	1	0	0	1	0	1	1	0	1	0	0
	2017	Post	1	0	0	1	0	1	1	0	1	0	0
	2018	Post	1	0	1	1	0	1	1	0	1	0	0
	2019	Post	1	1	1	1	1	0	1	1	0	0	0
	2020	Post	0	0	0	1	0	0	0	0	0	1	1
Beaver Pond	2011	Pre	0	1	0	0	1	1	0	0	1	0	0
	2012	Pre	1	0	0	0	0	1	0	0	1	0	0
	2013	Construction	1	0	0	0	0	1	0	0	1	0	0
	2014	Post	1	0	0	0	0	1	0	0	1	0	0
	2015	Post	1	0	0	0	0	0	0	0	0	0	0
	2016	Post	1	0	0	1	0	1	0	0	1	0	0
	2017	Post	1	0	0	1	0	1	0	0	1	0	0
	2018	Post	0	0	0	1	0	0	0	0	0	0	0
	2019	Post	1	1	0	1	1	0	1	1	0	0	0
	2020	Post	0	0	0	1	0	0	0	0	0	0	0

*Note: Angling was conducted in 2020 to ensure field crews could maintain COVID-19 physical distancing requirements.

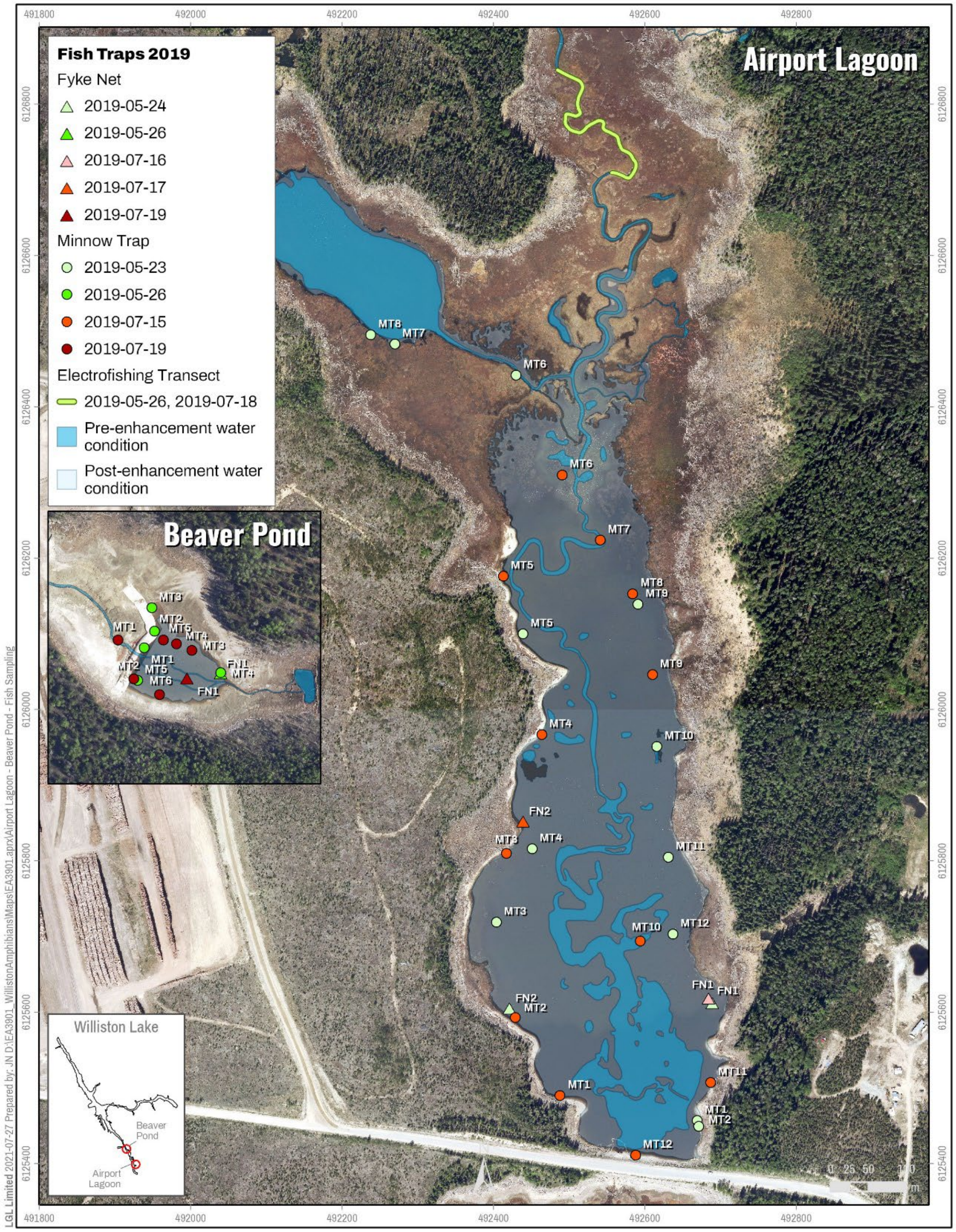

Figure 3. Fish sampling locations by date and method at the Airport Lagoon and Beaver Pond sites in 2019. These sites are representative of fish sampling locations from 2011 to 2020.

3.2 Wildlife Surveys

Data on waterfowl, shorebirds, songbirds and amphibians were collected to address the following management questions:

> MQ-2: Are the enhanced (or newly created) wetlands used by waterfowl and other wildlife?
>
> MQ-4: Is the area and quality of fish and wildlife habitat created by the wetland enhancement maintained over time?

The methods for specific surveys are described below.

3.2.1 Waterbird and Shorebird Surveys

Data collection on waterbird species commenced in 2011, whereas specific data for shorebirds was added in 2012 to provide additional detail on bird use of the sites. Survey methods for waterbird and shorebird were consistent each year and followed provincial standards for relative abundance inventories (RIC 1999a). Surveys were conducted at five observation stations at Airport Lagoon and one observation station at Beaver Pond (Figure 4). At least three replicates were conducted between April and June each year. Data on flock or individual number, species, sex, behaviour, and general habitat (e.g., mid pond, in water near pond edge, standing on shore in water, on shore) were recorded on a modified Resource Inventory Committee data form (RIC 1999a) and their corresponding location was recorded on a map with an orthophoto background of each site. Weather conditions were recorded at the beginning and end of each survey, and any unusual conditions or circumstances that potentially affected waterbird and shorebird presence in the wetland areas were noted.

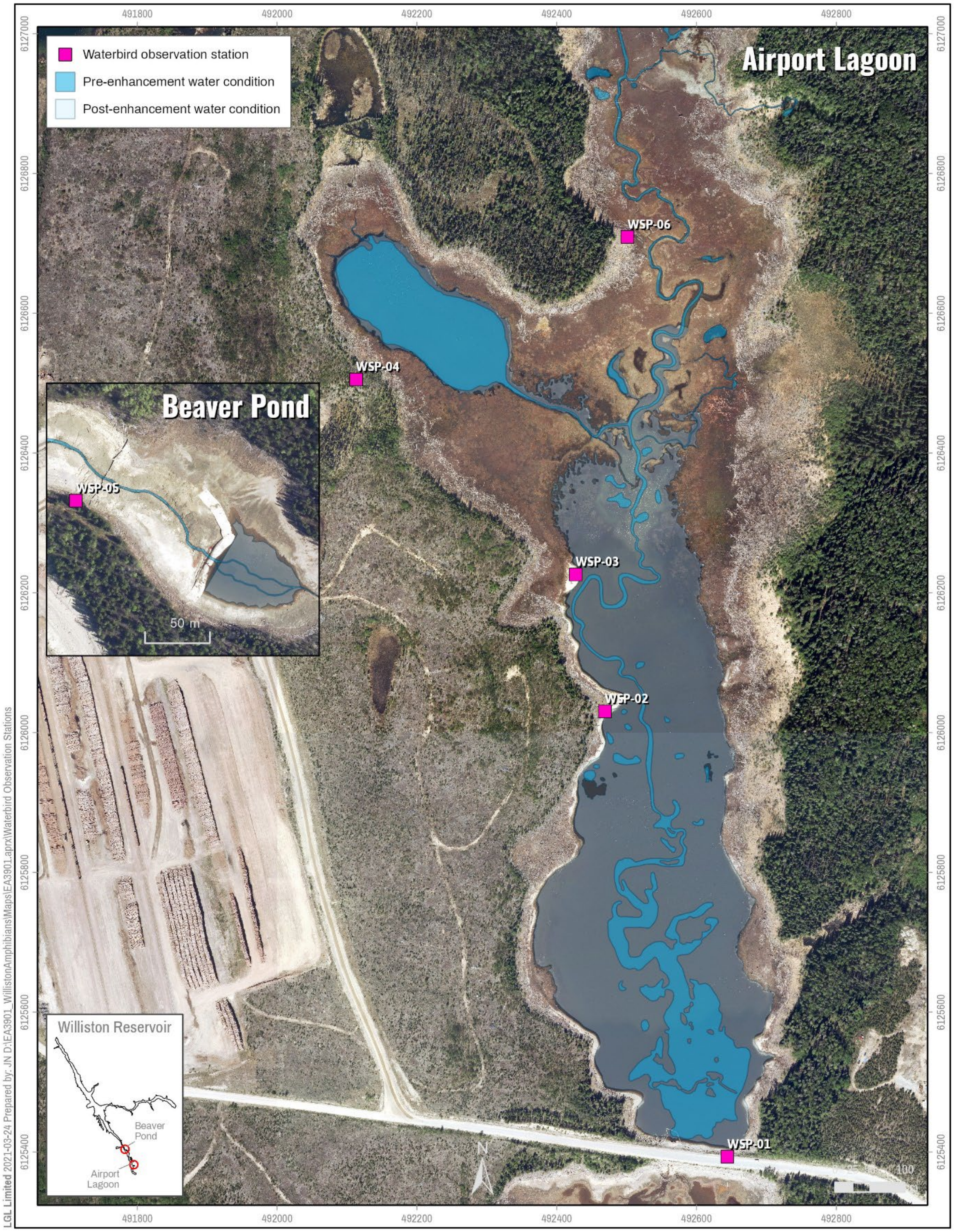

Figure 4. Waterbird and shorebird survey stations at Airport Lagoon and Beaver Pond sampled from 2011 to 2020 as part of GMSMON-15.

3.2.2 Songbird Surveys

Songbird surveys were conducted between May 30 and June 15 each year from 2011 to 2019 and followed provincial standards and established protocols (Ralph et al. 1995, RIC 1999b, Bird Studies Canada 2009). Point count surveys were conducted at 17 stations at Airport Lagoon and three stations at Beaver Pond (Figure 5) during acceptable weather conditions according to modified standards (RIC 1999b; Hentze and Cooper 2006). Surveys commenced at dawn and ended within four hours to capture the most stable song period (Ralph et al. 1995). At each station, counts were conducted for a duration of 5 minutes, during which all birds detected were recorded. Each detection was assigned to a temporal category based on the time of detection (0-3 and 3-5 minutes), and the species, sex, age, detection distance from the point count centre, direction to the bird, detection type, and habitat was recorded. Additional comments, such as breeding evidence, were also noted. Each point count station at Airport Lagoon and Beaver Pond was surveyed on three separate visits (i.e., replicates).

Due to transportation restrictions in 2020 because of the COVID-19 pandemic, point counts were not completed. Instead, acoustic autonomous recording units (ARU - Wildlife Acoustics Song Meter 4 [SM4]) were temporarily set-up at each point count station. Units were deployed at the 17 point count stations at Airport Lagoon on 15 June 2020 and collected 22 June 2020, and deployed at the three point count stations at Beaver Pond from 23 June to 07 July 2020. A single 10-minute recording was reviewed from the first hour after sunrise on two dates from each unit (June 16 and 17 for Airport Lagoon stations, and June 24 and 25 for Beaver Pond stations).

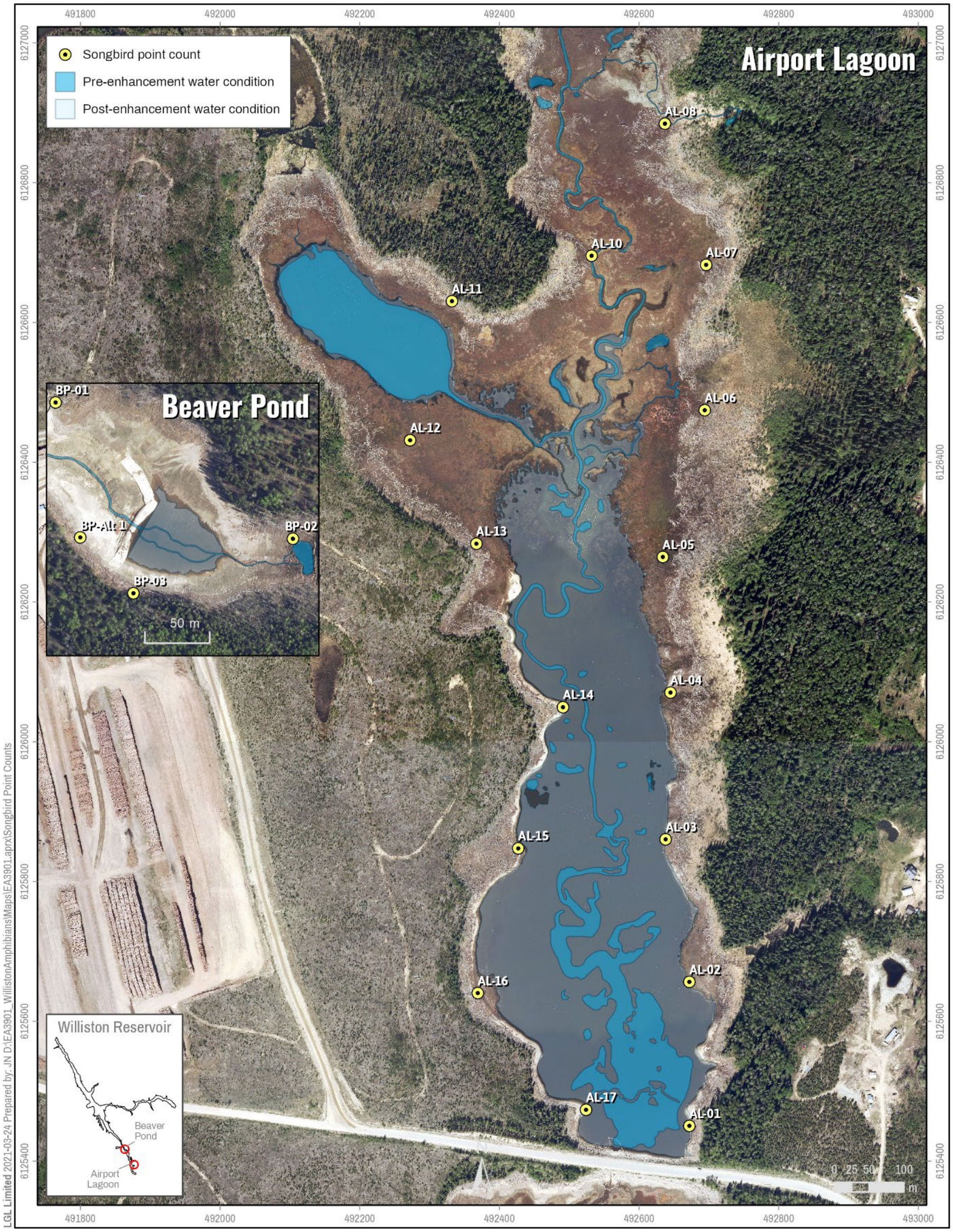

Figure 5. Songbird point count and ARU survey stations at Airport Lagoon and Beaver Pond (inset) sampled from 2011 to 2020 as part of GMSMON-15.

3.2.3 Amphibian Surveys

Systematic surveys were used to record amphibian species at both wetland sites across all years of study (RIC 1998) and allowed for the use of a single, repeatable method to provide diversity and relative abundance measures for all species detected. Amphibian surveys occurred over two to four sampling intervals (i.e., replicates) between April and June each year to coincide with the active period of amphibians (Table 2**Error! Reference source not found.**). Weather and site access constraints (e.g., ice cover on the reservoir) prevented the completion of amphibian surveys in some months in several years of study. For example, most often the April field survey was not conducted due to ice on the reservoir.

Table 2. Number of wetland site visits to Airport Lagoon and Beaver Pond in Williston Reservoir as part of GMSMON-15, 2011 to 2020.

	Airport Lagoon (11 transects)				Beaver Pond (1 transect)			
		# of Visits				# of Visits		
Year	**Phase**	Apr	May	June	**Phase**	Apr	May	June
2011	Pre		1	1	Pre			2
2012	Pre		4		Pre		1	3
2013	Pre		4	1	Pre		2	1
2014	Post		3	1	Pre		1	1
2015	Post		4		Post		2	2
2016	Post	1	3		Post	1	2	1
2017	Post		2		Post		2	
2018	Post	1	1	1	Post		1	1
2019	Post	1	2		Post		1	1
2020	Post		2	1	Post		1	1

At Airport Lagoon 11 transects distributed along the periphery of the inundated area were sampled; whereas, at Beaver Pond the entire site was considered a single transect (Figure 6). Transect start and end points (and survey tracks) were recorded using GPS units to allow for repeat surveys and for calculations of detections per unit distance. A photograph was taken at each transect start point, oriented towards the end point. Environmental conditions were recorded at the start and end of each transect.

The search area along each transect included shallow water (< 1 m deep), the shorelines, and areas within 3 m of the shoreline (ponds, streams, riparian areas). A zig-zag search pattern was applied to areas above the waterline and a linear pattern directly adjacent to the water (i.e., shoreline) to ensure complete coverage of the area. Habitat was visually scanned and in some cases a dip-net sweep was used in the shallow water zone in a standardized fashion and at a regular interval to sample amphibians. Observers on the shore and shoreline overturned pieces of woody debris and other potential cover objects to search for amphibians sheltering underneath. All pieces of woody debris and cover were returned to their original position after determining if amphibians were present. Observational data were recorded on animal observation forms modified from RIC (1998). Species, developmental stage, behavior and habitat variables were recorded for each adult, larvae and egg mass observed. Aggregations of tadpoles and metamorph amphibians were treated as a single detection and the total number of individuals was estimated.

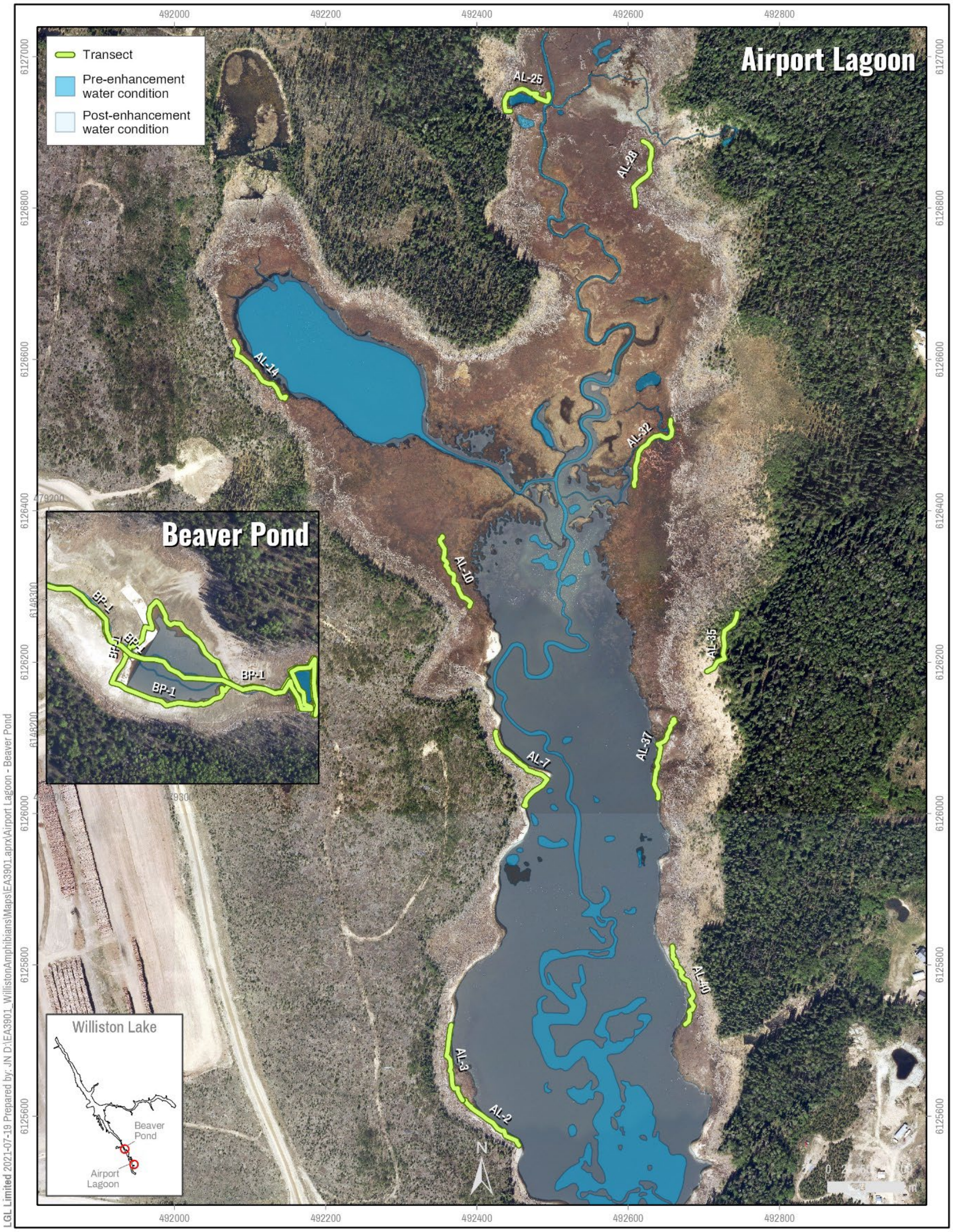

Figure 6. Amphibian survey transect locations at Airport Lagoon sampled from 2011 to 2020, Williston Reservoir.

3.3 Vegetation Surveys

A combination of habitat classification, ground sampling of terrestrial vegetation and sampling for aquatic vegetation was used to address management question #3:

> MQ-3: Is there a change in the abundance, diversity, and extent of vegetation in the enhancement area?

3.3.1 Habitat Classification

Ecological communities were originally delineated and classified at each site in 2011 using a combination of air photo interpretation and terrestrial ecosystem ground sampling (Province of British Columbia 2010, FLNRO 2011). Air photo interpretation was originally completed in 2-D softcopy using ArcGIS (version 9.3). Digital ortho-rectified 1:5000 air photos provided by BC Hydro were used as the background layer for delineating polygons (MacInnis et al. 2012). Since both sites were influenced by reservoir operations and not naturally recurring and stable wetlands, the BC wetland classification scheme (Mackenzie and Moran 2004) was not followed. Rather, habitat classes were first determined from an overview of the study area, following standard protocols (FLNRO 2011) to identify the larger vegetation features. Field notes on vegetation composition and structure from inspections of the study sites assisted with establishing the initial habitat classes based on a common plant species assemblage and elevation position within the drawdown zone (MacInnis et al. 2012).

The habitat classifications and their spatial distribution were reassessed in 2012 and 2013 and the classifications and mapping refined as additional information was collected. As result, the original 19 classes were reduced to 16 in 2013 and some of the habitat class names were revised to reflect the expected annual vegetation cover and location (MacInnis et al. 2014). A high resolution orthomosaic (5 cm pixel resolution) was provided by JR Canadian Mapping for Airport Lagoon in 2014 after construction of the enhancements at Airport Lagoon, which along with field notes on vegetation composition and structure allowed for further interpretation and updating of habitat classes (MacInnis et al. 2015). Habitat classes were refined to 12 at Airport Lagoon and six at Beaver Pond and their spatial distribution was reassessed in 2015 and 2016 (MacInnis et al. 2017).

Updated high resolution orthomosaic imagery of Airport Lagoon and Beaver Pond were obtained in May 2018 (Teri Neighbour, pers. comm.). The habitat class polygons delineated in 2014 were updated using a heads up (i.e., on screen) approach where each polygon was assessed relative to the 2018 imagery. Based on the visual comparison of 2014 to 2018, polygons delineated in 2014 were either left unchanged, modified to fit the extent of vegetation cover on the 2018 images, or deleted. Imagery interpretation was completed in QGIS (Version 3.4.1).

3.3.2 Ground Sampling of Terrestrial Vegetation

Ground sampling of terrestrial (i.e., riparian) vegetation was typically conducted in June or July along belt-transects. Sampling commenced as early as June 1 (2016) and was completed as late as July 7 (2020). Initially 10 transects were established at Airport Lagoon and five transects at Beaver Pond, but data collection for these varied throughout the program as access to transects changed as a result of water infiltration during the post-construction period and as reservoir levels fluctuated (Table 3). During post-enhancement, new transects were established in close proximity to ones that were no longer accessible.

Table 3. Ground sampling of terrestrial vegetation throughout the GMSMON-15 monitoring program.

Year	Julien date	Res. Elev.	Airport Lagoon		Beaver Pond	
			Phase	# of Transects	Phase	# of Transects
2011	171	655.418	Pre	10	Pre	5
2012	154	663.475	Pre	10	Pre	5
2013	160	665.967	Construction	7	Pre	5
2014	167	665.989	Post	9	Construction	3
2015	156	668.108	Post	8	Post	2
2016	152	667.687	Post	7	Post	3
2017	N/A	N/A	Post	N/A	Post	N/A
2018	187	666.716	Post	12	Post	5
2019	179	664.500	Post	12	Post	5
2020	188	669.691	Post	10	Post	4

Belt-transects were 20 m in length and consisted of ten 2 m by 0.5 m quadrats to allow for sub-sampling and to increase the accuracy of vegetation cover estimates. Each transect was laid out using a 30 m measuring tape and a 2 m measuring rod. Transect start and end coordinates were recorded (Figure 7), and photographs were taken at both the start and end points. Within each quadrat, all vegetation within or overhanging each quadrat was identified to species and the percent cover (vertical crown projection) of each species was visually estimated and rounded as follows: <1% - traces; 1-10% - rounded to nearest 1%; 11-30% - rounded to nearest 5%; 31-100% - rounded to nearest 10%.

Site and soil characteristics for each transect were recorded on provincial ecosystem field forms (Province of British Columbia 2010). The ground cover (per cent area) of each quadrat was apportioned among substrate classes as follows: organic matter, coarse woody debris, rock, mineral soil, and water (standing and flowing).

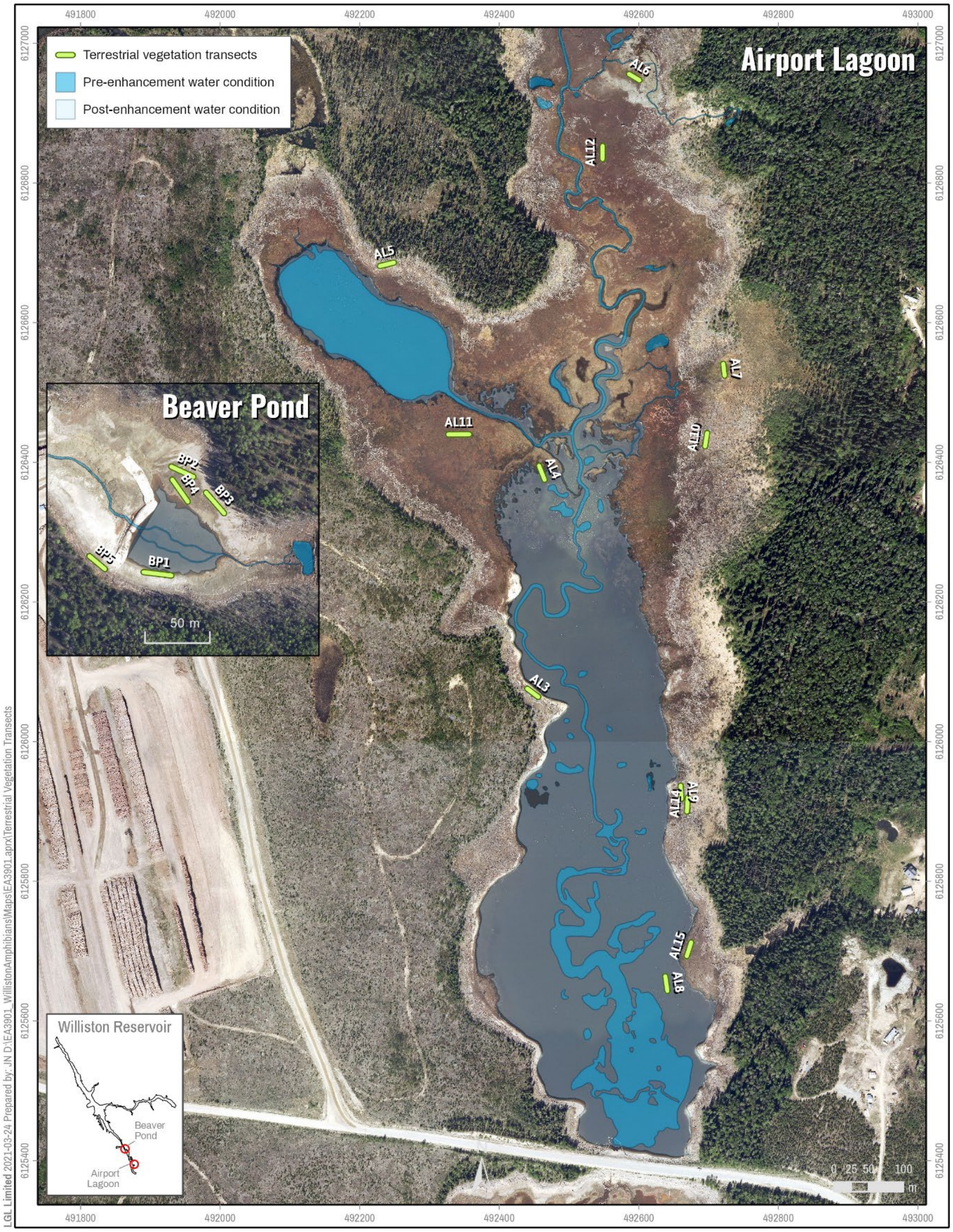

Figure 7. Terrestrial vegetation survey transect location at Airport Lagoon and Beaver Pond sampled from 2011 to 2020 for GMSMON-15.

3.3.3 Sampling of Aquatic Vegetation

Prior to the implementation of the two projects, aquatic vegetation was limited as a result of the annual drawdown of the site (Golder 2010); therefore, sampling for aquatic vegetation commenced in 2014 at Airport Lagoon and 2015 at Beaver Pond after construction of the enhancements. In 2014, 2015 and 2016, surface sampling of aquatic vegetation at Airport Lagoon included visual observations of aquatic plant cover along the shoreline and shallow water of the flooded areas (where water depth was <2 m). Benthic rake drags (i.e., using a double-headed rake attached to a rope) were also completed at select locations away from the shoreline where water depth limited visual observations of aquatic plant cover (i.e., in areas >2 m depth). At each location, the rake was dropped to the bed of the flooded area and dragged along the bed for a distance of approximately 1-3 m to collect samples. This method was repeated a total of 3 times at each location to obtain information on species composition and relative abundance.

Sampling of aquatic plants was not completed at Beaver Pond in 2014 since a reconnaissance of the site revealed no substantial cover of aquatic plants. However, surface sampling of aquatic vegetation was completed here in 2015 and 2016. Results from 2014, 2015 and 2016 were used to describe aquatic vegetation communities. Aquatic plant communities were identified and mapped along the water surface and shoreline of Airport Lagoon based on the dominant species for the community.

Sampling of aquatic vegetation in 2018, 2019 and 2020 was based on a systematic design (Hawkes et al. 2011, Miller and Hawkes 2013) using transects spaced across the wetlands at 100 m to 400 m intervals with sampling points located every 25 m to 50 m along each transect (Figure 8). Transect length and spacing varied depending on the width of the wetland and environmental conditions at the time of the survey. Geographical coordinates corresponding to the sample points were loaded into a hand-held GPS unit to facilitate navigation from point to point in the field.

Aquatic macrophyte species composition and relative abundance were recorded at each sample point using benthic rake drags. A cluster sampling approach was used in which two samples were taken at each location. The volume of each sample was estimated based on a categorical scale from 1 to 3 (Table 4). Also, each macrophyte species in the sample was assigned a relative cover class (Table 5). Water depths were measured by dropping a weighted tape measure to the bottom at each surface sample point.

Table 4. Volume classes for vegetation samples collected during the sampling of aquatic vegetation in 2018, 2019 and 2020.

Volume Class*	Sample Volume	Definition
1	Trace	Sample is restricted to one or very few strands of vegetation
2	Small	Sample fills less than half of the tines of the sampling rake
3	Large	Sample fills half or more of the tines of the sampling rake

* when a participate species was absent in a rake drag its volume class was defaulted to zero.

Table 5. Cover class for vegetation samples collected during the sampling of aquatic vegetation in 2018, 2019 and 2020.

Cover Class	Definition
T	Species is present but contributes negligibly (< 1 per cent) to the sample volume
1	Species contributes less than 10 per cent of the sample volume
2	Species contributes 11–20 per cent of the sample volume
3	Species contributes 21–50 per cent of the sample volume
4	Species contributes 51–75 per cent of the sample volume
5	Species contributes 76–100 per cent of the sample volume

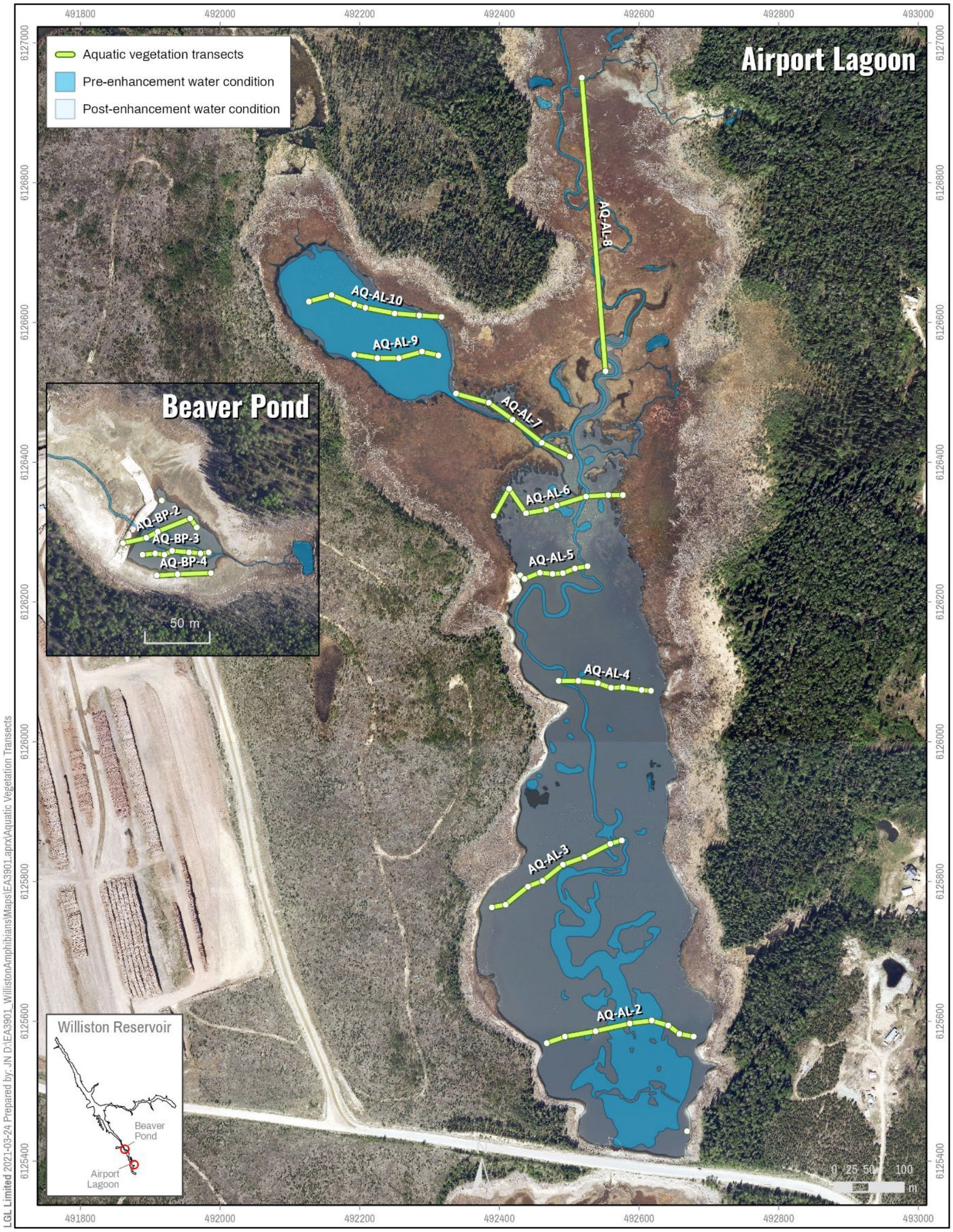

Figure 8. Example of aquatic vegetation survey transect sampled at Airport Lagoon and Beaver Pond from 2018 to 2020 for GMSMON-15. The white dots represent dredge locations.

4 DATASETS

The general study design was to collect annual data on each of the indicator groups at locations within the core area of the enhancement treatments and in peripheral riparian areas. The multi-year time-series dataset, which included data on the indicator groups both before and after the enhancements were in place, was analyzed to assess the program's management questions and hypotheses. The specific datasets used to answer the management questions for GMSMON-15 are presented in the sections below.

4.1 Dataset 1: Fish Surveys

The fish survey dataset includes the species captured, number captured, sampling type. Fish diversity and abundance (catch per unit effort [CPUE]) by wetland site (i.e., Airport Lagoon and Beaver Pond) can be summarized from this dataset. Data pooled across all years of sampling were used in most analyses and these data assisted in answering MQ-1 and MQ-4.

Fish Diversity – Over the 10-year period, fish sampling by electrofishing, minnow trapping, and fyke nets were effective methods at both sites and provided additional information on fish populations at both wetland enhancement sites. Between the two sites, the three methods of sampling resulted in the collection of 13 of 22 species known to occur in the Williston Reservoir (Table 6 to Table 8). At the Airport Lagoon, 12 fish species from five families were captured. At the Beaver Pond, six fish species from five families were captured.

The proportion of fish species captured by year at each enhancement site was tabulated. To assess fish composition and density, fish abundance data were standardized to the number of individuals per minute for electrofishing and individuals per trap hour for the minnow traps and fyke net (CPUE).

Table 6. Fish species caught during electrofishing, by year, at the Airport Lagoon and Beaver Pond sites in Williston Reservoir from 2011 to 2020.

Site	Species			Year										
	Family	Scientific name	Common name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Airport Lagoon	Catostomidae	*Catostomus catostomus*	Longnose sucker	4	1	3	1	6	3	1	7	0	NS	26
		C. commersoni	White sucker	0	0	0	0	1	0	0	0	0	NS	1
		C. macrocheilus	Largescale sucker	2	5	1	0	8	1	0	0	0	NS	17
			Unidentified sucker	0	0	0	0	1	0	0	0	0	NS	1
	Cottidae	*Cottus asper*	Prickly sculpin	22	17	25	13	3	18	0	13	5	NS	116
		C. cognatus	Slimy sculpin	0	0	1	0	0	0	0	0	0	NS	1
			Unidentified sculpin	32	3	2	0	0	97	0	0	0	NS	134
	Cyprinidae	*Couesius plumbeus*	Lake chub	49	12	127	41	66	146	15	17	49	NS	522
		Hybognathus hankinsoni	Brassy minnow	1	1	91	2	28	0	6	23	1	NS	153
		Mylocheilus caurinus	Peamouth chub	0	0	0	0	0	0	0	0	0	NS	0
		Ptychocheilus oregonensis	Northern pikeminnow	1	40	1	0	0	26	0	0	0	NS	68
		Richardsonius balteatus	Redside shiner	7	3	45	8	110	0	0	102	177	NS	452
			Unidentified minnow	0	0	0	0	0	8	0	0	0	NS	8
	Gadidae	*Lota lota*	Burbot	1	35	10	2	1	0	0	1	0	NS	50
	Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	1	1	1	0	1	0	0	0	0	NS	4
Beaver Pond	Catostomidae	*Catostomus catostomus*	Longnose sucker	4	0	3	0	0	2	0	NS	NS	NS	9
		C. commersoni	White sucker	0	0	0	0	0	0	0	NS	NS	NS	0
		C. macrocheilus	Largescale sucker	1	0	1	0	0	3	0	NS	NS	NS	5
			Unidentified sucker	43	0	53	0	2	14	0	NS	NS	NS	112
	Cottidae	*Cottus asper*	Prickly sculpin	1	0	0	0	5	7	3	NS	NS	NS	16
			Unidentified sculpin	0	0	0	0	0	0	0	NS	NS	NS	0
	Cyprinidae	*Couesius plumbeus*	Lake chub	1	0	5	0	3	0	0	NS	NS	NS	9
		Hybognathus hankinsoni	Brassy minnow	0	0	0	0	0	0	0	NS	NS	NS	0
		Mylocheilus caurinus	Peamouth chub	0	0	0	0	2	0	0	NS	NS	NS	2
		Ptychocheilus oregonensis	Northern pikeminnow	1	0	1	0	2	0	0	NS	NS	NS	4
		Richardsonius balteatus	Redside shiner	9	1	1	0	2	0	0	NS	NS	NS	13
			Unidentified minnow	0	0	0	0	0	0	0	NS	NS	NS	0
	Gadidae	*Lota lota*	Burbot	0	0	0	0	0	0	0	NS	NS	NS	0
	Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	0	0	0	0	0	0	3	NS	NS	NS	3
		Salvelinus confluentus	Bull trout	0	0	0	0	0	0	0	NS	NS	NS	0

*Note: NS = No sampling
*Note: NS = No electrfishing was conducted in 2020 due to COVID-19 restrictions.

Table 7. Fish species captured in minnow traps, by year, at the Airport Lagoon and Beaver Pond sites in Williston Reservoir from 2011 to 2020.

Site	Species			Year										
	Family	Scientific name	Common name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Airport Lagoon	Catostomidae	*Catostomus catostomus*	Longnose sucker	0	0	9	0	74	36	21	1	0	2	143
		C. commersoni	White sucker	0	0	0	62	29	6	7	7	0	0	111
		C. macrocheilus	Largescale sucker	0	2	3	37	44	10	4	0	0	0	100
			Unidentified sucker	0	0	3	285	100	0	1	0	1	0	390
	Cottidae	*Cottus asper*	Prickly sculpin	1	2	0	2	0	0	2	2	0	11	20
		C. cognatus	Slimy sculpin	1	0	0	0	0	0	0	0	0	1	2
			Unidentified sculpin	0	0	0	0	889	0	0	0	0	0	889
	Cyprinidae	*Couesius plumbeus*	Lake chub	49	12	127	884	31	168	115	162	77	37	1662
		Hybognathus hankinsoni	Brassy minnow	2	2	1123	959	0	34	12	230	5	1	2368
		Mylocheilus caurinus	Peamouth chub	0	0	0	0	12	0	1	0	0	0	13
		Ptychocheilus oregonensis	Northern pikeminnow	0	1	4	7	459	1	0	0	0	5	477
		Richardsonius balteatus	Redside shiner	4	10	8	720	0	867	227	964	439	61	3300
	Gadidae	*Lota lota*	Burbot	1	5	0	0	0	0	0	1	0	0	7
Beaver Pond	Catostomidae	*Catostomus catostomus*	Longnose sucker	4	0	3	0	0	1	0	0	0	0	8
		C. commersoni	White sucker	0	0	0	0	0	0	0	0	3	7	10
		C. macrocheilus	Largescale sucker	1	0	1	0	0	0	1	1	0	1	5
			Unidentified sucker	43	0	53	0	0	0	1	0	0	0	97
	Cottidae	*Cottus asper*	Prickly sculpin	1	0	0	0	0	6	0	0	0	1	8
		C. cognatus	Slimy sculpin	0	0	0	0	0	0	0	0	0	1	1
	Cyprinidae	*Couesius plumbeus*	Lake chub	1	0	5	0	0	0	0	1	0	0	7
		Mylocheilus caurinus	Peamouth chub	0	0	0	0	0	0	1	0	0	0	1
		Ptychocheilus oregonensis	Northern pikeminnow	1	0	1	10	0	0	0	1	1	0	14
		Richardsonius balteatus	Redside shiner	9	1	1	3	0	1	0	0	0	0	15
			Unidentified minnow	0	0	0	0	0	0	0	11	0	0	11

Table 8. Fish species caught in fyke nets, by year, at the Airport Lagoon and Beaver Pond sites in Williston Reservoir from 2011 to 2020.

Site	Species			Year										
	Family	Scientific name	Common name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Airport Lagoon	Catostomidae	*Catostomus catostomus*	Longnose sucker	1	48	5	331	6	13	25	6	55	NS	490
		C. commersoni	White sucker	0	14	0	437	64	50	161	191	73	NS	990
		C. macrocheilus	Largescale sucker	0	9	2	188	110	29	130	23	7	NS	498
			Unidentified sucker	0	0	0	620	3525	0	1	0	1	NS	4147
	Cottidae	*Cottus asper*	Prickly sculpin	0	0	0	0	5	0	1	4	29	NS	39
			Unidentified sculpin	0	0	0	0	0	8	0	465	0	NS	473
	Cyprinidae	*Couesius plumbeus*	Lake chub	0	166	268	2025	3924	2	170	480	946	NS	7981
		Hybognathus hankinsoni	Brassy minnow	0	53	213	7117	9121	1	430	6	3408	NS	20349
		Mylocheilus caurinus	Peamouth chub	0	1	0	5	0	32	9	33	2	NS	82
		Ptychocheilus oregonensis	Northern pikeminnow	2	43	22	90	76	249	8	3383	8	NS	3881
		Richardsonius balteatus	Redside shiner	0	113	192	2646	5746	0	181	0	2160	NS	11038
			Unidentified minnow	0	0	0	0	0	0	0	0	3	NS	3
	Gadidae	*Lota lota*	Burbot	1	7	0	0	0	5	0	14	0	NS	27
		Oncorhynchus mykiss	Rainbow trout	0	0	0	2	0	0	16	0	11	NS	29
	Salmonidae	*Salvelinus confluentus*	Bull trout	0	0	0	0	0	0	0	0	1	NS	1
Beaver Pond	Catostomidae	*Catostomus catostomus*	Longnose sucker	0	1	3	5	0	0	0	0	0	NS	9
		C. commersoni	White sucker	0	0	2	0	0	0	0	0	94	NS	96
		C. macrocheilus	Largescale sucker	0	1	6	5	0	0	1	0	0	NS	13
			Unidentified sucker	0	0	0	0	0	0	0	0	0	NS	0
	Cottidae	*Cottus asper*	Prickly sculpin	0	0	0	0	0	0	0	0	1	NS	1
			Unidentified sculpin	0	0	0	0	0	0	0	0	32	NS	32
	Cyprinidae	*Couesius plumbeus*	Lake chub	0	0	0	0	0	0	0	0	0	NS	0
		Hybognathus hankinsoni	Brassy minnow	0	0	0	0	0	0	0	0	0	NS	0
		Mylocheilus caurinus	Peamouth chub	10	0	54	16	0	2	0	0	0	NS	82
		Ptychocheilus oregonensis	Northern pikeminnow	4	1	38	41	0	10	2	0	0	NS	96
		Richardsonius balteatus	Redside shiner	0	0	16	11	0	0	0	0	53	NS	80
			Unidentified minnow	0	0	0	0	0	0	0	0	0	NS	0
	Gadidae	*Lota lota*	Burbot	0	0	0	0	0	1	0	0	0	NS	1
	Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	0	0	0	0	0	0	0	0	0	NS	0
		Salvelinus confluentus	Bull trout	0	1	0	0	0	0	0	0	0	NS	1

*Note: NS = No sampling.
**Note: No fyke net was deployed in 2020 due to COVID-19 restrictions

Abundance – To assess fish composition and diversity, fish abundance data were standardized to the number of individuals per minute for electrofishing and individuals per trap hour for the minnow traps and fyke net (CPUE; Table 10). In total, 61824 fish, predominantly adults, were captured, with the majority (99%; 61,063) captured in the Airport Lagoon (Appendix 2; Table 4). The fyke net captured the most fish (82%; 50,439), followed by minnow traps (16%; 9,659) and electrofishing (3%, 1,726; Table 9).

Table 9. Total fish species caught by gear type at the Airport Lagoon and Beaver Pond sites in Williston Reservoir from 2011 to 2020 (EF = electrofishing, MT = minnow trap, FN = fyke net).

Site	Species		Method			
			EF	MT	FN	
	Scientific name	Common name	Total	Total	Total	Grand Total
Airport Lagoon	*Catostomus catostomus*	Longnose sucker	26	143	490	659
	C. commersoni	White sucker	1	111	990	1102
	C. macrocheilus	Largescale sucker	17	100	498	615
		Unidentified sucker	1	390	4147	4538
	Cottus asper	Prickly sculpin	116	20	39	175
	C. cognatus	Slimy sculpin	1	2	0	3
		Unidentified sculpin	134	889	473	1496
	Couesius plumbeus	Lake chub	522	1662	7981	10165
	Hybognathus hankinsoni	Brassy minnow	153	2368	20349	22870
	Mylocheilus caurinus	Peamouth chub	0	13	82	95
	Ptychocheilus oregonensis	Northern pikeminnow	68	477	3881	4426
	Richardsonius balteatus	Redside shiner	452	3300	11038	14790
		Unidentified minnow	8	0	3	11
	Lota lota	Burbot	50	7	27	84
	Oncorhynchus mykiss	Rainbow trout	4	0	29	33
	Salvelinus confluentus	Bull trout	0	0	1	1
Beaver Pond	*Catostomus catostomus*	Longnose sucker	9	8	9	26
	C. commersoni	White sucker	0	10	96	106
	C. macrocheilus	Largescale sucker	5	5	13	23
		Unidentified sucker	112	97	0	209
	Cottus asper	Prickly sculpin	16	8	1	25
	C. cognatus	Slimy sculpin	0	1	0	1
		Unidentified sculpin	0	0	32	32
	Couesius plumbeus	Lake chub	9	7	0	16
	Hybognathus hankinsoni	Brassy minnow	0	0	0	0
	Mylocheilus caurinus	Peamouth chub	2	1	82	85
	Ptychocheilus oregonensis	Northern pikeminnow	4	14	96	114
	Richardsonius balteatus	Redside shiner	13	15	80	108
		Unidentified minnow	0	11	0	11
	Lota lota	Burbot	0	0	1	1
	Oncorhynchus mykiss	Rainbow trout	3	0	0	3
	Salvelinus confluentus	Bull trout	0	0	1	1

Size – Length measurements were collected from each of the thirteen species sampled and were pooled and compare between years for the fish species that had groups of 50 individual measurements or more. Results for the two sampling periods (May and July) were pooled.

Table 10. Effort and CPUE by year at wetland sites in Williston Reservoir from 2011 to 2020.

Site	Method		Year									
			2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Airport Lagoon	Electrofishing	Effort[a]	6500	9201	5715	2263	2142	2629	2029	1689	1714	NS
		CPUE[a]	1.1	0.8	3.2	2.8	6.3	6.9	0.9	11.6	17.3	NS
	Minnow Trap	Effort	379.58	536.62	240.27	413.41	418.6	399.11	407.25	535.3	434.5	1133.9
		CPUE	0.1	0.1	6.1	7.4	3.9	5.4	1.8	5.3	1.5	12.5
	Fyke Net	Effort	39.64	65.42	30.47	79.48	68.86	77.27	70.68	49.4	86.1	NS
		CPUE	0.1	6.9	23.0	169.4	328.0	5.4	28.4	347.9	147.7	NS
	Angling	Effort	NS	NS	NS	NS	NS	NS	NS	NS	NS	4.09
		CPUE	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0
Beaver Pond	Electrofishing	Effort	1048	897	1580	894	2843	456	1099	NS	NS	NS
		CPUE	3.4	0.1	2.4	0.0	5.1	3.4	0.3	NS	NS	NS
	Minnow Trap	Effort	129.72	133.5	150.42	176.98	NS	242.13	245.97	116	225.3	149.02
		CPUE	0.01	0.01	0.30	0.07	NS	0.1	0.04	0.1	2.3	4
	Fyke Net	Effort	21.75	22.75	17	22.83	NS	22.83	23.42	NS	19.6	NS
		CPUE	0.6	0.2	7.0	3.4	NS	0.6	0.13	NS	5.6	NS

[a]Catch per unit effort (CPUE): electrofishing CPUE = fish/minute; minnow trap and fyke net CPUE = fish/hour.
Grey shading in 2013 is the year of construction.

4.2 Dataset 2: Waterbird and Shorebird Surveys

This dataset was created to assess the abundance, richness, diversity and composition waterbird and shorebird species observed during the pre-enhancement, construction and post-enhancement periods at Airport Lagoon and Beaver Pond. A total of 49 species were observed during the monitoring program, including 35 species of waterbirds and 14 species of shorebirds (Table 11). Observations were divided into the migratory period (April-May) and the breeding period (June).

Table 11. Waterbird and shorebird species observed at Airport Lagoon and Beaver Pond between 2011 and 2020 for GMSMON-15.

Subgroup	Code	Common Name	Scientific Name	Migratory	Breeding
Shorebirds	AGPL	American Golder Plover	*Pluvialis dominica*	✔	
	GRYE	Greater Yellowlegs	*Tringa melanoleuca*	✔	✔
	KILL	Killdeer	*Charadrius vociferus*	✔	✔
	LESA	Least Sandpiper	*Calidris minutilla*	✔	
	LEYE	Lesser Yellowlegs	*Tringa flavipes*	✔	✔
	LBDO	Long-billed Dowitcher	*Limnodromus scolopaceus*	✔	
	PESA	Pectoral Sandpiper	*Calidris melanotos*	✔	
	SEPL	Semipalmated Plover	*Charadrius semipalmatus*	✔	
	SESA	Semipalmated Sandpiper	*Calidris pusilla*	✔	
	SOSA	Solitary Sandpiper	*Tringa solitaria*	✔	✔
	SPSA	Spotted Sandpiper	*Actitis macularius*	✔	✔
	WIPH	Wilson's Phalarope	*Phalaropus tricolor*	✔	

	WISN	Wilson's Snipe	*Gallinago delicata*	✔	✔
	YLEG	Yellowlegs sp.	*Tringa sp.*	✔	
Waterbirds	AMWI	American Wigeon	*Mareca americana*	✔	✔
	BAGO	Barrow's Goldeneye	*Bucephala islandica*	✔	
	BEKI	Belted Kingfisher	*Megaceryle alcyon*		✔
	BWTE	Blue-winged Teal	*Spatula discors*	✔	✔
	BOGU	Bonaparte's Gull	*Chroicocephalus philadelphia*	✔	✔
	BUFF	Bufflehead	*Bucephala albeola*	✔	
	CAGU	California Gull	*Larus californicus*	✔	
	CAGO	Canada Goose	*Branta canadensis*	✔	✔
	CANV	Canvasback	*Aythya valisineria*	✔	
	CITE	Cinnamon Teal	*Spatula cyanoptera*	✔	
	COGO	Common Goldeneye	*Bucephala clangula*	✔	
	COLO	Common Loon	*Gavia immer*	✔	✔
	COME	Common Merganser	*Mergus merganser*	✔	
	EUWI	Eurasian Wigeon	*Mareca penelope*	✔	
	GADW	Gadwall	*Mareca strepera*	✔	
	GRSC	Greater Scaup	*Aythya marila*	✔	
	GWFG	Greater White-fronted Goose	*Anser albifrons*	✔	✔
	GWTE	Green-winged Teal	*Anas crecca*	✔	✔
	GULL	Gull sp.	*Larus sp.*	✔	
	HEGU	Herring Gull	*Larus argentatus*	✔	✔
	HOME	Hooded Merganser	*Lophodytes cucullatus*	✔	
	LESC	Lesser Scaup	*Aythya affinis*	✔	
	LOON	Loon sp.	*Gavia sp.*	✔	
	MALL	Mallard	*Anas platyrhynchos*	✔	✔
	NOPI	Northern Pintail	*Anas acuta*	✔	✔
	NOSH	Northern Shoveler	*Spatula clypeata*	✔	✔
	RBME	Red-breasted Merganser	*Mergus serrator*		✔
	REDH	Redhead	*Aythya americana*	✔	
	RNGR	Red-necked Grebe	*Podiceps grisegena*	✔	
	RBGU	Ringed-billed Gull	*Larus delawarensis*	✔	✔
	RNDU	Ringed-necked Duck	*Aythya collaris*	✔	✔
	SACR	Sandhill Crane	*Antigone canadensis*	✔	✔
	SUSC	Surf Scoter	*Melanitta perspicillata*	✔	
	TRUS	Trumpeter Swan	*Cygnus buccinator*	✔	✔
	TUSW	Tundra Swan	*Cygnus columbianus*		✔

4.3 Dataset 3: Songbird Surveys

This dataset was created to summarize the species abundance, composition, and habitat associations of songbird species in enhancement areas by site (Airport Lagoon and Beaver Pond) and during the pre-enhancement, construction, and post-enhancement periods. A total of 64 songbird species (including hummingbirds and woodpeckers) were observed during the monitoring program within the constrained dataset (see below), including 63 species at Airport Lagoon over 17 point count stations and 35 species at Beaver Pond over three point count stations.

Point count station observations were the most granular unit of songbird data collection within each enhancement site; however, these data collected at fixed stations (n = 17 at Airport Lagoon, and n = 3 at Beaver Pond) were nested within survey occasion (3 surveys per year at each site), and surveys were nested within year (n = 10 years). Point count data were constrained to passerine (i.e., "songbirds"), hummingbird and woodpecker detections. Hereafter the term "songbird" is used for this whole grouping for ease of communication, while acknowledging that it is taxonomically incorrect. Birds detected flying over a station were excluded from the dataset, as these individuals were not utilizing the treatment area, with the exception of swallows and hummingbirds. Swallows were included as fly-overs as their foraging over the point count area could be related to wetland habitat enhancement. Point count data were further constrained to only observations within 75 m of the point count centre. This was to ensure that only individuals more closely associated with wetland enhancement were included and to ensure consistency among all years of data collection.

Table 12. Number of point count stations surveyed during all visits to Airport Lagoon and Beaver Pond in Williston Reservoir as part of GMSMON-15, 2011 to 2020.

	Airport Lagoon (17 point count stations)	# of Point Counts Surveyed / Visit			Beaver Pond (3 point count stations)	# of Point Counts Surveyed / Visit		
Year	**Phase**	1	2	3	**Phase**	1	2	3
2011	Pre	17	17	17	Pre	3	3	3
2012	Pre	17	16	17	Pre	3	3	3
2013	Construction	17	16	17	Pre	3	3	3
2014	Post	17	17	17	Construction	3	3	3
2015	Post	17	17	17	Post	3	3	3
2016	Post	17	17	15	Post	2	2	2
2017	Post	17	17	17	Post	2	2	2
2018	Post	17	17	17	Post	3	0	0
2019	Post	17	17	17	Post	3	3	3
2020*	Post	17	17	17	Post	3	3	0

*Surveys in 2020 were done by Autonomous Recording Unit

4.4 Dataset 4: Songbird ARU Surveys

This dataset was created to summarize the species composition and richness of songbird species at the point count stations during the 2020 sampling year when site visits were limited due to the COVID-19 pandemic. Autonomous recording units (ARUs) were established near all of the point count stations at Airport Lagoon (17 ARUs) and Beaver Pond (3 ARUs). A total of 62 bird species were recorded from ARU recordings, with 50 of those being songbirds (including hummingbirds and woodpeckers).

Songbird data were summarized based on the ARU as the basic sampling unit within each enhancement site. For data processing and analysis, ARU recordings were constrained to two 10-minute recordings per ARU, from within the first hour after sunrise on two separate dates within the same breeding bird period as sampled during point counts. ARU data cannot be analysed in the same way as point count data were, given that details such as the number of individuals, birds that are flying over, distance, or non-visual detections can be surmised.

4.5 Dataset 5: Amphibian Surveys

This dataset was created to summarize the presence–absence (i.e., detection or non-detection) of amphibian species by wetland site (i.e., Airport Lagoon and Beaver Pond). Data pooled across all years of sampling were used in most analyses and these data assisted in answering MQ-2. From this dataset, several measures were extracted, including species-specific site presence, species richness, species diversity, and abundance and detection rates (catch per unit effort [CPUE]). This dataset was also used to examine differences in amphibian abundance and occupancy between pre-enhancement and post-enhancement years.

Site Presence – For the purposes of this report, site presence (i.e., occupancy) was defined simply as the location where amphibians were documented during each year of study (i.e., the naïve occupancy rate; MacKenzie et al. 2006). Likewise, detection probabilities were not calculated. This dataset contained 64 surveys at the two wetland sites during which 549 detections across multiple life stages of four species were made. In total ~200,400 amphibians were observed, including 32 egg masses, ~200,000 tadpoles, ~200 metamorphs or juveniles, and 237 adults of the four amphibian species (not including unidentified amphibians; n = 18; Table 13). Approximately 106 hours were spent over 64 days surveying the study sites between April and June 2011 to 2020 (Table 14).

Table 13. Summary of amphibian raw observation data by life stage at wetland sites in Williston Reservoir from 2011 to 2020. A-AMMA = Long-toed Salamander, A-ANBO = Western Toad, A-LISY = Wood Frog, A-RALU = Columbia Spotted Frog, UNKN = unknown amphibian species, (#) = aggregations of tadpoles were recorded as single detection.

Site	Species	Life Stage				Total
		Egg Mass	Tadpole / Larvae	Juvenile	Adult	
Airport Lagoon	A-AMMA	7			7	14
	A-ANBO		4608 (18)	52	136	4796 (206)
	A-LISY		100 (1)		1	101 (2)
	A-RALU		10 (1)		3	13 (4)
	UNKN		5		1	6
Beaver Pond	A-AMMA	18	1		21	40
	A-ANBO	7	194996 (66)	132	43	195178 (247)
	A-LISY			6	23	29
	UNKN		23 (6)	4	2	29 (12)
Airport Lagoon		7	4723 (20)	52	148	4930 (227)
Beaver Pond		25	195020 (72)	142	89	195276 (328)
Total		**32**	**199743 (92)**	**194**	**237**	**200206**

Table 14. Survey effort (hours, days) by year and month and the number of days at wetland sites in Williston Reservoir from 2011 to 2020. Year of enhancement = light grey rows.

Site	Year	Survey Effort (hrs; [Number of Days])			Total	
		April	May	June	Hours	Days
Airport Lagoon	2011	0	1.42 (1)	3.70 (1)	5.12	2
	2012	0	9.45 (4)	0	9.45	4
	2013	0	6.63 (4)	2.67 (1)	9.30	5
	2014	0	6.98 (3)	1.92 (1)	8.90	4
	2015	0	8.75 (4)	0	8.75	4
	2016	1.50 (1)	5.78 (3)	0	7.28	4
	2017	0	4.02 (3)	0	4.02	3
	2018	2.40 (1)	2.80 (1)	2.68 (1)	7.88	3
	2019	2.33 (1)	3.35 (2)	3.27 (2)	8.95	5
	2020	0	5.95 (2)	3.07 (1)	9.02	3
	Total	6.23 (3)	55.13 (27)	17.31 (7)	78.67	37
Beaver Pond	2011	0	0.83 (1)	0.38 (1)	1.21	2
	2012	0	1.15 (1)	1.88 (3)	3.03	4
	2013	0	2.28 (2)	0.7 (1)	2.98	3
	2014	0	1.23 (1)	1.75 (1)	2.98	2
	2015	0	2.83 (2)	1.55 (2)	4.38	4
	2016	0.8 (1)	1.42 (1)	2.12 (2)	4.34	4
	2017	0	1.62 (2)	0	1.62	2
	2018	0	0.5 (1)	0.5 (1)	1	2
	2019	0	0.97 (1)	1.43 (1)	2.4	2
	2020	0	1.58 (1)	1.85 (1)	3.43	2
	Total	0.8 (1)	14.41 (13)	12.16 (13)	27.37	27

Diversity – Annual differences in species richness, diversity, and evenness were assessed. Species richness was defined as the number of species of amphibians recorded at each site. Species diversity and evenness were computed as Shannon's Entropy and corresponded to a measure of species composition, combining both the number of species and their relative abundances (Legendre and Legendre 1998). For each wetland site, diversity was computed as:

$$\sum_i p_i \log \frac{1}{p_i}.$$

where p_i is the relative proportion of species *i*.

A value of 0 means that the sampling unit contained only one species; species diversity then increases along with the number of species recorded in the sampling unit. A high value of species diversity means that many species were recorded.

Abundance and detection rates – The abundance of amphibians by species, wetland site, and year was assessed. To assess species-by-site relationships, all life stages were pooled, and species observations were examined to identify sites where the detection of a given species was the highest regardless of age class. Clusters of egg masses and aggregations of tadpoles or metamorphs were treated as a single observation per location, so as not to skew numbers. For example, estimates of 199,743 tadpoles were observed; however, when these tadpole aggregations were treated as single detections, the number of times tadpoles were observed was 98. We analyzed abundance through the calculation of detection rates. We calculated detection rates for each amphibian species at each monitoring site by dividing the number of observations per site and per species by survey effort in hours. Survey effort was calculated as the number of hours surveyed multiplied by the number of surveyors conducting the survey. Mean detection rates were calculated for each site (pooling data from all years) and by year.

4.6 Dataset 6: Habitat Classification

This dataset was comprised of habitat class descriptions, their spatial extent and area of coverage from data collected in 2011 (pre-enhancements), 2014 (post-enhancements), and 2018 (latter years of monitoring program). As GMSMON-15 progressed, updates to habitat classes were noted, which included the identification of new classes or the merging of two or more habitat classes into a new class. The original habitat classes defined in 2011 were reviewed and updated to ensure consistency of the description of habitat classes across the three years in this dataset.

One habitat class (floating island) that was added in 2014 was excluded from this dataset since it only accounted for <0.1% of the habitat coverage and decreased in size in subsequent years until it was no longer evident in 2018. The total area of and spatial extent habitat classes was compared across years (Table 15).

Table 15. Area and proportion of habitat classes at Airport Lagoon and Beaver Pond measured at time series intervals during the GMSMON-15 monitoring period.

			2011		2014		2018	
Airport Lagoon	Code	Habitat Classification	Area (ha)	%	Area (ha)	%	Area (ha)	%
	BM	Basin Moss (Cattail Thread Rush, Cinquefoil Moss, Cinquefoil Fireweed)	30.13	45.5%	17.98	27.6%	14.58	22.3%
	BS	Basin Smartweed (Smartweed Moss)	4.03	6.1%	4.82	7.4%	3.06	4.7%
	SD	Shoreline Driftwood	16	24.2%	8.08	12.4%	10.99	16.8%
	SG	Shoreline Grassland	-	-	0.43	0.7%	2.19	3.4%
	SP	Streams and Ponds	7.28	11.0%	26.1	40.1%	27.02	41.3%
	SS	Shoreline Sand	0.74	1.1%	1.18	1.8%	0.72	1.1%
	SW	Shoreline Willow	2.94	4.4%	3.63	5.6%	3.91	6.0%
	WD	Wetland Dead Trees	0.45	0.7%	0.17	0.3%	0.17	0.3%
	WH	Wetland Horsetail	1.97	3.0%	0.75	1.2%	0.75	1.1%
	WS	Wetland Sedge	1.54	2.3%	1.06	1.6%	1.06	1.6%
	WW	Wetland Willow	1.1	1.7%	0.92	1.4%	0.92	1.4%
			66.18	*100.0%*	*65.12*	*100.0%*	*65.37*	*100.0%*
			2011		2014		2018	
Beaver Pond	Code	Habitat Classification	Area (ha)	%	Area (ha)	%	Area (ha)	%
	BC	Basin Cryptantha (Cryptantha Speedwell, Cinquefoil Bluegrass)	1.7	38.7%	1.32	32.0%	1.18	27.5%
	SC	Shoreline Clay (Shoreline Cinquefoil)	1.25	28.5%	1.6	38.7%	1.62	37.8%
	SE	Stream Sedge (Stream Bluejoint)	0.32	7.3%	0.04	1.0%	0.01	0.2%
	SR	Shoreline Gravel	0.15	3.4%	0.07	1.7%	0.15	3.5%
	SP	Streams and Ponds	0.03	0.7%	0.15	3.6%	0.38	8.9%
	SW	Shoreline Willow	0.94	21.4%	0.95	23.0%	0.95	22.1%
			4.39	*100.0%*	*4.13*	*100.0%*	*4.29*	*100.0%*

4.7 Dataset 7: Terrestrial Vegetation

The terrestrial vegetation dataset was the compiled presence/not detected data of observed vegetation species that was used to measure diversity and abundance using the average percent cover of terrestrial vegetation species across the 10 quadrats in each transect. These averages were used to calculate an average per cent cover by vegetation layer (e.g., moss, herb, shrub, tree) for each transect during each year of the monitoring program (Table 16). In summary, this dataset was comprised of 1259 records for 130 individual species.

Table 16. Compiled data from multiple transects was used to measure the diversity and abundance of terrestrial vegetation species at Airport Lagoon and Beaver Pond throughout the monitoring program.

	Airport Lagoon		Beaver Pond	
Year	Phase	Number of Transects	Phase	Number of Transects
2011	Pre	10	Pre	5
2012	Pre	10	Pre	5
2013	Construction	7	Pre	5
2014	Post	9	Construction	3
2015	Post	8	Post	2
2016	Post	7	Post	3
2017	Post	-	Post	-
2018	Post	12	Post	5
2019	Post	12	Post	5
2020	Post	10	Post	4

Differences in cover and species richness by vegetation layer were assessed with general linear mixed models, which included a fixed factor for period (before, during, and after enhancements) and a random effect for transect, to account for the repeated-measure nature of the data. A magnitude of effect was computed, using principal component ordination and multivariate regression trees, to show how much more or less vegetation cover and richness was present in the construction and post-enhancement period compared to vegetation cover in the pre-enhancement period.

4.8 Dataset 8: Aquatic Vegetation

Quantitative data on aquatic plant communities at Airport Lagoon, in terms of area (ha) and percent coverage, was provided for 2014 – 2016 (Table 17). During these years, species composition and relative abundance of aquatic vegetation was based on dredge point data. However, while dredge locations were presented on maps in the annual reports, coordinates and water depth data were not provided, so the analysis was limited to a qualitative description of species occurrence and distribution at Airport Lagoon. No cover of aquatic plants was documented at Beaver Pond in 2015 and 2016; therefore, analysis is limited to the data collected from 2018 to 2020 at this site.

Table 17. Aquatic plant communities documented at Airport Lagoon between 2014 and 2016.

Aquatic Plant Community	2014		2015		2016	
	ha	%	ha	%	ha	%
Closed-leaved Potamogeton / Fennel-leaved Pondweed	9.29	33.12	12.24	43.63	12.24	43.63
Lady's Thumb / Water Smartweed	5.41	19.29	4.43	15.81	4.43	15.81
Water Smartweed	0.06	0.21	0.94	3.35	0.94	3.35
Common Hornwort	2.86	10.12	2.86	10.2	2.86	10.2
Non-aquatic	10.43	37.19	7.58	27.02	7.58	27.02

From 2014 to 2020, aquatic macrophyte frequency (defined as the proportion of sample plots in which a species or group of species was detected) was compared across each year at Airport Lagoon (Table 18). Macrophyte frequency (a proxy for overall cover) was calculated as the number of sample points in which a species was detected divided by the total number of sample points.

Table 18. Frequency (%) of aquatic macrophyte species detected in random samples (rake grabs) at Airport Lagoon from 2014 to 2020.

Scientific Name	Common Name	2014	2015	2016	2018	2019	2020
Callitriche palustris	spring water-starwort	-	-	27.3%	3.2%	-	-
Ceratophyllum demersum	common hornwort	36.4%	-	54.5%	45.2%	28.3%	-
Chara sp.	stonewort		18.2%	36.4%	4.8%	13.3%	91.7%
Drepanocladus aduncus	common hook moss	45.5%	81.8%	72.7%	56.5%	36.7%	-
Hippuris vulgaris	common mare's tail	-	-	9.1%	1.6%	1.7%	-
Myriophyllum sibiricum	verticillate water-milfoil	-	9.1%	36.4%	64.5%	80.0%	-
Najas flexilis	wavy water nymph	-	9.1%	-	-	-	-
Persicaria maculosa	lady's thumb	-	-	-	3.2%	-	-
Potamogeton foliosus	closed-leaved potamogeton	-	36.4%	90.9%	45.2%	25.0%	53.3%
Potamogeton praelongus	long-stalked potamogeton	9.1%	-	18.2%	17.4%	11.7%	23.3%
Ranunculus aquatilis	white water-buttercup	-	-	-	1.6%	10.0%	-
Sparganium sp.	bur-reed	-	-	-	1.6%	-	-
Stuckenia pectinata	fennel-leaved pondweed	27.3%	27.3%	-	-	36.7%	-
Utricularia macrorhiza	common bladderwort	-	-	18.2%	21.0%	-	-
Utricularia spp.	bladderwort	9.1%	-	-	3.2%	-	-

From 2018 to 2020, macrophyte density was estimated for each species and sample point as volume multiplied by relative cover (Miller and Hawkes 2013). Volume classes ranged from 1 through 3, and relative abundance classes ranged from 0.1 (for trace) to 1 through 5 (Table 4, Table 5). For each sample point, the values were averaged across two rake grabs. Thus, the minimum possible volume value was 0.5 and the minimum possible relative cover value was 0.05. The minimum possible (non-zero) value for the volume x cover metric was then 0.5 x 0.05 = 0.025, and the maximum possible value for the volume x cover metric was 3 x 5 = 15.

A total of 14 species and 2 taxa, identified only to genus, were included in the dataset for the last three years of the monitoring program. For this dataset, changes in density of aquatic species (volume x abundance) per species and changes in richness were examined. The relationship between total density, water depths and years for both sites and all species were analyzed with principal component ordination and multivariate regression trees.

5 Management Questions

Below, we summarize our overarching responses to each MQ as per the Terms of Reference (BC Hydro 2008). Cumulative data analysis, conducted after the final monitoring year (2020), was primarily used to support each management question. Original analysis of the various dataset is included in the appendices. In addition to providing information relevant for addressing each MQ, we discuss methodological challenges, associated knowledge gaps, and opportunities for future monitoring.

5.1 MQ-1: Are the enhanced (or newly created) wetlands used by fish?

Both enhanced wetland site at Airport Lagoon and Beaver Pond were being used by fish. During the 10-year study period, fish were consistently captured both pre (2011 to 2012) and post (2013 to 2020) construction of enhanced wetlands. Fish were captured by electrofishing, minnow trapping, and fyke nets at both wetlands during each year of the study at both enhancement site (Table 6 to Table 9; Appendix 2). Species composition was relatively consistent across monitoring years. The three sampling methods employed resulted in the collection of 13 of 22 species known to occur in the Williston reservoir. Fish species diversity remained high at both sites from 2011 to 2020 (up to 13 species from five families). A higher diversity of fish and CPUE was evident after the enhancement works were completed, which indicates that fish species were utilizing and benefiting from the enhanced habitat. This was especially evident at Airport Lagoon where water levels were more stable compared to the conditions at Beaver Pond.

Airport Lagoon

Twelve fish species from five families were captured and 99% of all fish sampled for GMSMON-15 were captured at Airport Lagoon (Table 9; Appendix 2). Minnows dominated catches, followed by suckers (*Catostomidae*), prickly sculpin (*Cottus asper*), and burbot (*Lota lota*). The most abundant fish species caught was brassy minnow (*Hybognathus hankinsoni*). The proportion of fish species varied between years. In 2013, the highest proportion of brassy minnow were captured in Airport Lagoon; however, there was an increase in the proportion of redside shiner (*Richardsonius balteatus*) captured at the Airport Lagoon in the latter years of the program.

The CPUE for fyke netting was the highest amongst all sampling methods. However, the CPUE varied between years. The CPUE from electrofishing and minnow trapping tended to increase throughout the monitoring program and particularly in the post-enhancement period (Figure 4 in Appendix 2).

Beaver Pond

At Beaver Pond, six fish species from five families were captured. In total, 749 fish were captured, with the highest catch rate occurring in 2019 (n = 184). Fyke nets captured the most (59%; n = 408) fish, followed by the minnow traps and then electrofishing. Suckers dominated catches, followed by minnows, prickly sculpin, bull trout (*Salvelinus confluentus*) and burbot. The most abundant fish species caught at the Beaver Pond was the northern pikeminnow (*Ptychocheilus oregonensis*).

The proportion of fish species varied between years. In 2014, the highest proportion of prickly sculpin were captured. The CPUE for electrofishing was the highest amongst all sampling methods. The highest CPUE's for fyke nets and minnow traps occurred in 2013 and 2019, respectively.

5.1.1 Challenges and Opportunities

Due to some of the limitations of the sampling gear (i.e., minnow trap opening) and fish species life histories (i.e., size range, habitat preferences) it was possible that there were biases in species size and composition. Williston Reservoir is dynamic waterbody, with water level fluctuations, therefore an increase or decrease in fish species diversity and abundance can occur that is not directly related to increased spawning and survival or die off. An increase or decrease in fish species diversity and abundance may be due to the introduction or removal of fish into or out of the enhancement sites during the fluctuating water levels.

Fluctuating water levels also affects sampling procedures in certain years, particularly at Beaver Pond. Low water levels during some sampling events prohibited the use of the fyke net; therefore, data from those years was solely based on captures from electrofishing and minnow trapping. Likewise, sampling in 2020 was impacted by the COVID-19 pandemic. During this year, electrofishing, and deployment of fyke nets was not conducted due to the risk of field staff not being able to maintain physical distancing guidelines. Minnow traps were predominantly used in 2020; although, angling was also performed but 2020 was the only year angling was conducted.

Despite these challenges, the dataset allowed for a fulsome multiyear analysis for each site. There was enough data collected on fish species at Airport Lagoon and Beaver Pond to address the management question.

5.2 MQ-2: Are the enhanced (or newly created) wetlands used by waterfowl and other wildlife?

Waterfowl and other wildlife consistently used the newly created wetlands that were monitored under GMSMON-15. The key changes noted for the wildlife indicator groups are summarized in the sections below. In addition to these species groups, incidental observation of other wildlife species were recorded over the course of the monitoring program and included species such as moose (*Alces americanus*), black bear (*Ursus americanus*), river otter (*Lontra canadensis*), red fox (*Vulpes vulpes*) and coyote (*Canis latrans*).

5.2.1 Waterbirds and shorebirds

Both the enhanced wetland sites were used by waterbirds and shorebirds during the migratory and breeding periods. Species richness of waterbirds and shorebirds was generally higher at Airport Lagoon in the post-enhancement period compared with baseline conditions; although survey effort the post-enhancement period was completed over seven years compared to the three years in the pre-enhancement period. This longer monitoring period likely allowed for capturing greater annual variation in species occurrences, which may have influenced the higher species richness. However, this longer time series provided stronger evidence of waterbird and shorebird species use of the enhanced sites where there was no suitable habitat prior to enhancement. The data also showed higher occurrence of waterbirds and shorebirds during the migratory period, so it appeared the enhanced habitats at Airport Lagoon were being used by several species as a stopover site.

There was a diverse mix of waterfowl species using Airport Lagoon post-enhancement, including dabbling ducks, diving ducks, geese, and swans. Other water-associated birds were predominantly recorded during the post-enhancement period. Upon closer examination, more birds were using the northern sections of Airport Lagoon. The water depths at the northern end of Airport Lagoon were typically shallower and there were likely better foraging opportunities for birds here. Riparian and aquatic vegetation were more prolific here compared to the southern areas where there was more coarse woody debris and shoreline sand (see Section 5.3.1 and Appendix 7). The northern sections were also typically ice-free earlier that other sections of the site during the migration period. Ice cover was recorded during several surveys in late April, but during these surveys sections of open water were present in the northern section where birds were observed.

Construction of the berm at Beaver Pond resulted in more water being impounded compared to the pre-enhancement condition, where the water feature was limited to a drainage channel. It was clear from the monitoring program that waterbirds and shorebirds were using this enhanced site, but the occurrence of species within these subgroups was relatively lower compared to what was observed at Airport Lagoon. This is likely a reflection of the size of the impounded area at Beaver Pond and the lower habitat complexity, compared to Airport Lagoon.

Like Airport Lagoon, more waterbirds and shorebirds appeared to be using Beaver Pond during migration. Despite higher numbers of birds using the enhanced wetland during migration, confirmed breeding was recorded at Airport Lagoon. Breeding records were limited to 1-3 observations per year, except for 2014, 2015 and 2016 when no breeding observations were recorded. Confirmed breeding was determined based on observations of birds on the nest and by the presence of broods. Breeding species included Bonaparte's Gull (*Chroicocephalus philadelphia*), Canada Goose (*Branta canadensis*), Common Loon (*Gavia immer*), Northern Shoveler (*Spatula clypeata*), Trumpeter Swan (*Cygnus buccinator*) and Tundra Swan (*Cygnus columbianus*)[1]. Breeding of waterbirds and shorebirds at Beaver Pond was not confirmed; although, there were similarities in the total number of birds observed here between the migratory and breeding periods, suggesting that birds were consistently present and likely breeding in the area.

5.2.2 Songbirds

A total of 64 songbird (including hummingbirds and woodpeckers) species were observed during the monitoring program within 75 m of a point count centre (,). This included 63 species at Airport Lagoon over 17 point count stations and 35 species at Beaver Pond over three point count stations. Frequently detected species at Airport Lagoon included Tree Swallow (*Tachycineta bicolor*), Lincoln's Sparrow (*Melospiza lincolnii*), American Robin (*Turdus*

[1] Since there are no past breeding records for this species in British Columbia, it is expected this is a mis-identification and was likely a Trumpeter Swan.

migratorius) and Dark-eyed Junco (*Junco hyemalis*). Of these, only the Tree Swallow, as an aerial insectivore, might be expected to benefit from wetland enhancement. There was no obvious trend in overall species composition or abundance in the pre- and post-enhancement periods for songbirds at Airport Lagoon. Vegetation characteristics explained only a small amount (9%) of variation in species composition, though species composition of drawdown zone habitats did cluster distinctly from shrub and forest habitats. Overall, there was no direct linkage (either an increase or decrease) between wetland enhancement and overall songbird species richness and total abundance.

At Beaver Pond the most frequently detected species were American Redstart (*Setophaga ruticilla*), Warbling Vireo (*Vireo gilvus*), Orange-crowned Warbler (*Leiothlypis celata*), and Yellow-rumped Warbler (*Setophaga coronate*). These are all forest and shrub-associated species which may benefit from wetland enhancement only if shrubby vegetation (e.g., willows) is increased around the wetland edges. There was no obvious trend in overall species composition or abundance in the pre- and post-enhancement periods for songbirds at Beaver Pond. Vegetation characteristics explained only a small amount (9%) of variation in species composition, though species composition of forest habitats did cluster distinctly from shrub and drawdown zone habitats. Overall, there was no direct linkage (either an increase or decrease) between wetland enhancement and overall songbird species richness and total abundance.

At both locations, it has been demonstrated that songbirds are using the enhancement area, based on observations of birds within the drawdown zone of the reservoir. However, wetland enhancement does not seem to have had an impact on overall richness or abundance. Songbirds were not the focus of this enhancement work, perhaps contributing to this neutral result.

5.2.3 Amphibians

Since the inception of GMSMON-15, four species of amphibians were detected at the wetland enhancement sites: Western Toad (*Anaxyrus boreas*), Wood Frog (*Lithobates sylvaticus*), Columbia Spotted Frog (*Rana luteiventris*), and Long-toed Salamander (*Ambystoma macrodactylum*). All four species breed in ponds. Western Toad was by far the most encountered amphibian at both sites across all study years (83% of all detections; Appendix 6). Overall, the amphibian survey results were generally consistent with other inventory work that has been completed in the area (Hengeveld 2000; Hawkes et al. 2006), showing the same species assemblages across the region.

Overall, Airport Lagoon had 41% of the individual detections and the highest species richness (n = 4), although not all species were consistently observed across the years (e.g., Wood Frog detected only in 2011 and 2016). Western Toad was the most abundant species (91% of all detections), with tadpoles, metamorphs and adults observed in multiple years. Breeding was confirmed in Airport Lagoon for all amphibian species by observations of egg masses, tadpoles/larvae, or metamorphs. The most productive area for amphibians at Airport Lagoon appeared to be transects AL-25 and AL-28 in the northeastern section of the enhanced wetland area (Figure 9), although observations of Western Toads were made at 10 of the 11 transects.

Despite being a smaller site and having only one survey transect, Beaver Pond had 59% of the individual detections over the 10 years, but only three species were observed. Similar to Airport Lagoon, Western Toad was the most abundant species (78% of all detections), with all life stages observed in multiple years (Figure 10). Beaver Pond showed a greater consistency of species diversity across the years as three species were typically detected there, whereas Airport Lagoon had several years where only one species was detected (e.g., Western Toad in 2017, 2018, and 2020), thereby reducing diversity values. Amphibian abundances (detection rates) varied from year to year and by species, with the highest overall detection rates occurring in 2014 at Airport Lagoon and 2015 at Beaver Pond for Western Toad followed by Long-toed Salamander (Appendix 6). Both of these years were immediately following construction (Figure 11), and in general post-enhancement surveys recorded higher numbers of Western Toad than in the pre-enhancement surveys at both sites. There were no other consistent patterns in other amphibian species detection rates by year, site, or enhancement condition.

Columbia Spotted Frog and Wood Frog are widely distributed in northern B.C., although to a lesser extent than Western Toad. Both species were observed during this study with Wood Frog detected at both sites and Columbia Spotted Frog only at Airport Lagoon. Adult Wood Frog individuals were observed on multiple occasions at Beaver Pond and one individual was noted at Airport Lagoon. The only evidence of breeding in this species was a single tadpole was documented at AL-25. Long-toed Salamanders were present at both wetland areas, with BP-1 having the most observations (n = 40). Most observations were of adults and egg masses: 18 egg masses were observed at Beaver Pond and six egg masses on transect AL-25 at Airport Lagoon.

Amphibian populations (e.g., abundance, productivity) are known to vary considerably from year to year (RIC 1998, US EPA 2002); therefore, species with only a few detections in this study (e.g., Columbia Spotted Frog, Wood Frog) would require further study to confirm its long-term occupancy of the sites and summarize life history information (e.g., productivity, foraging habits, overwintering sites).

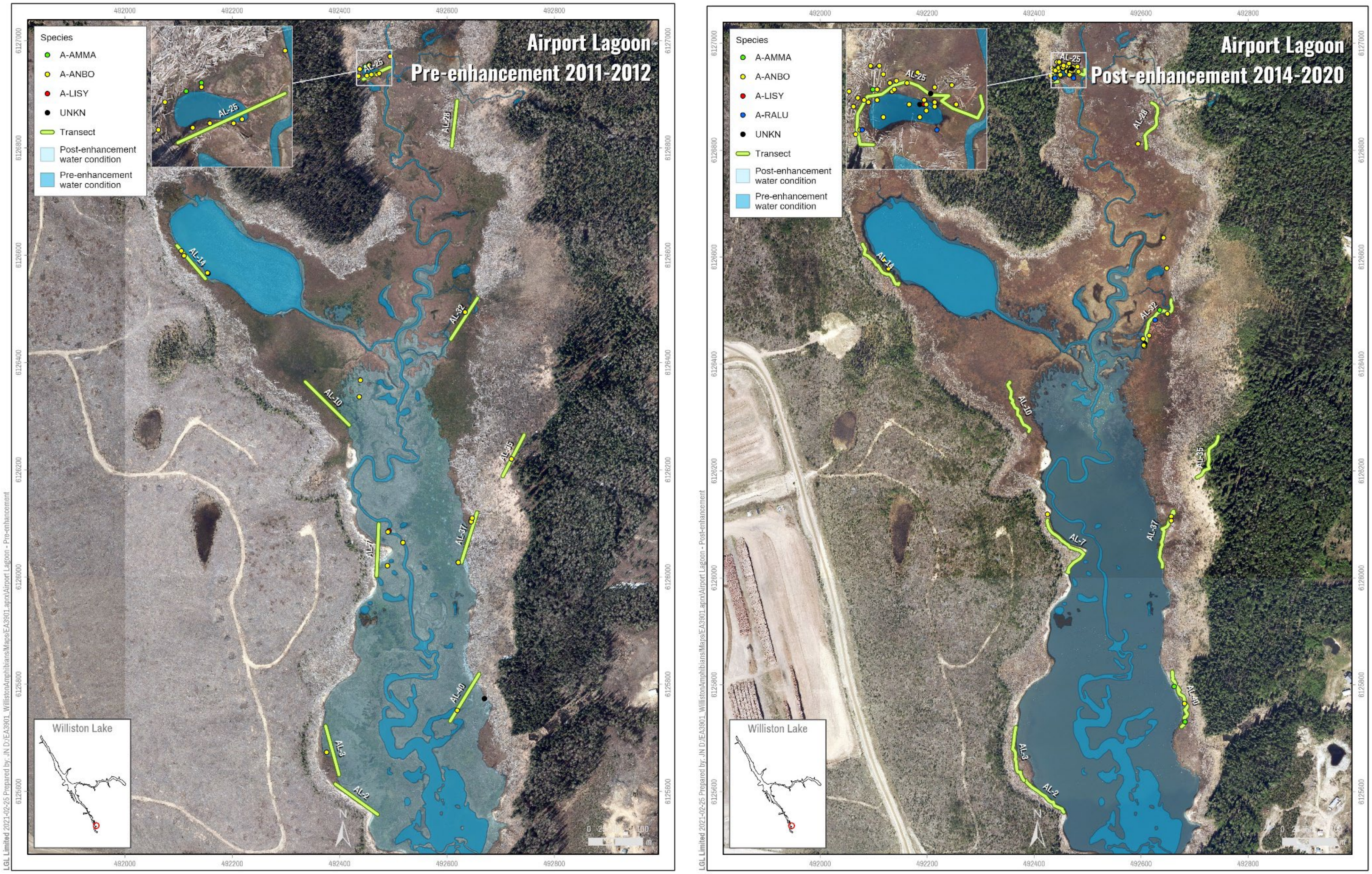

Figure 9. Amphibian detections at Airport Lagoon in pre-enhancement years (2011 to 2012) and post-enhancement years (2014 to 2020).

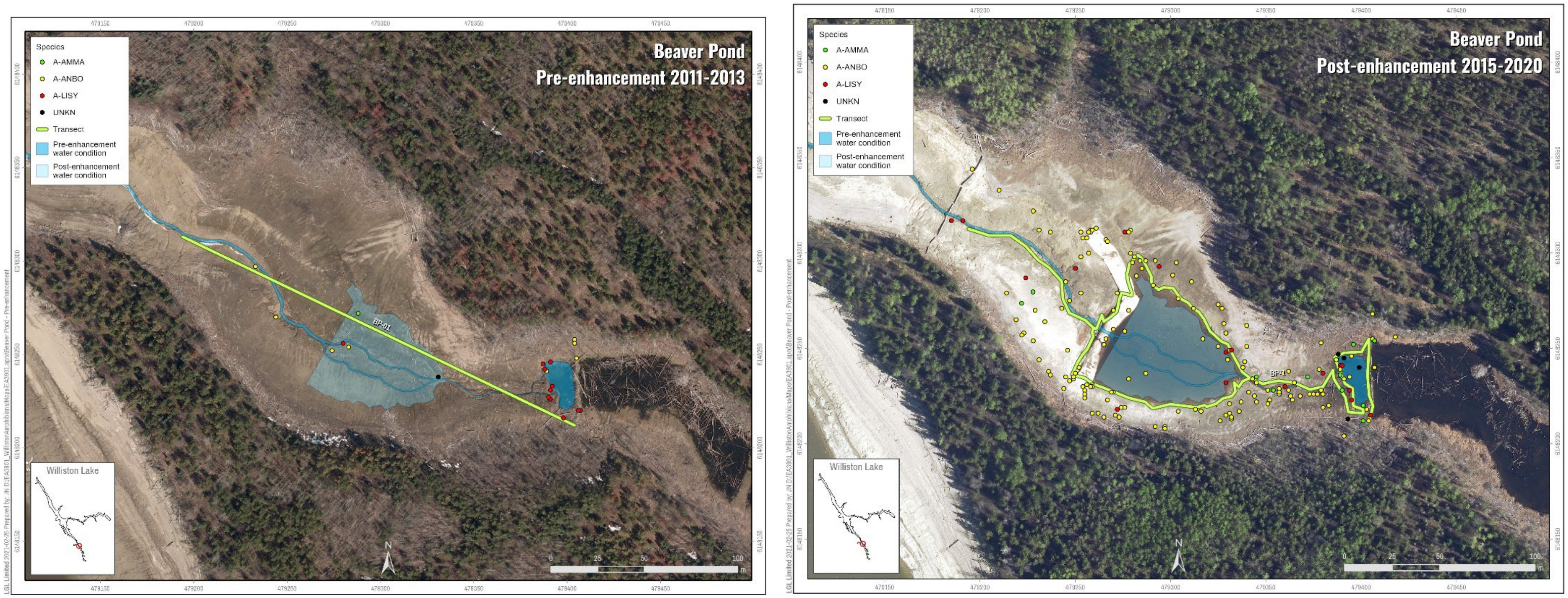

Figure 10. Amphibian detections at Beaver Pond in pre-enhancement years (2011 to 2013) and post-enhancement years (2015 to 2020).

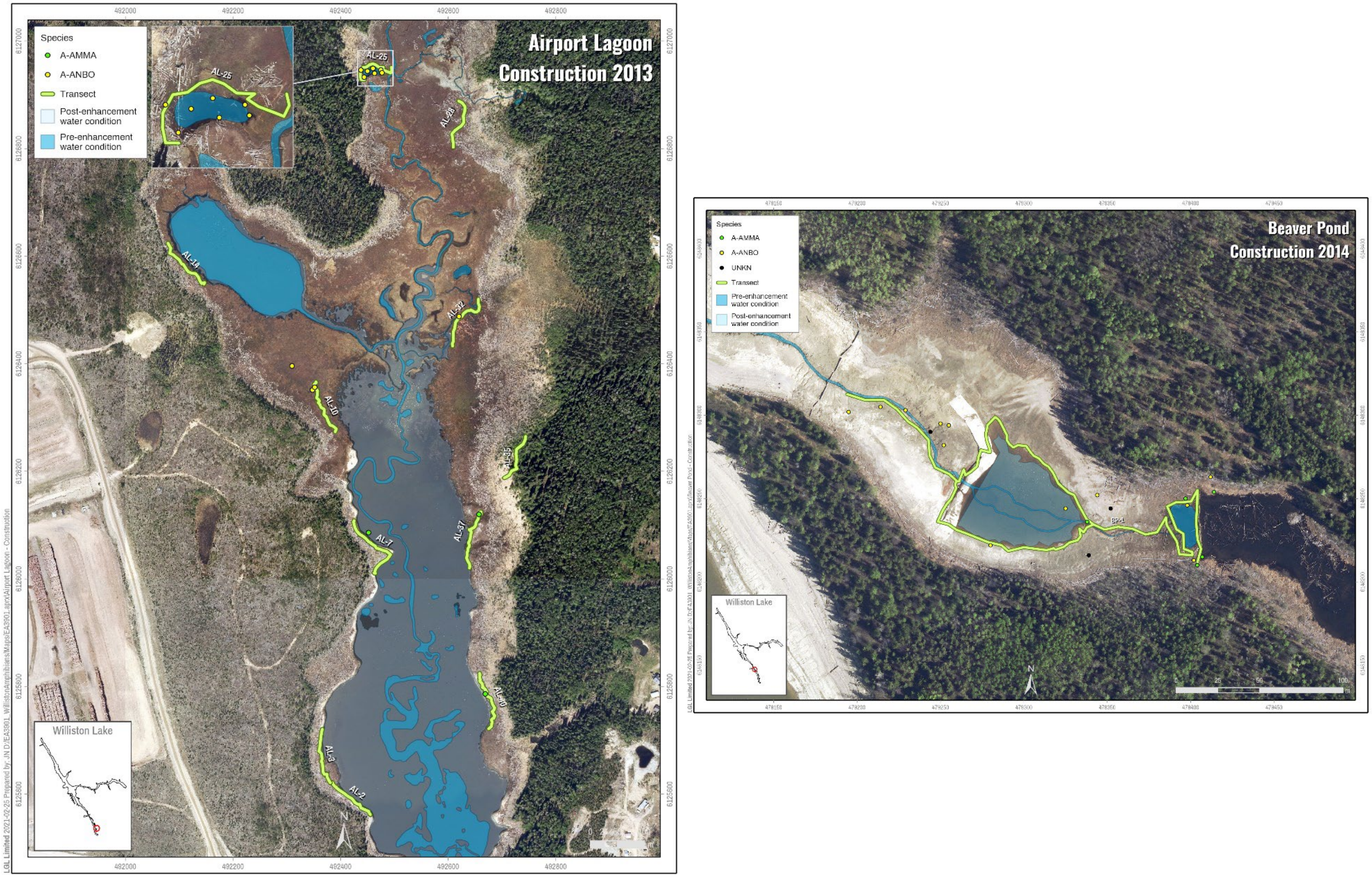

Figure 11. Amphibian detections during enhancement construction years at Airport Lagoon (2013) and Beaver Pond (2014), Williston Reservoir.

5.2.4 Challenges and Opportunities

The predominant challenges associated with the wildlife data related to observer bias, seasonal access issues, and data management; however, the 10 year span of GMSMON-15 and the employment of standardized and repeatable survey methods allowed for the compilation of a robust dataset used to address MQ-2 (Are the enhanced (or newly created) wetlands used by waterfowl and other wildlife?). Although, the aforementioned challenges exerted limitations on more granular questions about the effectiveness of the projects for wildlife. We discuss these issues below.

5.2.4.1 Waterbirds and Shorebirds

Although annual survey dates were relatively consistent across the years, in some years the ability to collect data was affected by ice cover.

Observer bias was likely introduced into the monitoring program given the 10-year timeframe and the change in observers among years. Some issues with data consistency and quality control were noted. A small number of records had missing dates, although other information (e.g., species, survey location) could be used in the analysis. Given the length of the monitoring program, any outliers in the data would not have affected the overall analysis and result. Despite these challenges, the waterbird and shorebird dataset was useful for addressing the management question.

5.2.4.2 Songbirds

Some data consistency issues were noted in the songbird data. For example, in 2019 surveys only classified bird detection distances in distance bands up to 75 m, and farther than 75 m. This differed from previous years which classed distances in bands up to 100 m and farther than 100 m. In order for all data to be comparable across all years, the 75 m distance band was used to constrain data.

Wetland enhancements were not created with a specific focus on songbirds. As songbird counts included the edge and forest habitats around the enhanced wetland, it is perhaps unsurprising that no obvious trends were observed in the pre- and post-enhancement periods, as forest communities appeared to have remained intact across all years. This was possibly evident at Beaver Pond, where forest bird richness appeared to decline post-enhancement while drawdown zone bird richness appeared to increase. However, trends were subject to the vagaries of low sample size as the Beaver Pond area was small enough to only permit three point count stations to be established over all years. Further, the pre- and post-enhancement periods were unbalanced, with two years (Airport Lagoon) or three years (Beaver Pond) of pre-enhancement data compared with six and five years of post-enhancement survey data, respectively. Despite these challenges, the songbird dataset was useful for addressing the management question.

5.2.4.3 Amphibians

Amphibian populations naturally exhibit large degrees of variation with the number detected dependent upon current environmental conditions, overwinter survival, and predation pressure

(Hansen et al. 2012). The following points outline some of the challenges for this study which likely affected this monitoring program's data collection, results, and the ability to confidently report on various aspects of enhancement outcomes:

- As mentioned in the methods, data collection focused primarily on systematic surveys to monitor amphibians during their active seasons (approx. May to June). Several of the target species (Western Toad) are easily located and identified via this survey method (at least in one life stage); however, some other species may not have been detected, due to their inconspicuous nature, natural annual population variation, environmental conditions, or inconsistent use of the drawdown zone, affecting both relative abundance and diversity measures.
- One of the major assumptions of the methodology used to assess abundance was that observations were a good representation of the true abundance at each site and that detection rates were not impacted differently across sites or years. A second assumption made was that all observers over the 10 years had the same level of skill surveying for amphibians, which was likely not the case.
- Estimating abundance in amphibians from egg mass and larval counts can be particularly challenging for a number of reasons including varying environmental conditions (e.g., rain affects visibility), species with small egg masses (e.g., Long-toed Salamander, Boreal Chorus Frog), difficulty counting individual egg strings (e.g., Western Toad), or low frequency of sampling (can miss the reproduction window).
- Small, inconspicuous amphibian species are generally difficult to locate; however, multiple surveys across and between years likely provided an adequate understanding of species occupancy and diversity at both sites. For example, Long-toed Salamander possibly occurred more frequently than we reported but went undocumented due to this species often being difficult to locate because they have an early breeding period and are inconspicuous during the remainder of the year (Wilkinson and Hanus 2002). Given this, it was possible that Long-toed Salamanders 1) occurred at more transects sites but were not observed them, and 2) were more abundant than detection rates determined, which likely contributed to the lack of Long-toed Salamander observations in several study years.
- A challenge to the dataset for this study was that animals observed were not necessarily unique individuals, as individuals were not tagged or marked for identification in the field. Therefore, adult individuals could have been counted as unique between field sampling sessions and years, when in fact the same adult could have been captured twice, potentially inflating abundance values.
- One challenge to this study was that surveys may have been conducted too late in the season to catch early breeding species such as Long-toed Salamanders or Wood Frogs, especially for Beaver Pond which was frequently inaccessible until May. For example, the earlier start of the surveys in 2012 and 2016 may have assisted in the detection of Long-

toed salamander. Long-toed Salamanders and Wood Frog are known to start breeding before the snow and ice melts in northern British Columbia (Matsuda et al. 2006). However, the weather conditions during the early season surveys were generally cool and windy and are the probable reason for the lack of detections.

- A related challenge to later surveys times was as ectotherms, amphibian activity is limited by environmental conditions. They are more active during warm weather and after rainfall (RIC 1998). Logistically, survey times could not always be timed for the most ideal conditions, which may have affected results (e.g., reduced visibility of tadpoles during rainfall). Additionally, no night surveys were conducted, which can often be an ideal time to observe moving or breeding amphibians (RIC 1998).
- The low vegetation cover observed at both sites may have also contributed to the lower number of observations because of reduced cover. Although not tested, most of the amphibian observations at Beaver Pond were in the upper zone of the drawdown, near a small vegetated, beaver-dammed wetland, where vegetation cover appeared to be higher.
- A final challenge to this study involved missing, incomplete or incorrect data values that could not be resolved through examination of original files and/or annual reports. For example, 17 amphibian records were left out of the analyses due to missing dates, transects and coordinates; these records could have been duplicates or simply missing too much information to ensure accuracy. Additionally, three records of Boreal Chorus Frog (*Pseudacris maculate*) were changed to "Unknown Frog" due to this species' range not currently overlapping in Williston Reservoir.

5.3 MQ-3: Is there a change in the abundance, diversity, and extent of vegetation in the enhancement area?

The wetland enhancements at Airport Lagoon and Beaver Pond created larger areas of permanently flooded habitat. Colonization of the drawdown zone by riparian vegetation and the proliferation of aquatic macrophytes was evident because of the enhancements. Specific changes noted during the monitoring of habitat classes, terrestrial and aquatic vegetation are described below.

5.3.1 Habitat classification

The habitat classes at both sites have responded to the wetland enhancements and to annual flooding events (Appendix 7). The amount of surface water (e.g., pond) has increased at both sites resulting in a modification to the shoreline/riparian area, compared to the pre-enhancement condition.

At Airport Lagoon, the general pattern of riparian habitat from the water's edge starts with either mineral soil (sand) or mosses and perennials that transitions into a band of coarse woody debris (driftwood) followed by graminoid-dominated areas and then shrub habitats. Tree seedlings were documented in 2019 and 2020 in the Basin Cryptantha habitat class at Beaver Pond and the Basin

Moss and Shoreline Driftwood habitat classes at Airport Lagoon, but it may be too early to determine if these trees can become established.

There were generally 12 distinct vegetation classifications that were functionally consistent throughout the program (i.e., the same dominant species were used to define each community each year); however, the area and coverage of these communities changed between 2016 and 2018 in the post-enhancement period. The biggest changes were a reduction in the area coverage for Basin Moss (BM) by approximately 23%. The amount of Shoreline Driftwood was also reduced; by approximately 7%. These reductions were the result of an increase in surface water (i.e., Streams and Ponds habitat class) because of the enhancements (Appendix 7). The other habitat classes remained relatively stable over the course of the program. The plant species assemblages identified within habitat classes consisted mostly of herbaceous perennials (grasses and herbs) and bryophytes with minimal woody shrubs and no live tree cover (except for occasional paper birch [*Betula papyrifera*] and trembling aspen [*Populus tremuloides*] seedlings). A few classes had a high percentage of coarse woody debris (≥50%) from driftwood accumulation.

At Beaver Pond, mud and clay remained present at the water's edge after project completion, but perennial species were becoming established along the pond shoreline. The partitioning of communities observed along these habitat classes suggested that succession to stable wetland/riparian communities will require additional time, but that this successional trajectory was occurring. Eight habitat classes were identified and mapped in Year 1 (MacInnis et al. 2012). These were reduced to six in Year 4 and some habitat class names were also revised (MacInnis et al. 2015). No substantial changes in the distribution and abundance of habitat classes were noted in the latter years of the program. Basin Cryptantha and Stream Sedge were reduced by about 11% and 7%, respectively. Conversely, Shoreline Clay and the amount of surface water (i.e., Steams and Ponds) increased by approximately 9% and 8%, respectively. The other habitat classes at Beaver Pond remained relatively stable throughout the monitoring program. Like Airport Lagoon, the plant species assemblages identified within habitat classes consisted mostly of herbaceous perennials. Shrub cover was sparse, except for the habitat class located at the edge of the forest cover and there was no tree cover. One class had a high percentage of coarse woody debris (27%) from driftwood accumulation.

In conclusion, gradual changes to habitat classes were observed at both sites over the course of the monitoring program. These changed appeared to be driven by the consistent presence of surface water, which was a design objective for each site. On-going succession of habitat is expected to continue but will be influenced by reservoir operations and larger climatic events.

5.3.2 Terrestrial vegetation

The cover of herbaceous vegetation increased slightly on average during construction and immediately after the enhancements at Airport Lagoon (2012 and 2013); however, there was no clear trend in herb cover throughout most of the monitoring program (2014 to 2018), until Years 2019 and 2020 when cover began to increase (Appendix 8). Cover of herbs was, on average, 2.5

to 3.8 times greater during construction (2013) and 2.3 to 3.3 times greater in the post-enhancement period (2014-2020) compared to the pre-enhancement period (2011-2012).

Species richness was highest for herbs at Airport Lagoon with an average around five species being recorded before enhancement, to averages closer to 10 species after enhancements. A significant decrease in herb richness was noted during construction, but this was followed by a significant increase in richness in the post-enhancement period. Twenty species were recorded in 2012, in the pre-enhancement period; all of which were recorded again in the post-enhancement period. Between 2013 and 2018 a few more unique species were recorded; however, the highest number of species was recorded in Year 9 (n=90 species), and 35 of these were unique to that year. *Potentilla norvegica* (Norwegian cinquefoil) was most frequently the dominant species in the herb layer (i.e., it had the highest cover in 10 transects), followed by *Calamagrostis canadensis* (bluejoint; 6 transects), and *Carex* sp. (sedge), *Cryptantha torreyana* (Torrey's cryptantha) and *Equisetum arvense* (common horsetail) (5 transects each). Species composition along individual transects at Airport Lagoon remained quite stable throughout the program for certain transects (e.g., AL-6, AL-5, AL-10, AL-7, AL-12), whereas other transects changed quite a bit over time (e.g., AL-4, AL-2, AL-9, AL-10).

Species richness for mosses was generally low (1-2 species), though five species of moss were recorded in the post-enhancement period at Airport Lagoon. Cover of moss was relatively high in 2011 but declined sharply in 2012 and stayed low afterwards. Throughout the monitoring of terrestrial vegetation at Airport Lagoon there was very low coverage of shrubs, except for one transect (AL-7) in 2019 and 2020 where cover was around 10%. The species richness of shrubs also increased after Year 8. *Salix* species (willow) were dominant in the shrub layer, especially *Salix bebbiana* (Bebb's willow) and *Salix barclayi* (Barclay's willow). Only three tree species were documented, and only with less than 1% of cover in 2019 and 2020 (*Pinus contorta* [lodgepole pine], *Populus tremuloides* [trembling aspen], and *Populus balsamifera* [balsam poplar]).

At Beaver Pond, the amount of terrestrial vegetation was less than what was recorded at Airport Lagoon; however, some notable changes occurred. The cover of herbaceous vegetation increased significantly during construction and the post-enhancement period. Likewise, species richness was relatively low before the enhancement (e.g., five species) but increased to 15 species in the post-enhancement period. Finally, species composition transitioned over time with distinct changes occurring in the latter years of the program.

There was barely any cover of shrubs or moss at Beaver Pond before, during or after construction. Trace amounts of shrub cover (approximately 3%) were present in 2011 but this was reduced to mostly nil throughout the monitoring program until shrubs reappeared in 2020. Similarly, cover of moss was nil in all years except for 2011 and 2020. Tree species were only present on the transects at Beaver Pond in 2019 and 2020.

5.3.3 Aquatic vegetation

The density, diversity and spatial extent of aquatic vegetation has changed following the enhancement in 2013. There were changes in the extent of aquatic vegetation communities in the initial years of the monitoring program at Airport Lagoon. The closed-leaved pondweed / fennel-leaved pondweed community appeared to increase in coverage after construction. This community was predominant in the central area of the lagoon where water depths were 1-2 m. Conversely, the lady's thumb / water smartweed community appeared to decrease in coverage after construction, as did the non-aquatic habitat. Lady's thumb was more predominant at shallower water depths (e.g., <1 m), and its reduction in abundance over the years could be a result of more persistent deeper water in the flooded habitat. Likewise, with the reduction of non-aquatic habitat.

Myriophyllum sibiricum (verticillate water-milfoil) was typically recorded in deeper waters in the latter years of the monitoring program (Appendix 9). One of the more common species recorded at Airport Lagoon, *Drepanocladus aduncus* (common hook moss), showed relatively high frequencies in 2015 and 2016, but declined in the latter years. *Drepanocladus aduncus* is prevalent in shallower waters and was commonly recorded on the terrestrial vegetation transects.

The pre-enhancement condition of Airport Lagoon showed the presence of some vegetation communities dominated by aquatic vegetation species. These included the Cinquefoil Moss and Smartweed Moss communities located at the northern and northwestern ends of the site (MacInnis et al. 2013). Here soils are poorly drained, and some surface water was persistent, partly from the small creek. Similarly, there was more open water at the south end of the lagoon where less aquatic vegetation was growing. Monitoring for aquatic species only commenced after construction, but with these features present in the pre-enhancement condition, some aquatic vegetation species were likely established, which allowed certain species to increase in abundance in the post-enhancement period.

At Airport Lagoon, between 2014 and 2016 immediately after the construction of the enhancements, the most widely distributed and common aquatic plant species were *Persicaria maculosa* (lady's thumb) and *Callitriche palustris* (spring water-starwort), which were recorded in very shallow water (<1 m; shoreline). Species prone to deeper waters (1-2 m depth) were recorded in the central section of the wetland and included *Stuckenia pectinata* (fennel-leaved pondweed). The deepest sections of the wetland (>2 m depth) were primarily on the west side and the northwest arm of the lagoon. Here *Ceratophyllum demersum* (common hornwort), *Potamogeton praelongus* (long-stalked pondweed) and *Myriophyllum sibiricum* (verticillate watermilfoil) were recorded; although, these species were less prevalent in 2014 and began to be recorded in 2015 and 2016.

There was a sharp decline in species richness over time at Airport Lagoon, with species richness going from a total of 15 in 2018, to 9 in 2019, to only three in 2020. Species richness was more stable but much lower in Beaver Pond, varying between two species in 2018 and 2020 and four species in 2019. Only *Potamogeton natans* (floating pondweed) was recorded at Beaver Pond (and only once in 2019) but not in Airport Lagoon. Species composition varied each year but *Persicaria maculosa* and *Callitriche palustris* were consistently recorded in the shallow, shoreline areas. *Potamogeton foliosus* (closed-leaved pondweed) and *Myriophyllum sibiricum* were the two most frequently species (83 and 84 samples, respectively), both of which were more commonly recorded from deeper water (Appendix 9). The species occurrence and distribution from the final three years of data collection provided an indication that aquatic macrophyte community was still in flux.

The total density (volume x abundance) of aquatic vegetation generally declined over time at Airport Lagoon but remained constant at Beaver Pond. Total density also varied in relation to water depth and years, with density generally declining with increasing water depth at Airport Lagoon in 2018 and 2019 but increased along with water depth in 2020. No clear relationships between density and water depth were obvious for Beaver Pond.

5.3.4 Challenges and Opportunities

The primary challenges with the vegetation datasets were associated with observer bias and data management. Some specific data attributes were missing or not recorded, which only became evident when the full 10-year dataset was compiled and processed. Likewise, observation data on aquatic vegetation from 2017 and spatial data on aquatic vegetation communities was not provided to the report authors; therefore, these components were not discussed in this comprehensive report.

The sampling methods for collecting data on aquatic vegetation differed between 2014 – 2016 and 2018 – 2020 (as mentioned, no data was provided for 2017). Comparable analysis across all years could not be performed. Although, this was not a major drawback since all data on aquatic vegetation were collected in the post-enhancement period, but post-enhancement trend interpretation will remain challenging. At the conclusion of GMSMON-15, ample vegetation data from both the terrestrial and aquatic environments were collected to answer the management question.

5.4 MQ-4: Is the area and quality of fish and wildlife habitat created by the wetland enhancement maintained over time?

The area of aquatic habitat created by the wetland enhancements is clearly being maintained. In Year 10 water levels at Airport Lagoon and Beaver Pond appeared to be stable and the enhancement structures were performing as intended. The quality of this habitat varied differently for fish and wildlife species. Further discussion of these indictor groups is below.

5.4.1 Fish

The wetland enhancements at both sites led to an increase in available fish habitat and during the 10-year study period; fish were consistently captured in different areas and habitat types (pelagic vs benthic) at both the Airport Lagoon and Beaver Pond. It is expected fish will benefit from this increase in habitat through greater access to spawning sites, food resources, and/or overwintering areas (e.g., increased depth).

A higher diversity of fish and CPUE was evident after the 2013 enhancement works were completed, which indicated that fish species were utilizing and benefiting from the increased habitat. This was especially evident at Airport Lagoon where water levels were more stable compared to the conditions at Beaver Pond (Table 9; Appendix 2).

During the 10-year monitoring program, electrofishing, minnow traps, and fyke nets proved effective at capturing 11 species of fish with different life histories and habitat preferences (e.g., pelagic vs. benthic). Throughout the program it was found that the Airport Lagoon supported resident cyprinid, sculpin, and sucker populations (MacInnis et al. 2017, d'Entremont et al. 2019, d'Entremont et al. 2020). Brassy minnow and redside shiners were captured in very high numbers relative to other species. Lake chub and white suckers were also caught in relatively high numbers, which indicated that the increased available habitat is being utilized by these species.

5.4.2 Wildlife

The wetland enhancements at Airport Lagoon and Beaver Pond resulted in an increase in available aquatic habitat. It was evident that waterbirds and shorebirds are using this newly created habitat during the migratory and breeding seasons. At Airport Lagoon, more birds were using habitat in the northern sections of the site. The water depths here were typically shallower and there were likely better foraging opportunities for birds. Riparian and aquatic vegetation were more prolific here compared to the southern areas where there was more coarse woody debris and shoreline sand. The northern sections were also typically ice-free earlier than other sections of the site during the migration period. Ice cover was recorded during several surveys in late April, but during these surveys sections of open water were present in the northern section where birds were observed. Construction of the berm at Beaver Pond resulted in more water being impounded compared to the pre-enhancement condition, where the water feature was limited to a drainage channel. The occurrence of species within these subgroups was relatively lower than what was observed at Airport Lagoon. This is likely a reflection of the size of the impounded area at Beaver Pond and the lower habitat complexity, compared to Airport Lagoon.

Songbirds were utilizing the suite of habitats available at and near the enhanced wetland sites at Airport Lagoon and Beaver Pond. At Airport Lagoon, songbird richness appeared to increase in drawdown zone habitat in the post-enhancement period, while remaining stable in shrub habitats. Forest habitat had an increase in songbird richness in 2018 relative to other years. Beaver Pond had fewer data points, but richness appeared to increase in drawdown zone and decrease in forest habitats post-enhancement.

In theory, the increase in available aquatic habitat would have benefited amphibians by providing an increased amount of aquatic habitat available for breeding, foraging, or overwintering (for some species). This was particularly true for the Beaver Pond site where the wetland enhancement resulted in a large increase in the amount of amphibian breeding habitat available. During the pre-enhancement phase of the monitoring program (2011 to 2013), the use of both sites by three species of breeding amphibians was confirmed. A spike in Western Toad observations (as well as higher numbers of Long-toed Salamander, including the first observations of Columbia Spotted Frog) occurred at the sites in 2014 for Airport Lagoon and 2015 for Beaver Pond during the first season of post-construction monitoring. The low abundance of amphibians detected at Beaver Pond and Airport Lagoon during baseline monitoring compared to values seen immediately post-enhancement showed that habitat enhancements resulted in increased abundance for two species of amphibians (Western Toad, Long-toed Salamander) at both sites. Too few detections were made for the other two species to support any evidence of change in amphibian use post-enhancement. Although, a large increase in amphibian population numbers were not observed for the subsequent years post-enhancement for Airport Lagoon. It is unknown why amphibian abundances dropped off, in some cases to near zero levels at Airport Lagoon, post-enhancement. Tuttle (2013) observed increases in multiple species of amphibian (Red-legged Frog [*Rana aurora*], Pacific Chorus Frog [*Pseudacris regilla*]) for two years post-construction in a ~0.74-hectare wetland build, as newly created pond habitat was available for use in an area that previously was only a water seep into a reservoir drawdown zone, so similar trends were expected at Airport Lagoon.

5.4.3 Challenges and Opportunities

This management question is generally well addressed. Specific challenges and opportunities on the fish and wildlife indicators are described in earlier sections of the report.

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Appendix 1

Timeline of GMSMON-15

Year	Activities
2008	The Terms of Reference for the Peace River Water Use Plan Monitoring Program: GMSMON-15 Reservoir Wetland Habitat was prepared. The objective of the monitoring program was to address the management questions by collecting the data necessary to draw inferences and to test the hypotheses. The monitoring program was to primarily focus on the effectiveness of wetland enhancement to improve fish and wildlife habitat as well as maintain this habitat over the life of the project.
2011	First year of monitoring and baseline data collection completed by Cooper Beauchesne and Associates Ltd at Airport Lagoon and Beaver Pond. Field surveys were comprised of: • Habitat classification of vegetation communities • Terrestrial vegetation surveys • Waterfowl surveys • Songbird point count surveys • Amphibian surveys • Fish population sampling
2012	Second year of monitoring and baseline data collection completed by Cooper Beauchesne and Associates Ltd at Airport Lagoon and Beaver Pond. Field surveys were comprised of: • Review of habitat classifications and descriptions • Terrestrial vegetation surveys • Waterfowl and shorebird surveys • Songbird point count surveys • Amphibian surveys • Fish population sampling
2013	Third year of monitoring and baseline data collection completed by Cooper Beauchesne and Associates Ltd at Airport Lagoon and Beaver Pond. Field surveys were comprised of: • Review of habitat classifications and descriptions • Terrestrial vegetation surveys • Waterfowl surveys • Songbird point count surveys • Amphibian surveys • Fish population sampling Construction of the wetland enhancements at Airport Lagoon.
2014	Fourth year of monitoring and baseline data collection completed by Cooper Beauchesne and Associates Ltd at Airport Lagoon and Beaver Pond. Field surveys were comprised of: • Update of habitat classifications and descriptions • Terrestrial vegetation surveys • Aquatic vegetation surveys • Waterfowl surveys • Songbird point count surveys • Amphibian surveys • Fish population sampling Construction of the wetland enhancements at Beaver Pond.
2015	Fifth year of monitoring and baseline data collection completed by Cooper Beauchesne and Associates Ltd at Airport Lagoon and Beaver Pond. Field surveys were comprised of: • Review of habitat classifications and descriptions • Terrestrial vegetation surveys • Aquatic vegetation surveys • Waterfowl surveys • Songbird point count surveys • Amphibian surveys

	• Fish population sampling
2016	Sixth year of monitoring and baseline data collection completed by Cooper Beauchesne and Associates Ltd at Airport Lagoon and Beaver Pond. Field surveys were comprised of: • Review of habitat classifications and descriptions • Terrestrial vegetation surveys • Aquatic vegetation surveys • Waterfowl surveys • Songbird point count surveys • Amphibian surveys • Fish population sampling
2017	Seventh year of monitoring and baseline data collection completed by Cooper Beauchesne and Associates Ltd at Airport Lagoon and Beaver Pond. Field surveys were comprised of: • Review of habitat classifications and descriptions • Terrestrial vegetation surveys • Aquatic vegetation surveys • Waterfowl surveys • Songbird point count surveys • Amphibian surveys • Fish population sampling An annual report from 2017 was not completed
2018	Eighth year of monitoring and baseline data collection completed by LGL Limited at Airport Lagoon and Beaver Pond. Field surveys were comprised of: • Update of habitat classifications and descriptions • Terrestrial vegetation surveys • Aquatic vegetation surveys • Waterfowl surveys • Songbird point count surveys • Amphibian surveys • Fish population sampling
2019	Ninth year of monitoring and baseline data collection completed by LGL Limited at Airport Lagoon and Beaver Pond. Field surveys were comprised of: • Update of habitat classifications and descriptions • Terrestrial vegetation surveys • Aquatic vegetation surveys • Waterfowl surveys • Songbird point count surveys • Amphibian surveys • Fish population sampling
2020	Tenth year of monitoring and baseline data collection completed by LGL Limited at Airport Lagoon and Beaver Pond. Field surveys were comprised of: • Update of habitat classifications and descriptions • Terrestrial vegetation surveys • Aquatic vegetation surveys • Waterfowl surveys • Songbird point count surveys • Amphibian surveys • Fish population sampling

Appendix 2

Analysis of Fish Data

Introduction

The wetland enhancements at Airport Lagoon and Beaver Pond were designed to address the lack of riparian, wildlife and fish habitat around the Williston Reservoir (BC Hydro 2008). The effectiveness of the enhanced wetland habitats was monitored by collecting annual data on the presence of fish species to address the following management questions:

MQ1: Are the enhanced (or newly created) wetlands used by fish?

MQ4: Is the area and quality of fish and wildlife habitat created by the wetland enhancement maintained over time?

The primary hypothesis to be tested was:

H_1: Fish species composition and density in wetland changes following enhancement.

The newly created enhancement wetlands were used by fish for the study duration. Fish survey methods and effort were consistent with the Terms of Reference (BC Hydro 2008), previous years of the project (McInnis et al. 2017, d'Entremont et al. 2019 and d'Entremont et al. 2019), and provincial standards (RIC 2001).

Methods

Fish sampling sessions were completed one or two times between May and July each year. A combination of methods was used to capture and sample both large and small fish. These included electrofishing, minnow trapping, fyke nets. Fish surveys commenced in Year 1 (2011) of GMSMON-15 and were conducted each year until 2020. At Airport Lagoon, between six to 12 minnow traps were deployed, one reach was electrofished, and two fyke nets were deployed in May and July each year (Figure 1). At Beaver Pond, between three to six minnow traps were deployed, one reach was electrofished from 2011 to 2016, and one or two fyke nets were deployed between May and July each sampling year. Given the size of the Beaver Pond, one fyke net was typically deployed and insufficient water levels prevented effective electrofishing in the latter years of the program.

Fish sampling was conducted under Scientific Fish Collection Permit issued by the Ministry of Forest, Lands and Natural Resource Operations and Rural Development. All captured fish were measured for fork length and total length was recorded for sculpins. When catches were high for a species and method, the first 50 fish were measured for length (mm) and the remainder were enumerated without measurement. Due to the limitations of the sampling gear (i.e., minnow trap opening) and fish species life histories (i.e., size range, habitat preferences) it was possible there were biases is species size and composition.

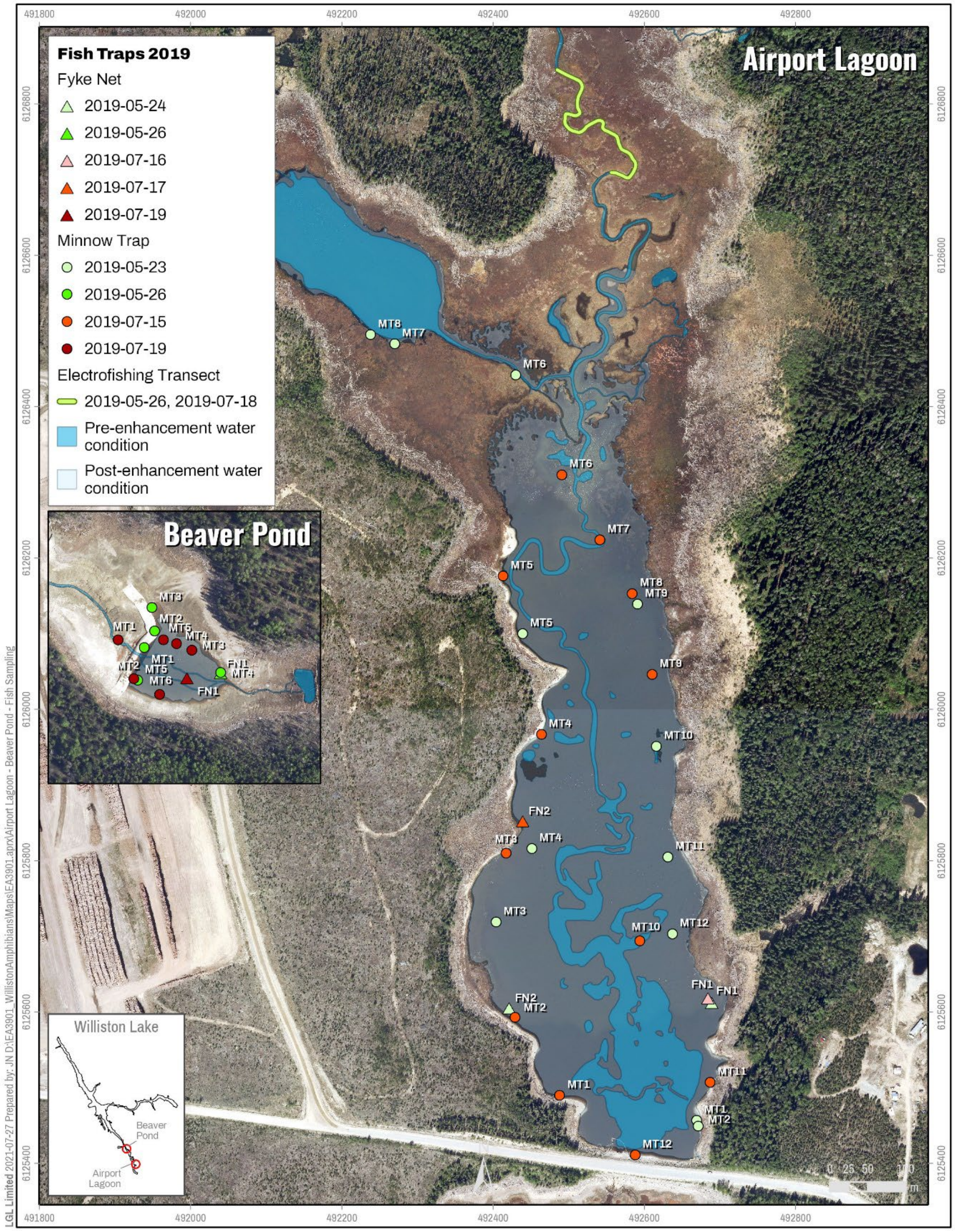

Figure 1. Fish sampling locations by date and method at the Airport Lagoon and Beaver Pond sites in 2019. These sites are representative of fish sampling locations from 2011 to 2020.

Using a YSI Pro Plus multi-parameter meter (YSI Inc., Ohio) water quality measurements were taken during each site visit. These parameters included water temperature, water depth, water clarity (relative turbidity or Secchi depth), pH, dissolved oxygen (DO), and conductivity. Water temperature, pH, DO, and conductivity were recorded at the surface. Relative turbidity was recorded for each electrofishing reach according to RIC (2001) standards. Secchi depth (20 cm diameter disk) was used as a measure of turbidity for the inundated areas.

Dataset

The fish dataset was created to summarizes fish diversity and abundance (catch per unit effort [CPUE]) by wetland site (i.e., Airport Lagoon and Beaver Pond). Data pooled across all years of sampling were used in most analyses and these data assisted in answering MQ1 and MQ4.

Fish Diversity – Over the 10-year period, fish sampling by electrofishing, minnow trapping, and fyke nets were effective methods at both sites and provided additional information on fish populations at both wetland enhancement sites. Between the two sites, the three methods of sampling resulted in the collection of 13 of 22 species known to occur in the reservoir (Table 1 to Table 3). At the Airport Lagoon, 12 fish species from five families were captured (Table 1 to Table 3).

The proportion of fish species captured by year at each enhancement site was tabulated (Figure 2 and Figure 3). To assess fish composition and density, fish abundance data were standardized to the number of individuals per minute for electrofishing individuals per trap hour for the minnow traps and fyke net.

Table 1. Fish species caught from electrofishing each year at wetland sites in Williston Reservoir from 2011 to 2020. Year of enhancement was 2013.

Site	Species			Year										
	Family	Scientific name	Common name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Airport Lagoon	Catostomidae	*Catostomus catostomus*	Longnose sucker	4	1	3	1	6	3	1	7	0	NS	26
		C. commersoni	White sucker	0	0	0	0	1	0	0	0	0	NS	1
		C. macrocheilus	Largescale sucker	2	5	1	0	8	1	0	0	0	NS	17
			Unidentified sucker	0	0	0	0	1	0	0	0	0	NS	1
	Cottidae	*Cottus asper*	Prickly sculpin	22	17	25	13	3	18	0	13	5	NS	116
		C. cognatus	Slimy sculpin	0	0	1	0	0	0	0	0	0	NS	1
			Unidentified sculpin	32	3	2	0	0	97	0	0	0	NS	134
	Cyprinidae	*Couesius plumbeus*	Lake chub	49	12	127	41	66	146	15	17	49	NS	522
		Hybognathus hankinsoni	Brassy minnow	1	1	91	2	28	0	6	23	1	NS	153
		Mylocheilus caurinus	Peamouth chub	0	0	0	0	0	0	0	0	0	NS	0
		Ptychocheilus oregonensis	Northern pikeminnow	1	40	1	0	0	26	0	0	0	NS	68
		Richardsonius balteatus	Redside shiner	7	3	45	8	110	0	0	102	177	NS	452
			Unidentified minnow	0	0	0	0	0	8	0	0	0	NS	8
	Gadidae	*Lota lota*	Burbot	1	35	10	2	1	0	0	1	0	NS	50
	Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	1	1	1	0	1	0	0	0	0	NS	4
Beaver Pond	Catostomidae	*Catostomus catostomus*	Longnose sucker	4	0	3	0	0	2	0	NS	NS	NS	9
		C. commersoni	White sucker	0	0	0	0	0	0	0	NS	NS	NS	0
		C. macrocheilus	Largescale sucker	1	0	1	0	0	3	0	NS	NS	NS	5
			Unidentified sucker	43	0	53	0	2	14	0	NS	NS	NS	112
	Cottidae	*Cottus asper*	Prickly sculpin	1	0	0	0	5	7	3	NS	NS	NS	16
			Unidentified sculpin	0	0	0	0	0	0	0	NS	NS	NS	0
	Cyprinidae	*Couesius plumbeus*	Lake chub	1	0	5	0	3	0	0	NS	NS	NS	9
		Hybognathus hankinsoni	Brassy minnow	0	0	0	0	0	0	0	NS	NS	NS	0
		Mylocheilus caurinus	Peamouth chub	0	0	0	0	2	0	0	NS	NS	NS	2
		Ptychocheilus oregonensis	Northern pikeminnow	1	0	1	0	2	0	0	NS	NS	NS	4
		Richardsonius balteatus	Redside shiner	9	1	1	0	2	0	0	NS	NS	NS	13
			Unidentified minnow	0	0	0	0	0	0	0	NS	NS	NS	0
	Gadidae	*Lota lota*	Burbot	0	0	0	0	0	0	0	NS	NS	NS	0
	Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	0	0	0	0	0	0	3	NS	NS	NS	3
		Salvelinus confluentus	Bull trout	0	0	0	0	0	0	0	NS	NS	NS	0

*Note: NS = No sampling
*Note: NS = No electrfishing was conducted in 2020 due to COVID-19 restrictions.

Table 2. Fish species caught from minnow trapping by year at wetland sites in Williston Reservoir from 2011 to 2020. Year of enhancement was 2013.

Site	Species			Year										
	Family	Scientific name	Common name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Airport Lagoon	Catostomidae	*Catostomus catostomus*	Longnose sucker	0	0	9	0	74	36	21	1	0	2	143
		C. commersoni	White sucker	0	0	0	62	29	6	7	7	0	0	111
		C. macrocheilus	Largescale sucker	0	2	3	37	44	10	4	0	0	0	100
			Unidentified sucker	0	0	3	285	100	0	1	0	1	0	390
	Cottidae	*Cottus asper*	Prickly sculpin	1	2	0	2	0	0	2	2	0	11	20
		C. cognatus	Slimy sculpin	1	0	0	0	0	0	0	0	0	1	2
			Unidentified sculpin	0	0	0	0	889	0	0	0	0	0	889
	Cyprinidae	*Couesius plumbeus*	Lake chub	49	12	127	884	31	168	115	162	77	37	1662
		Hybognathus hankinsoni	Brassy minnow	2	2	1123	959	0	34	12	230	5	1	2368
		Mylocheilus caurinus	Peamouth chub	0	0	0	0	12	0	1	0	0	0	13
		Ptychocheilus oregonensis	Northern pikeminnow	0	1	4	7	459	1	0	0	0	5	477
		Richardsonius balteatus	Redside shiner	4	10	8	720	0	867	227	964	439	61	3300
	Gadidae	*Lota lota*	Burbot	1	5	0	0	0	0	0	1	0	0	7
Beaver Pond	Catostomidae	*Catostomus catostomus*	Longnose sucker	4	0	3	0	0	1	0	0	0	0	8
		C. commersoni	White sucker	0	0	0	0	0	0	0	0	3	7	10
		C. macrocheilus	Largescale sucker	1	0	1	0	0	0	1	1	0	1	5
			Unidentified sucker	43	0	53	0	0	0	1	0	0	0	97
	Cottidae	*Cottus asper*	Prickly sculpin	1	0	0	0	0	6	0	0	0	1	8
		C. cognatus	Slimy sculpin	0	0	0	0	0	0	0	0	0	1	1
	Cyprinidae	*Couesius plumbeus*	Lake chub	1	0	5	0	0	0	0	1	0	0	7
		Mylocheilus caurinus	Peamouth chub	0	0	0	0	0	0	1	0	0	0	1
		Ptychocheilus oregonensis	Northern pikeminnow	1	0	1	10	0	0	0	1	1	0	14
		Richardsonius balteatus	Redside shiner	9	1	1	3	0	1	0	0	0	0	15
			Unidentified minnow	0	0	0	0	0	0	0	11	0	0	11

Table 3. Fish species caught from the fyke net by year at wetland sites in Williston Reservoir from 2011 to 2020.

Site	Species			Year										
	Family	Scientific name	Common name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Airport Lagoon	Catostomidae	*Catostomus catostomus*	Longnose sucker	1	48	5	331	6	13	25	6	55	NS	490
		C. commersoni	White sucker	0	14	0	437	64	50	161	191	73	NS	990
		C. macrocheilus	Largescale sucker	0	9	2	188	110	29	130	23	7	NS	498
			Unidentified sucker	0	0	0	620	3525	0	1	0	1	NS	4147
	Cottidae	*Cottus asper*	Prickly sculpin	0	0	0	0	5	0	1	4	29	NS	39
			Unidentified sculpin	0	0	0	0	0	8	0	465	0	NS	473
	Cyprinidae	*Couesius plumbeus*	Lake chub	0	166	268	2025	3924	2	170	480	946	NS	7981
		Hybognathus hankinsoni	Brassy minnow	0	53	213	7117	9121	1	430	6	3408	NS	20349
		Mylocheilus caurinus	Peamouth chub	0	1	0	5	0	32	9	33	2	NS	82
		Ptychocheilus oregonensis	Northern pikeminnow	2	43	22	90	76	249	8	3383	8	NS	3881
		Richardsonius balteatus	Redside shiner	0	113	192	2646	5746	0	181	0	2160	NS	11038
			Unidentified minnow	0	0	0	0	0	0	0	0	3	NS	3
	Gadidae	*Lota lota*	Burbot	1	7	0	0	0	5	0	14	0	NS	27
		Oncorhynchus mykiss	Rainbow trout	0	0	0	2	0	0	16	0	11	NS	29
	Salmonidae	*Salvelinus confluentus*	Bull trout	0	0	0	0	0	0	0	0	1	NS	1
Beaver Pond	Catostomidae	*Catostomus catostomus*	Longnose sucker	0	1	3	5	0	0	0	0	0	NS	9
		C. commersoni	White sucker	0	0	2	0	0	0	0	0	94	NS	96
		C. macrocheilus	Largescale sucker	0	1	6	5	0	0	1	0	0	NS	13
			Unidentified sucker	0	0	0	0	0	0	0	0	0	NS	0
	Cottidae	*Cottus asper*	Prickly sculpin	0	0	0	0	0	0	0	0	1	NS	1
			Unidentified sculpin	0	0	0	0	0	0	0	0	32	NS	32
	Cyprinidae	*Couesius plumbeus*	Lake chub	0	0	0	0	0	0	0	0	0	NS	0
		Hybognathus hankinsoni	Brassy minnow	0	0	0	0	0	0	0	0	0	NS	0
		Mylocheilus caurinus	Peamouth chub	10	0	54	16	0	2	0	0	0	NS	82
		Ptychocheilus oregonensis	Northern pikeminnow	4	1	38	41	0	10	2	0	0	NS	96
		Richardsonius balteatus	Redside shiner	0	0	16	11	0	0	0	0	53	NS	80
			Unidentified minnow	0	0	0	0	0	0	0	0	0	NS	0
	Gadidae	*Lota lota*	Burbot	0	0	0	0	0	1	0	0	0	NS	1
	Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	0	0	0	0	0	0	0	0	0	NS	0
		Salvelinus confluentus	Bull trout	0	1	0	0	0	0	0	0	0	NS	1

*Note: NS = No sampling.
**Note: No fyke net was deployed in 2020 due to COVID-19 restrictions

Abundance – The annual difference in species diversity and abundance was documented at each site. To assess fish composition and diversity, fish abundance data were standardized to the number of individuals per minute for electrofishing and individuals per trap hour for the minnow traps and fyke net (CPUE; Table 1 to 4). In total, 61824 fish, predominantly adults, were captured, with the majority (99%; 61,063) captured in the Airport Lagoon. The fyke net captured the most fish (82%; 50,439), followed by minnow traps (16%; 9,659) and electrofishing (3%, 1,726; Table 4).

Table 4. Total fish species caught by gear type at the Airport Lagoon and Beaver Pond sites in Williston Reservoir from 2011 to 2020.

Site	Species		Method			
			EF	MT	FN	
	Scientific name	Common name	Total	Total	Total	Grand Total
Airport Lagoon	*Catostomus catostomus*	Longnose sucker	26	143	490	659
	C. commersoni	White sucker	1	111	990	1102
	C. macrocheilus	Largescale sucker	17	100	498	615
		Unidentified sucker	1	390	4147	4538
	Cottus asper	Prickly sculpin	116	20	39	175
	C. cognatus	Slimy sculpin	1	2	0	3
		Unidentified sculpin	134	889	473	1496
	Couesius plumbeus	Lake chub	522	1662	7981	10165
	Hybognathus hankinsoni	Brassy minnow	153	2368	20349	22870
	Mylocheilus caurinus	Peamouth chub	0	13	82	95
	Ptychocheilus oregonensis	Northern pikeminnow	68	477	3881	4426
	Richardsonius balteatus	Redside shiner	452	3300	11038	14790
		Unidentified minnow	8	0	3	11
	Lota lota	Burbot	50	7	27	84
	Oncorhynchus mykiss	Rainbow trout	4	0	29	33
	Salvelinus confluentus	Bull trout	0	0	1	1
Beaver Pond	*Catostomus catostomus*	Longnose sucker	9	8	9	26
	C. commersoni	White sucker	0	10	96	106
	C. macrocheilus	Largescale sucker	5	5	13	23
		Unidentified sucker	112	97	0	209
	Cottus asper	Prickly sculpin	16	8	1	25
	C. cognatus	Slimy sculpin	0	1	0	1
		Unidentified sculpin	0	0	32	32
	Couesius plumbeus	Lake chub	9	7	0	16
	Hybognathus hankinsoni	Brassy minnow	0	0	0	0
	Mylocheilus caurinus	Peamouth chub	2	1	82	85
	Ptychocheilus oregonensis	Northern pikeminnow	4	14	96	114
	Richardsonius balteatus	Redside shiner	13	15	80	108
		Unidentified minnow	0	11	0	11
	Lota lota	Burbot	0	0	1	1
	Oncorhynchus mykiss	Rainbow trout	3	0	0	3
	Salvelinus confluentus	Bull trout	0	0	1	1

Size – Measured fork lengths were pooled and compare between years. Length measurements were collected from each of the thirteen species sampled. The measured fork lengths were pooled and compare between years with the fish species that had groups of 50 individual measurements or more (Figure 4 and Figure 5).

Table 5. Effort and CPUE by year at wetland sites in Williston Reservoir from 2011 to 2020. Year of enhancement = light grey rows.

Site	Method		Year								
			2011	2012	2013	2014	2015	2016	2018	2019	2020
Airport Lagoon	Electrofishing	Effort[a]	6500	9201	5715	2263	2142	2629	1689	1714	NS
		CPUE[a]	1.1	0.8	3.2	2.8	6.3	6.9	11.6	17.3	NS
	Minnow Trap	Effort	379.58	536.62	240.27	413.41	418.6	399.11	535.3	434.5	1133.9
		CPUE	0.1	0.1	6.1	7.4	3.9	5.4	5.3	1.5	12.5
	Fyke Net	Effort	39.64	65.42	30.47	79.48	68.86	77.27	49.4	86.1	NS
		CPUE	0.1	6.9	23.0	169.4	328.0	5.4	347.9	147.7	NS
	Angling	Effort	NS	NS	NS	NS	NS	NS	NS	NS	4.09
		CPUE	NS	NS	NS	NS	NS	NS	NS	NS	0.0
Beaver Pond	Electrofishing	Effort	1048	897	1580	894	2843	456	NS	NS	NS
		CPUE	3.4	0.1	2.4	0.0	5.1	3.4	NS	NS	NS
	Minnow Trap	Effort	129.72	133.5	150.42	176.98	NS	242.13	116	225.3	149.02
		CPUE	0.01	0.01	0.30	0.07	NS	0.1	0.1	2.3	4
	Fyke Net	Effort	21.75	22.75	17	22.83	NS	22.83	NS	38.9	NS
		CPUE	0.6	0.2	7.0	3.4	NS	0.6	NS	554	NS

[a]Catch per unit effort (CPUE): electrofishing CPUE = fish/minute; minnow trap and fyke net CPUE = fish/hour.

Analysis

The proportion of fish species caught at each enhancement site varied between years (Figure 2 and Figure 3). To assess fish composition and density, fish abundance data was standardized to the number of individuals per minute for electrofishing and individuals per trap hour for the minnow traps and fyke net (CPUE; Table 4, Figure 4).

The measured fork lengths were pooled and compare between years. Length measurements were collected from each of the twelve species sampled. Results for the two sampling periods were pooled and are presented in Figure 5 and Figure 6. The measured fork lengths were pooled and compare between years with the fish species that groups of 50 individual measurements or more (Figure 5 and Figure 6).

Results

During the ten-year study, 13 fish species from five families were captured between both sites. In total, 61824 fish, predominantly adults, were captured, with the majority (99%; 61,063) captured in the Airport Lagoon. The fyke net captured the most (82%; 50,439) fish, followed by the minnow traps (16%; 9,659) and electrofishing (3%, 1,726; Table 4).

Airport Lagoon

At the Airport Lagoon, 12 fish species from five families were captured in Airport Lagoon (Table 1 to Table 3). In total, 61,063 were captured, with 2015 having the highest catch rate (n = 24,440;

Figure 2). The fyke net captured the most fish (82%; 50,028), followed by the minnow traps (15%; 9,482) and then electrofishing (2%; 1,553). Minnows (*Cyprinidae*) dominated catches, followed by suckers (*Catostomidae*), prickly sculpin (*Cottus asper*) and burbot (*Lota lota*). The most abundant fish species caught at Airport Lagoon was the brassy minnow (*Hybognathus hankinsoni*).

The proportion of fish species varied between years (Figure 2). In 2013, the highest proportion of brassy minnow were captured. There was an increase in the proportion of redside shiner (*Richardsonius balteatus*) caught at the Airport Lagoon in the final years of the monitoring program.

The CPUE for fyke netting was the highest amongst all sampling methods. However, the CPUE varied between years, with an increase in 2014 and 2015, a decrease in 2016, another increase in 2018 followed by a slightly decrease in 2019. The CPUE for electrofishing increased from 2011 to 2019 (Figure 4). Likewise, for minnow trapping there was increase in CPUE from 2013 to 2018.

Length measurements collected from seven of the 12 species sampled were pooled and are presented in Figure 6. White suckers (*Catostomus commersonii*) had a variety of size classes ranging from 36 mm to 380 mm. Largescale suckers (*Catostomus macrocheilus*, range = 48 to 360 mm) and redside shiners (range = 15 and 124 mm) also had a variety of size classes (Figure 6).

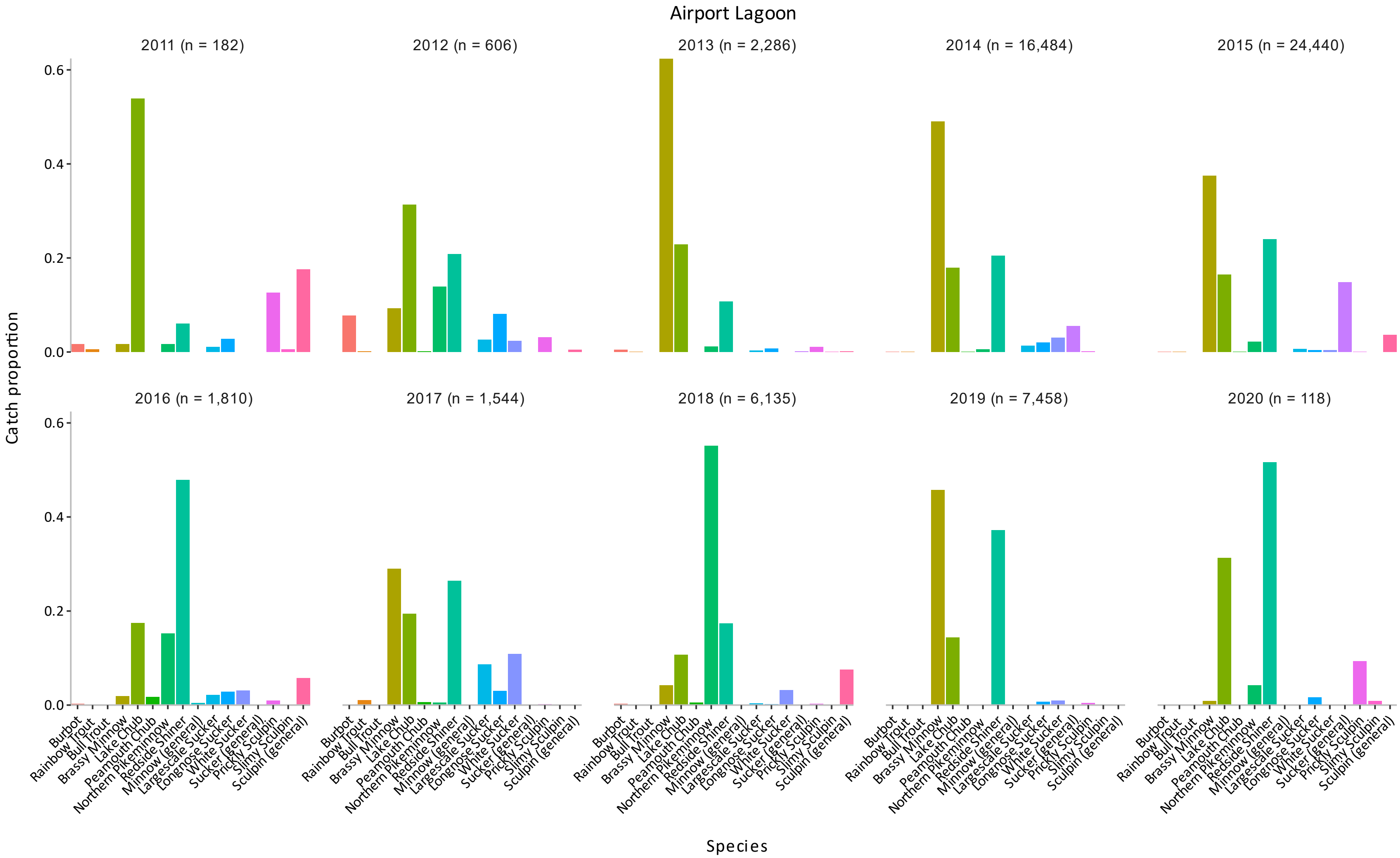

Figure 2. The Airport Lagoon fish species catch proportion from 2011 to 2020, Williston Reservoir.

Beaver Pond

At Beaver Pond six fish species from five families were captured (Table 1 to Table 3). In total, 761 fish were captured, with 2019 having the highest catch rate (n = 184; Figure 5). The fyke net captured the most fish (54%; 411), followed by the minnow traps (23%; 177) and then electrofishing (22%; 171; Table 1 to Table 3). Suckers dominated catches, followed by minnows, prickly sculpin, bull trout (*Salvelinus confluentus*) and burbot. The most abundant fish species caught at the Beaver Pond was the northern pikeminnow (*Ptychocheilus oregonensis*).

Length measurements were collected from four of the six species sampled were pooled and are presented in Figure 7. The northern pikeminnow had a variety of size classes ranging from 34 mm to 352 mm. The white sucker also had a variety of size classes ranging from 28 mm to 369 mm.

The proportion of fish species varied between years (Figure 3). In 2014, the highest proportion of prickly sculpin were captured. The CPUE for electrofishing was the highest amongst all sampling methods. The highest CPUE for minnow trapping occurred in 2019 and 2013 for fyke netting (Table 4 and Figure 7).

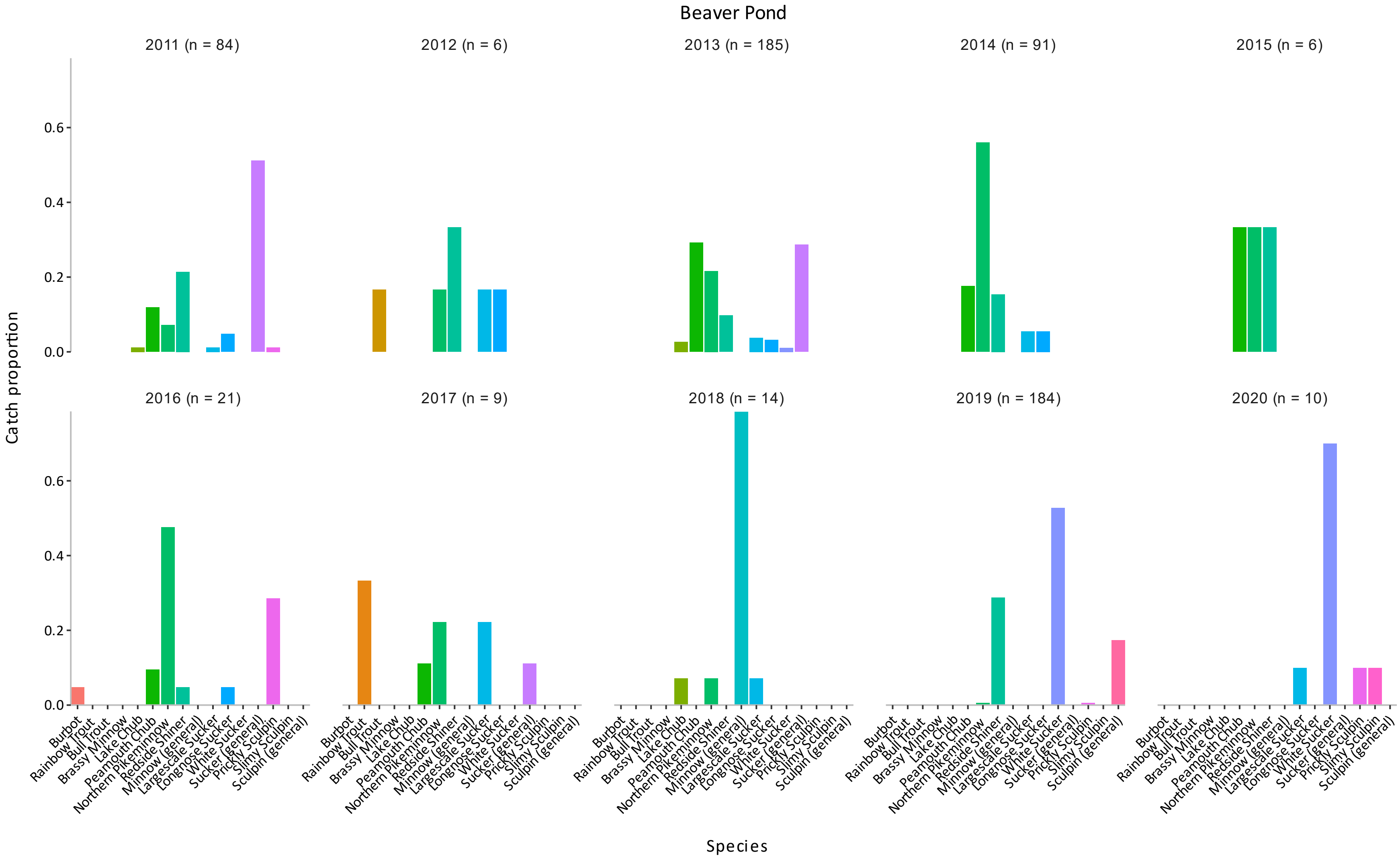

Figure 3. The Beaver Pond fish species catch proportion from 2011 to 2020, Williston Reservoir.

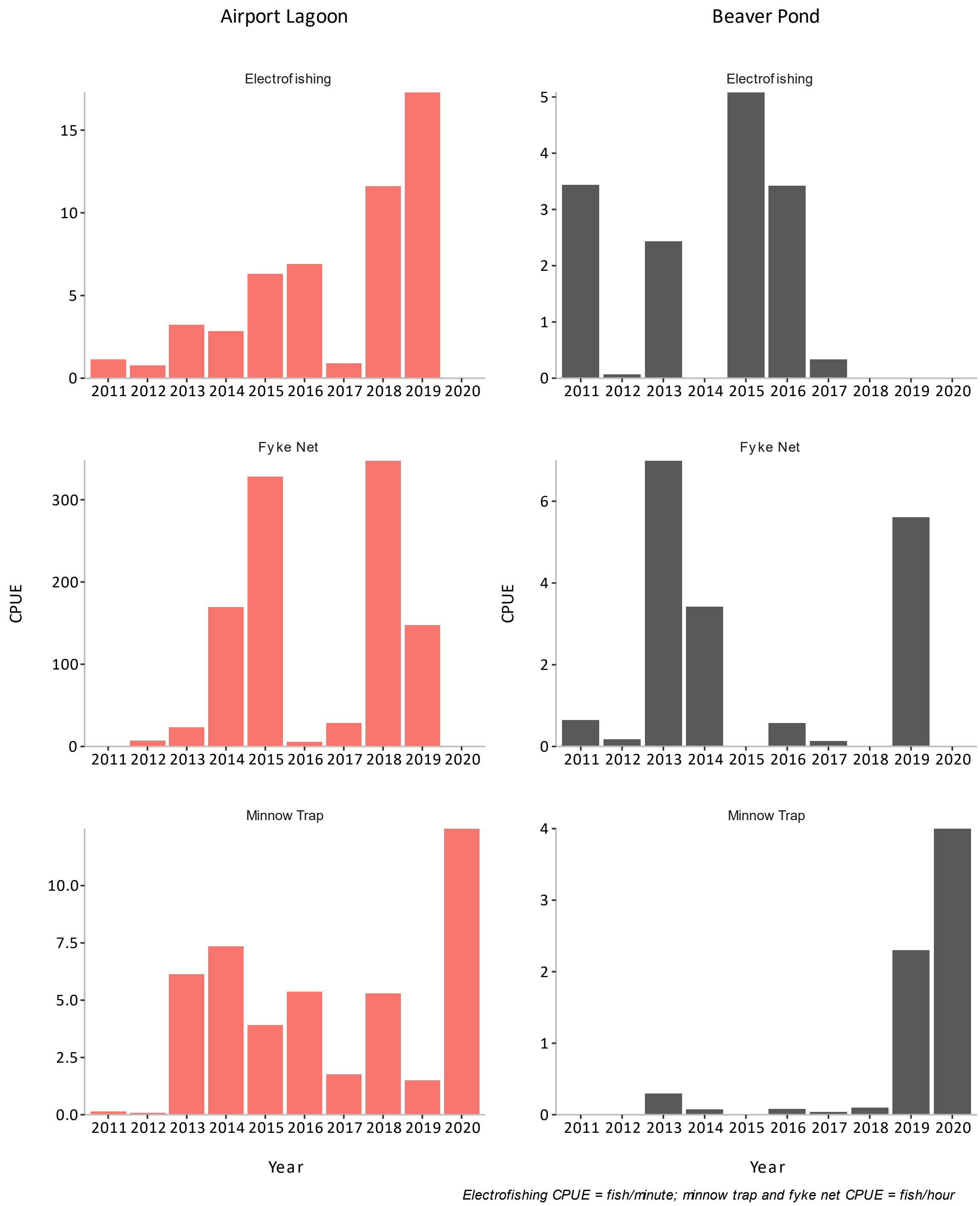

Figure 4. Annual total CPUE for each of the three sampling methods at Airport Lagoon and Beaver Pond used from 2011 to 2020. Construction of the project was completed in the spring of 2013.

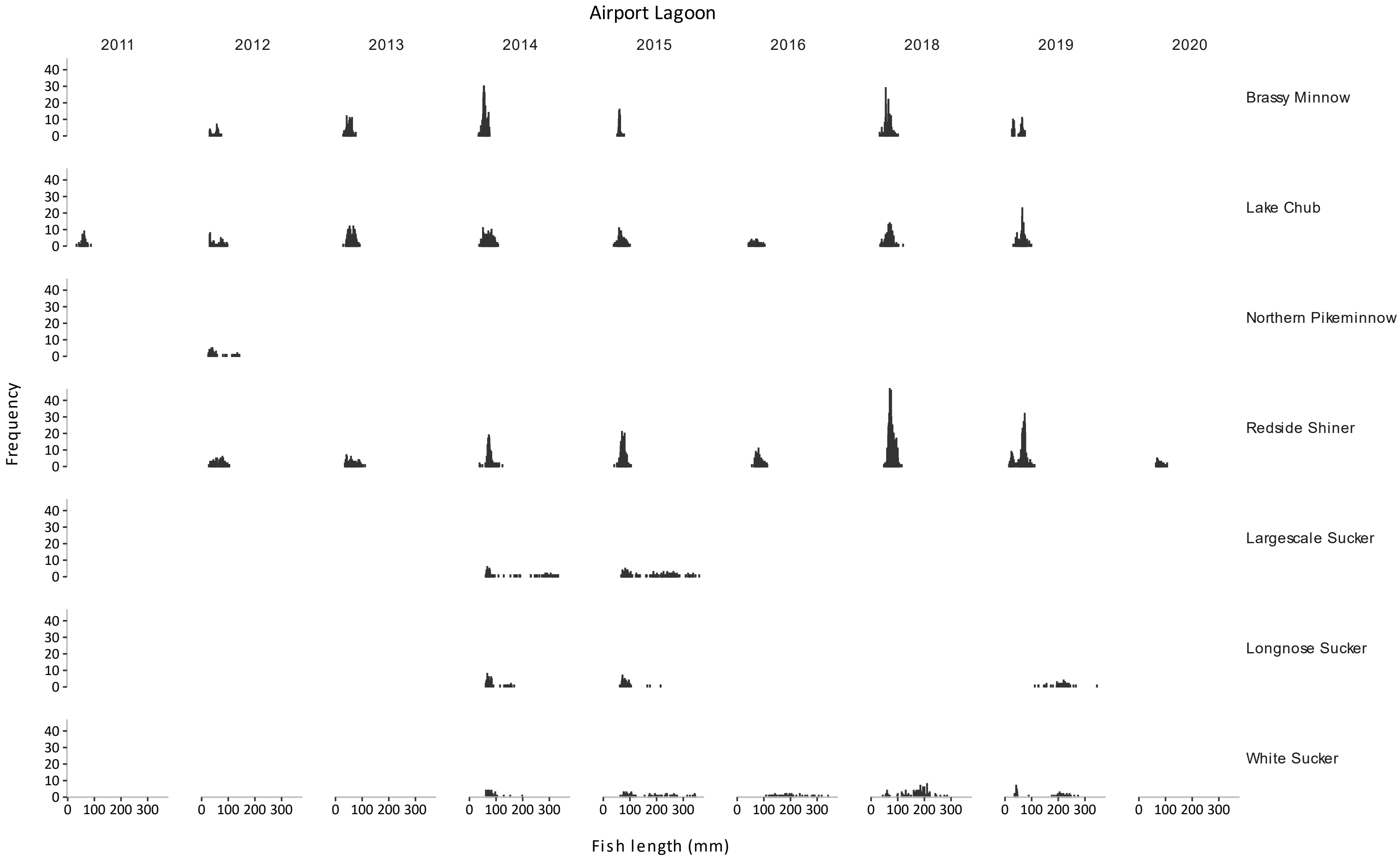

Figure 5. Fork length (mm) range of fish species captured at Airport Lagoon from 2011 to 2020.

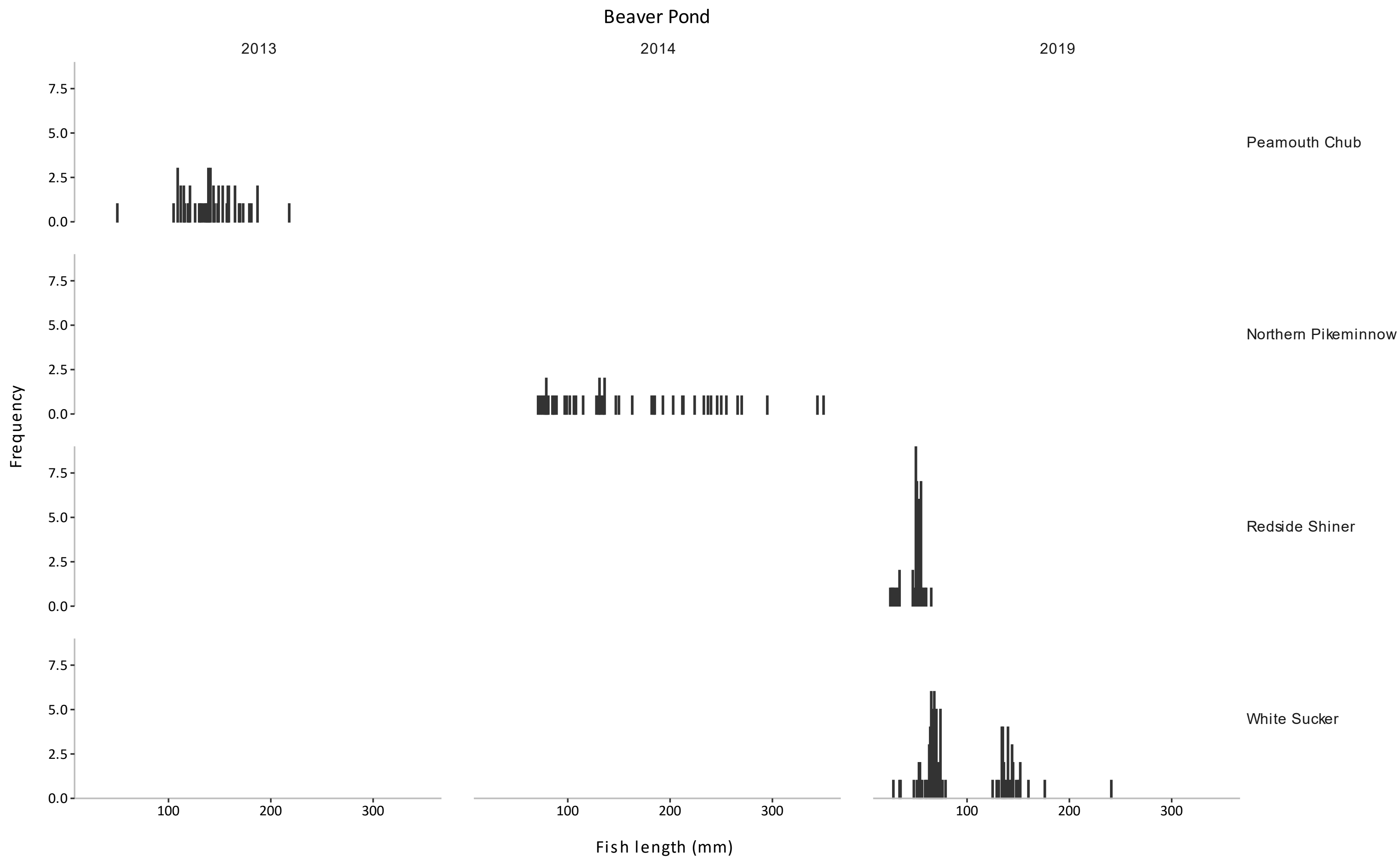

Figure 6. Fork length (mm) range of fish species captured at Beaver Pond from 2011 to 2020.

Discussion

The wetland enhancements at the Airport Lagoon and Beaver Pond, both led to an increase in available fish habitat. During the 10-year study period, fish were consistently captured at both wetlands, with 13 fish species representing five families captured between both sites. The increase in habitat may have potentially benefited fish by providing an increased amount of habitat available for spawning, food sources, or overwintering (for some species). The consistent fish species diversity and abundance captured at each site during the study period supports this theory.

During the 10-year monitoring program, electrofishing, minnow traps, and fyke nets proved effective at capturing 11 species of fish with different life histories and habitat preferences (e.g., pelagic vs. benthic), including species with relatively very low abundance (e.g., bull trout), at Airport Lagoon. Throughout the 10-year fish survey it was found that the Airport Lagoon supported resident cyprinid, sculpin, and sucker populations (MacInnis et al. 2017, d'Entremont et al. 2019, d'Entremont et al. 2020). Brassy minnow and redside shiners were captured in very high numbers relative to other species. Lake chub and white suckers were also caught in relatively high numbers, which indicated that the increased available habitat is being utilized by these species. The rainbow trout and bull trout captured are resident in the Williston Reservoir and were likely taking advantage of the abundant prey available in the lagoon. These fish are likely accessing the lagoon through the upgraded culverts at the south end of the lagoon when the reservoir elevation exceeds 667 m. No suitable salmonid spawning habitat was observed, and no juvenile salmonids (<20 cm) were captured. At Beaver Pond, suckers dominated catches, followed by minnows, prickly sculpin, bull trout and Burbot. The most abundant fish species caught at the Beaver Pond was the Northern pikeminnow.

Due to some of the limitations of the sampling gear (i.e., minnow trap opening) and fish species life histories (i.e., size range, habitat preferences) it is possible that there were biases in species size and composition. Williston Reservoir is dynamic waterbody, with water level fluctuations, therefore an increase or decrease in fish species diversity and abundance can occur that is not directly related to increased spawning and survival or die off. An increase or decrease in fish species diversity and abundance may be due to the introduction or removal of fish from into or out of the enhancement sites during the fluctuating water levels.

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Appendix 3

Analysis of Waterbirds and Shorebirds

Introduction

The wetland enhancements at Airport Lagoon and Beaver Pond were designed to address the lack of riparian and wildlife habitat around the Williston Reservoir (BC Hydro 2008). The effectiveness of the enhanced wetland habitats was monitored by collecting annual data on the presence of waterbird and shorebird species to address the following management question:

> MQ2: Are the enhanced (or newly created) wetlands used by waterfowl and other wildlife?

The primary hypothesis to be tested was:

> H_3: The species composition and density of waterfowl changes following enhancement.

The terms of reference for GMSMON-15 specifically identified waterfowl and an indicator species group, and this is reflected in the management questions; however, for the 10-year comprehensive report observations of all waterbirds are included. This group included all waterfowl species (e.g., ducks, geese, swans), plus other water-associated birds that could use the wetland features, such as gulls, kingfishers and cranes. Data collection for waterbirds commenced in Year 1 (2011) of GMSMON-15 and was conducted each year until 2020. The collection of specific data on shorebirds began in Year 2 (2012).

Methods

Data collection on waterbird species commenced in 2011, whereas specific data shorebirds was added in 2012 to provide additional detail on bird use of the sites. Survey methods for waterbird and shorebird were consistent each year and followed provincial standards for relative abundance inventories (RIC 1999). Surveys were conducted at five observation stations at Airport Lagoon and one observation station at Beaver Pond (Figure 1). At least three replicates were conducted between April and June each year. Data on flock or individual number, species, sex, behaviour, and general habitat (e.g., mid pond, in water near pond edge, standing on shore in water, on shore) were recorded on a modified Resource Inventory Committee data form (RIC 1999) and their corresponding location was recorded on a map with an orthophoto background of each site. Weather conditions were recorded at the beginning and end of each survey, and any unusual conditions or circumstances that potentially affected waterfowl and shorebird presence in the wetland areas were noted.

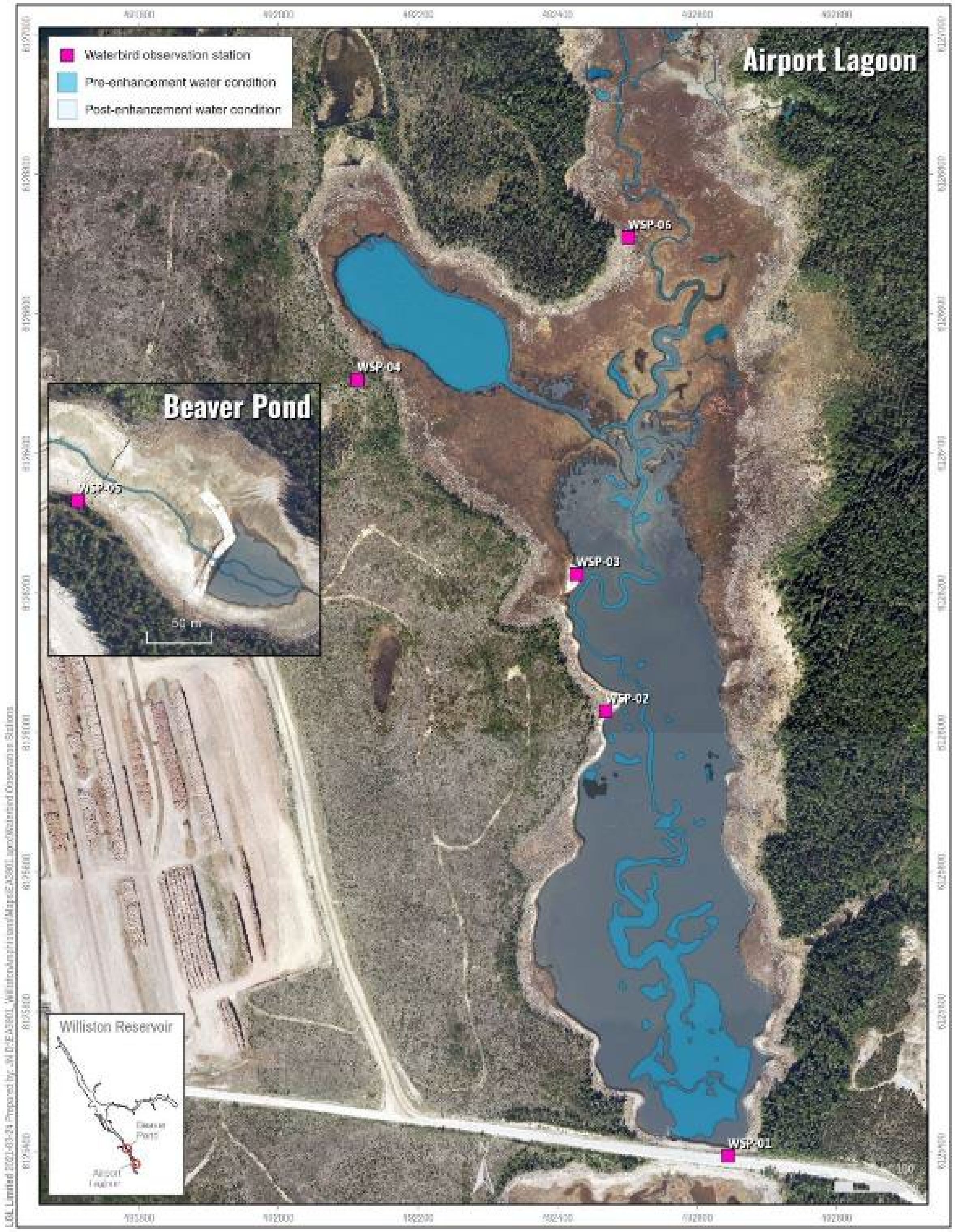

Figure 1. Waterfowl and shorebird survey stations at Airport Lagoon and Beaver Pond sampled from 2011 to 2020 as part of GMSMON-15.

Dataset

This dataset was created to assess the abundance, richness, diversity and composition waterbird and shorebird species observed during the pre-enhancement, construction and post-enhancement periods at Airport Lagoon and Beaver Pond. A total of 49 species were observed during the monitoring program, including 35 species of waterbirds and 14 species of shorebirds (Table 1). Observations were divided into the migratory period (April-May) and the breeding period (June).

Table 1. Waterbird and shorebird species observed at Airport Lagoon and Beaver Pond between 2011 and 2020 for GMSMON-15.

Subgroup	Code	Common Name	Scientific Name	Migratory	Breeding
Shorebirds	AGPL	American Golder Plover	*Pluvialis dominica*	✔	
	GRYE	Greater Yellowlegs	*Tringa melanoleuca*	✔	✔
	KILL	Killdeer	*Charadrius vociferus*	✔	✔
	LESA	Least Sandpiper	*Calidris minutilla*	✔	
	LEYE	Lesser Yellowlegs	*Tringa flavipes*	✔	✔
	LBDO	Long-billed Dowitcher	*Limnodromus scolopaceus*	✔	
	PESA	Pectoral Sandpiper	*Calidris melanotos*	✔	
	SEPL	Semipalmated Plover	*Charadrius semipalmatus*	✔	
	SESA	Semipalmated Sandpiper	*Calidris pusilla*	✔	
	SOSA	Solitary Sandpiper	*Tringa solitaria*	✔	✔
	SPSA	Spotted Sandpiper	*Actitis macularius*	✔	✔
	WIPH	Wilson's Phalarope	*Phalaropus tricolor*	✔	
	WISN	Wilson's Snipe	*Gallinago delicata*	✔	✔
	YLEG	Yellowlegs sp.	*Tringa sp.*	✔	
Waterbirds	AMWI	American Wigeon	*Mareca americana*	✔	✔
	BAGO	Barrow's Goldeneye	*Bucephala islandica*	✔	
	BEKI	Belted Kingfisher	*Megaceryle alcyon*		✔
	BWTE	Blue-winged Teal	*Spatula discors*	✔	✔
	BOGU	Bonaparte's Gull	*Chroicocephalus philadelphia*	✔	✔
	BUFF	Bufflehead	*Bucephala albeola*	✔	
	CAGU	California Gull	*Larus californicus*	✔	
	CAGO	Canada Goose	*Branta canadensis*	✔	✔
	CANV	Canvasback	*Aythya valisineria*	✔	
	CITE	Cinnamon Teal	*Spatula cyanoptera*	✔	
	COGO	Common Goldeneye	*Bucephala clangula*	✔	
	COLO	Common Loon	*Gavia immer*	✔	✔
	COME	Common Merganser	*Mergus merganser*	✔	

EUWI	Eurasian Wigeon	*Mareca penelope*	✓	
GADW	Gadwall	*Mareca strepera*	✓	
GRSC	Greater Scaup	*Aythya marila*	✓	
GWFG	Greater White-fronted Goose	*Anser albifrons*	✓	✓
GWTE	Green-winged Teal	*Anas crecca*	✓	✓
GULL	Gull sp.	*Larus sp.*	✓	
HEGU	Herring Gull	*Larus argentatus*	✓	✓
HOME	Hooded Merganser	*Lophodytes cucullatus*	✓	
LESC	Lesser Scaup	*Aythya affinis*	✓	
LOON	Loon sp.	*Gavia sp.*	✓	
MALL	Mallard	*Anas platyrhynchos*	✓	✓
NOPI	Northern Pintail	*Anas acuta*	✓	✓
NOSH	Northern Shoveler	*Spatula clypeata*	✓	✓
RBME	Red-breasted Merganser	*Mergus serrator*		✓
REDH	Redhead	*Aythya americana*	✓	
RNGR	Red-necked Grebe	*Podiceps grisegena*	✓	
RBGU	Ringed-billed Gull	*Larus delawarensis*	✓	✓
RNDU	Ringed-necked Duck	*Aythya collaris*	✓	✓
SACR	Sandhill Crane	*Antigone canadensis*	✓	✓
SUSC	Surf Scoter	*Melanitta perspicillata*	✓	
TRUS	Trumpeter Swan	*Cygnus buccinator*	✓	✓
TUSW	Tundra Swan	*Cygnus columbianus*		✓

Counts of waterfowls and shorebirds were summarized by computing the maximum count of individuals recorded over all visits at each observation station by species and years. The presence and counts of waterbirds and shorebirds were then summarized for each year and each season (migratory season in April and May, and breeding season in June) at Airport Lagoon and Beaver Pond with a series of tables and figures. The significance of differences in average species richness and total counts at Airport Lagoon were tested over time with a one-way analysis of variance (ANOVA, tested with 9,999 permutations). Significant differences in average species richness or total counts was also tested between periods by combining years 2011, 2012 and 2013 into a "pre-enhancement" period, and all years after 2014 into a "post-enhancement" period. Differences in Beaver Pond could not be tested given the lack of replication.

The variation in species composition over time was analyzed (with a focus on changes pre- and post-enhancement) with ordinations (Principal Coordinate Analysis, PCoA) and multivariate regression trees (MRT). PCoAs summarized the multivariate nature of similarities among samples, based on species counts, mediated through similarity coefficients (Legendre and Legendre 2012).

Results were visualized on an ordination diagram to assess which samples were most similar or most different in terms of species composition. Two different similarity coefficients were used: the percentage difference (formerly the Bray-Curtis index, D14) and the Euclidian distance (D17). Both coefficients are asymmetrical, which means that they exclude double absences of a species at two samples in the computation of their similarity (the "double-zero" problem). However, D14 gives the same importance to abundant and rare species in the computation of similarities among samples while abundant species contribute more to differences than rare species for D17 (Legendre and Legendre 2012). PCoAs were used to assess if the species composition of waterfowls and shorebirds were most similar among plots, years or seasons (migratory or breeding).

MRTs were used to further understand how years, plots and seasons influenced the composition in waterbird and shorebird species over time. MRTs are interesting methods since they deal well with continuous or discrete variables, nonlinear relationships, complex interactions, missing values in both dependent and independent variables, and outliers (De'ath and Fabricious 2000, Moisen 2008). They work by doing recursive partitioning of the response variables into a series of boxes (the leaves) that contain the most homogeneous groups of objects (for waterbirds and shorebirds, observation points in each given season and year), constrained by the independent variables (De'ath 2002, Legendre and Legendre 2012). The splits were constructed by seeking the threshold levels of independent variables that accounted for the greatest similarity among observation stations, and each group also corresponded to a species assemblage (i.e., indicator species, De'ath 2002). The amount of variation in the data explained by the tree is expressed in terms of cross-validation error (CV error), corresponding to the ratio of variation unexplained by the tree to the total variation in the dependent variables (Legendre and Legendre 2012). The trees are read from top to bottom. The variables that create the splits at each node are labelled with the threshold at which the splits occur. By reading the tree, the characteristics in terms of species composition and characteristics that describe the plots that are grouped at each terminal leaf can be interpreted. The relative error at each leaf corresponds to the sum of squared distances of all plots in the cluster to their common centroid (Legendre and Legendre 2012); higher values mean that groups are less tight and more diverse. The analysis was completed by looking for indicator species using the index IndVal (Dufrêne and Legendre 1997). The index was based on within-species abundance and occurrence comparisons and tested by permutations (Legendre and Legendre 2012). Its value is maximal (i.e., 1) when the species is observed at all the observation stations belonging to the same group.

All analyses were performed in the R software language (version 4.0.3).

Analysis

Higher numbers of species were recorded during the migratory period compared to the breeding period. Thirty two waterbird species were recorded during the migratory period and 18 were recorded during the breeding period. Of these, only two species of waterfowl (i.e., Red-breasted Merganser, Tundra Swan) were recorded during breeding that were not recorded during migration. Likewise, 14 species of shorebirds were observed during the migratory period, whereas only six of these were recorded during the breeding period. All shorebird species recorded during the breeding period were recorded during the migratory period.

At Airport Lagoon, a total of seven species were recorded each year. Only two species were recorded before but not after enhancement (i.e., Red-necked Grebe, Cinnamon Teal), whereas 24 different species were recorded in the post-enhancement period and not before construction. In summary, the average total species richness before enhancement was 19, and it increased to 24.7 species after enhancement.

Table 2. Species presence and total species richness in Airport Lagoon over time. Shorebird species are in bold. Species codes are presented in Table 1.

Species	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Number of years sampled	Presence before and during construction (%)	Presence after construction (%)
LEYE	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**10**	**100**	**100**
BWTE	1	1	1	1	1	1	1	1	1	1	10	100	100
CAGO	1	1	1	1	1	1	1	1	1	1	10	100	100
MALL	1	1	1	1	1	1	1	1	1	1	10	100	100
AMWI	1	1	1	1	1	1	1	1	1	1	10	100	100
BUFF	1	1	1	1	1	1	1	1	1	1	10	100	100
GWTE	1	1	1	1	1	1	1	1	1	1	10	100	100
NOSL	1	1	1	1	1	1	1	1		1	9	100	86
NOPI	1	1	1	1	1	1		1	1		8	100	71
RNDU	1	1	1	1	1	1	1		1		8	100	71
LESC	1	1	1	1	1		1		1		7	100	57
BAGO	1	1	1	1				1			5	100	29
GRYE		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**9**	**67**	**100**
KILL		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**9**	**67**	**100**
SPSA		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**9**	**67**	**100**
COME		1	1		1	1	1	1	1		7	67	71
SEPL		**1**	**1**		**1**	**1**	**1**				**5**	**67**	**43**
SESA		**1**	**1**	**1**		**1**					**4**	**67**	**29**
RNGR	1	1									2	67	0
CITE	1		1								2	67	0
COLO		1		1	1	1	1	1	1	1	8	33	100
LBDO		**1**		**1**	**1**	**1**		**1**		**1**	**6**	**33**	**71**
CANV		1		1		1	1			1	5	33	57
HOME		1		1	1		1				4	33	43
GWFG	1									1	2	33	14
BOGU				1	1	1	1	1	1	1	7	0	100
TRUS				1		1		1	1	1	5	0	71
GADW					1	1			1	1	4	0	57
RBGU				1	1			1	1		4	0	57
HEGU								1	1	1	3	0	43
GULL						1			1	1	3	0	43
BEKI								1	1		2	0	29
CAGU								1	1		2	0	29
SOSA							**1**		**1**		**2**	**0**	**29**
LESA					**1**	**1**					**2**	**0**	**29**
PESA				**1**		**1**					**2**	**0**	**29**
GRSC				1		1					2	0	29
WIPH				1	1						2	0	29
TUSW										1	1	0	14
YLEG										**1**	**1**	**0**	**14**
LOON										1	1	0	14
SUSC										1	1	0	14
SACR									1		1	0	14
EUWI									1		1	0	14
WISN								**1**			**1**	**0**	**14**
AGPL						**1**					**1**	**0**	**14**
REDH					1						1	0	14
RBME				1							1	0	14
COGO				1							1	0	14
Total richness	15	23	19	28	25	27	20	23	26	24	--	--	--

At Beaver Pond, no particular species of waterbirds or shorebirds were observed each year of the monitoring program, although Spotted Sandpiper was recorded on all years in the post-enhancement period. Four species were recorded before the enhancements were constructed, no shorebirds were observed in 2013 and 2014 and seven different species were recorded in the post enhancement period (Table 3). In summary, the average total species richness before enhancement was 1, and it increased to 3.8 species after enhancement.

Table 3. Species presence and total species richness in Beaver Pond over time. Shorebird species are in bold. Species codes are presented in Table 1.

Species	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Number of years sampled	Presence before and during construction (%)	Presence after construction (%)
CAGO	1				1	1	1	1	1		6	25	83
KILL		**1**					**1**	**1**	**1**		**4**	**25**	**50**
MALL	1					1					2	25	17
SEPL		**1**									**1**	**25**	**0**
SPSA					**1**	**1**	**1**	**1**	**1**	**1**	**6**	**0**	**100**
BUFF							1		1		2	0	33
LESA								**1**			**1**	**0**	**17**
WISN								**1**			**1**	**0**	**17**
SACR								1			1	0	17
GRYE									**1**		**1**	**0**	**17**
BWTE									1		1	0	17
CAGU									1		1	0	17
Total richness	2	2	0	0	2	3	4	6	7	1	--	--	--

Species richness was higher in the migratory period compared to the breeding period for both waterbirds and shorebirds at Airport Lagoon and Beaver Pond (Figure 2). Although, there was no significant differences in average richness over time for each period (migratory, breeding) (ANOVA with 9999 permutations, p>0.05).

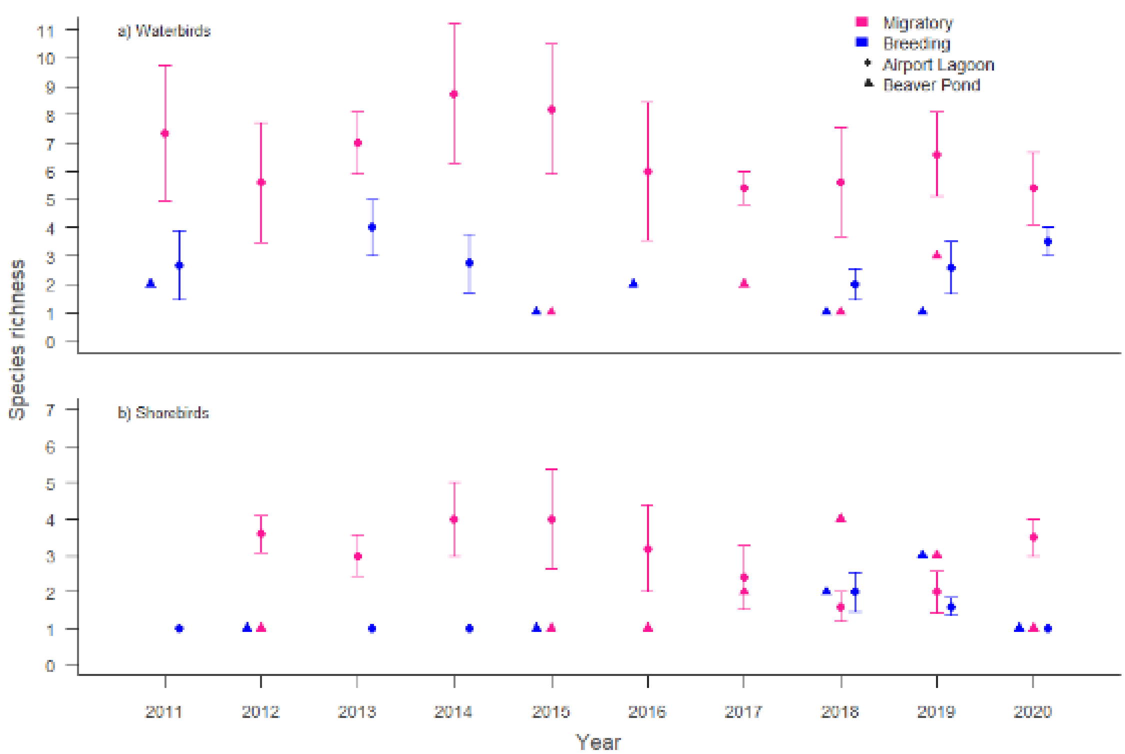

Figure 2. Average richness for migratory and breeding subgroups at Airport Lagoon and Beaver Pond over time for a) waterbirds, and b) shorebirds. Error bars are standard errors.

Overall, the total counts of birds was higher for waterbirds than for shorebirds (Figure 3). Counts were also higher during the migratory period at Airport Lagoon compared to the breeding period. There was a statistically significant decline in average total count between the pre-enhancement and post-enhancement periods for breeding waterbirds in Airport Lagoon ($F=6.2$, $p=0.02$; 2013 was considered to be in pre-enhancement period), but not for migratory waterbirds or shorebirds in Airport Lagoon. There were too few shorebirds recorded at Airport Lagoon during the breeding period to test. At Beaver Pond, total counts were similar across migratory and breeding periods.

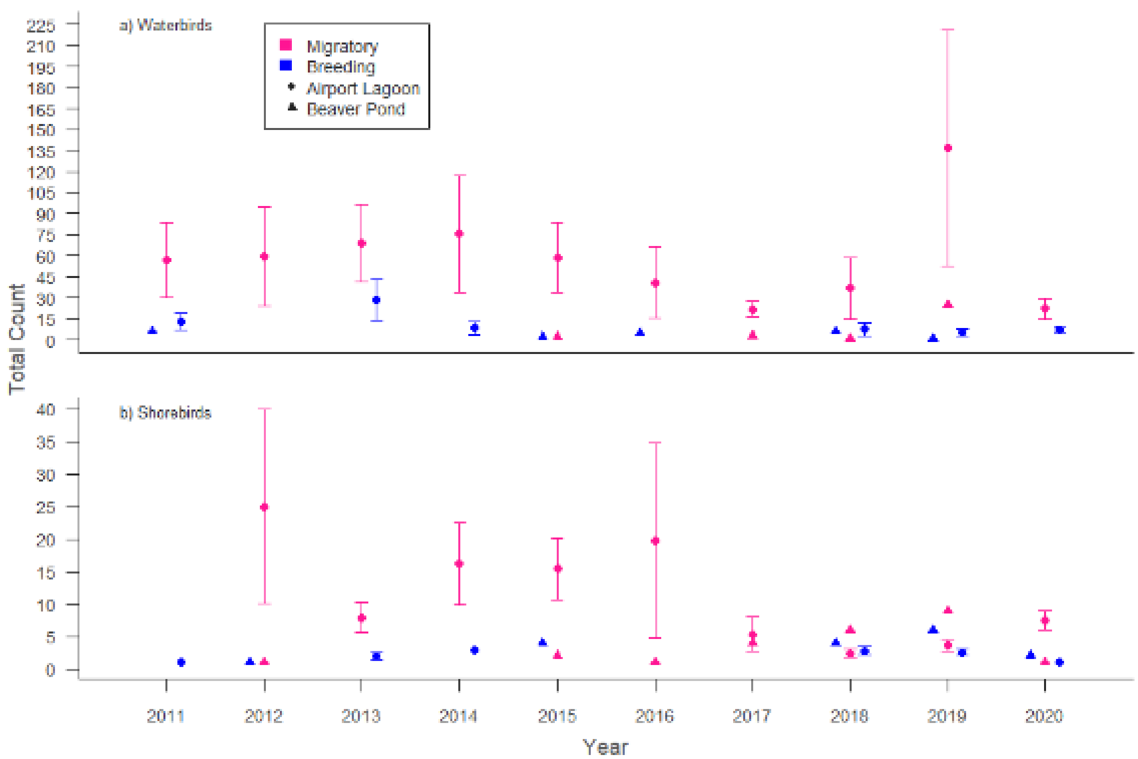

Figure 3. Average total count for migratory and breeding subgroups at Airport Lagoon and Beaver Pond over time for a) waterbirds, and b) shorebirds. Error bars are standard errors.

At Airport Lagoon, observations of waterbirds and shorebirds were generally higher at the observation stations on the northern section of the wetland (i.e., WSP-03, WSP-04, WSP-06) during the migratory period (Figure 4). During the breeding period, the distribution of waterbirds and shorebirds varied annual with higher numbers typically being recorded from WSP-03 and WSP-04 (Figure 5).

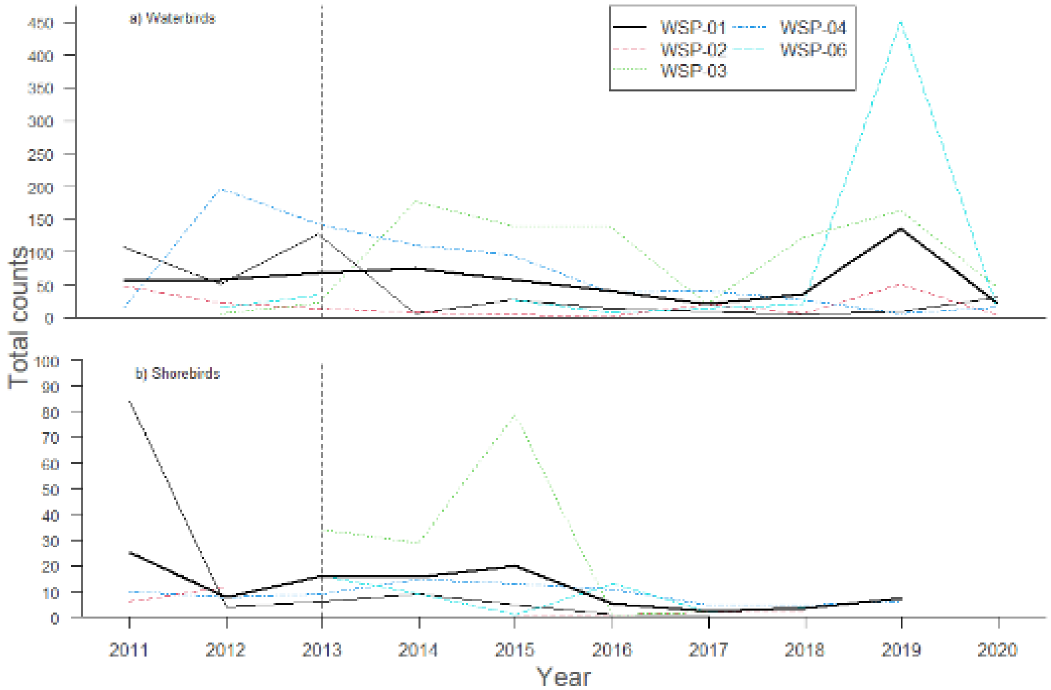

Figure 4. Total counts of migratory birds per transect in Airport Lagoon over time for a) waterbirds, and b) shorebirds. The bold black line is the average count over all transects.

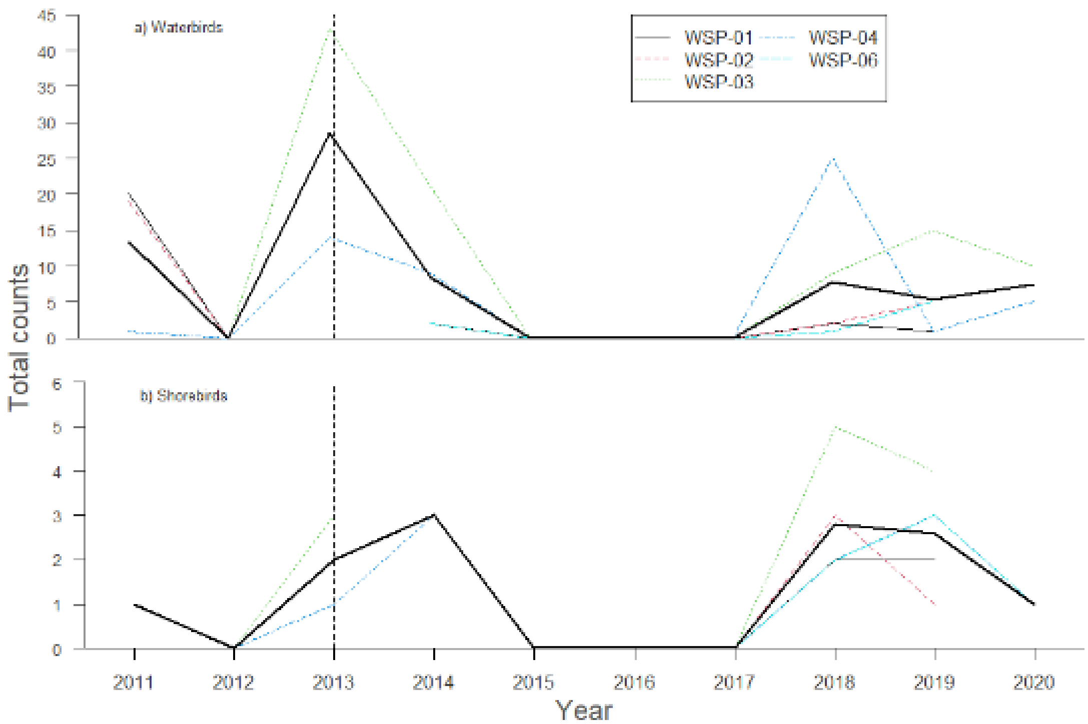

Figure 5. Total counts of breeding birds per transect in Airport Lagoon over time for a) waterbirds, and b) shorebirds. The bold black line is the average count over all transects.

There were no clear differences in species composition between Airport Lagoon and Beaver Pond (Figure 6a). Likewise, there was not a clear trend in species composition over time; although observations from breeding seasons in 2018, 2019, and 2020 tended to cluster together more (see on bottom left of the ordination diagram, Figure 7). Observations in the pre-enhancement period were generally clustered together on the right-top portion of the ordination.

Species composition of migratory birds generally were more similar together than to species composition of breeding birds.

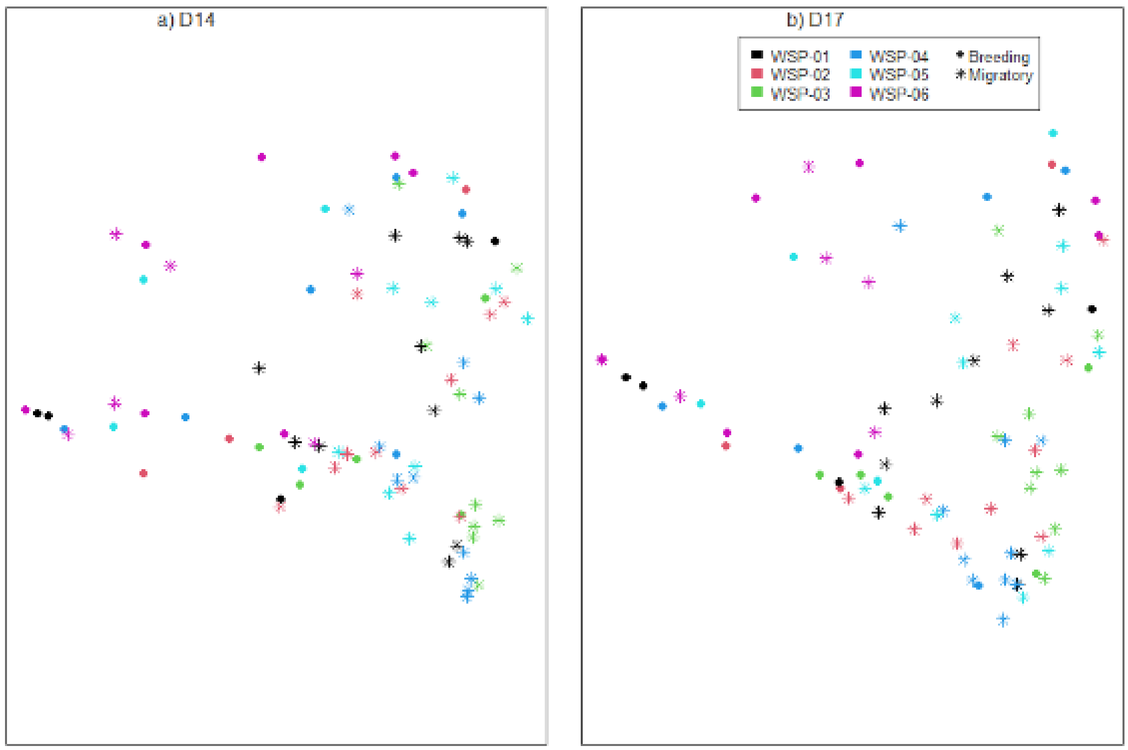

Figure 6. PCoA diagram showing the similarity in species composition of waterbirds and shorebirds among plots over time in Airport Lagoon and Beaver Pond as computed with a) Bray-Curtis distance (D14), and b) Euclidian distance (D17). Axis X explains 18% and axis Y explains 13% of the variation in species composition for D14 and 18% and 16% for D17. Colors code for plots sampled and symbols refer to the season of sampling.

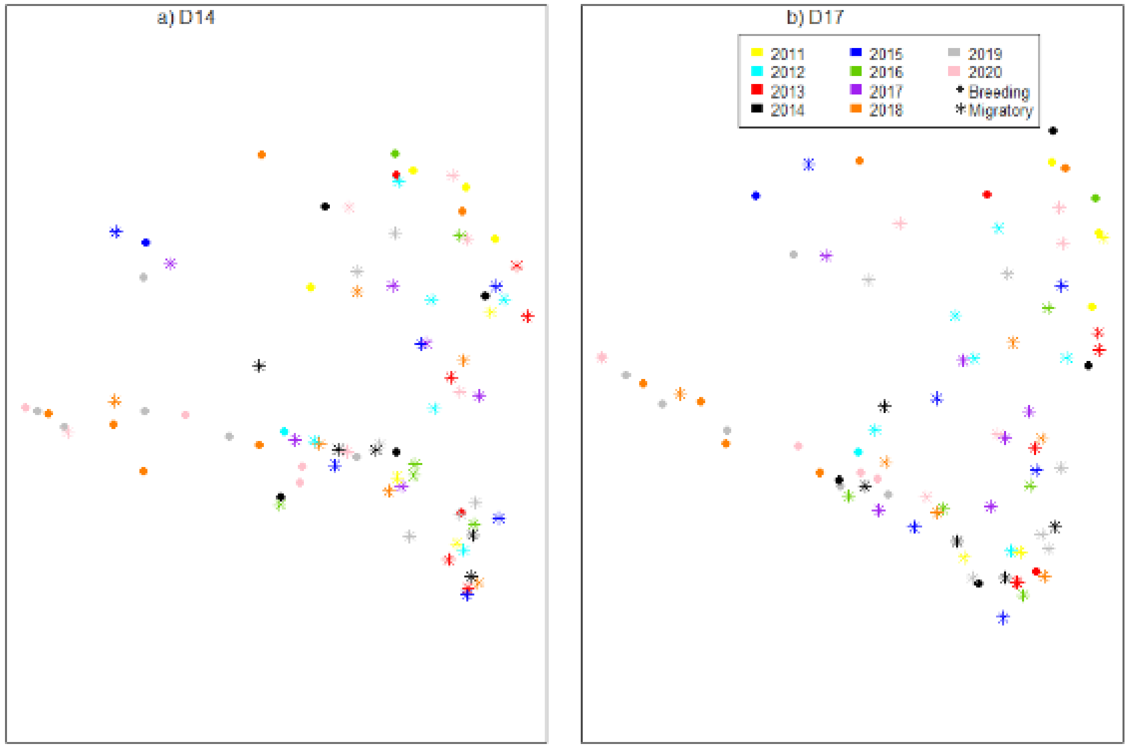

Figure 7. PCoA diagram showing the similarity in species composition of waterbirds and shorebirds among plots over time in Airport Lagoon and Beaver Pond as computed with a) Bray-Curtis distance (D14), and b) Euclidian distance (D17). Axis X explains 18% and axis Y explains 13% of the variation in species composition for D14 and 18% and 16% for D17. Colors code for years of sampling and symbols refer to the season of sampling.

Waterbird and shorebird observations can be easily split between the two wetland sites (Figure 8). At Beaver Pond, Spotted Sandpiper was the indicator species that was present in each year during the post-enhancement period. At Airport Lagoon, species assemblages varied by season. Gull species (Ringed-billed Gull, Herring Gull) were indicators during the breeding season, whereas several waterfowl (duck) species had more influence on the species composition during the migratory period (Table 4).

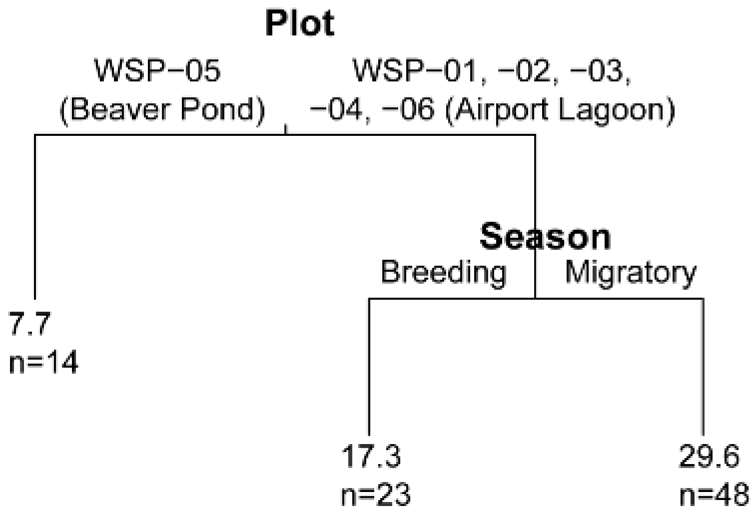

Figure 8. Multivariate regression tree (MRT) showing the partition of plots based on waterbirds and shorebirds species compositions from 2011 to 2020 in Airport Lagoon and Beaver Pond. Numbers at each leaf are relative errors and number of transects per leaf. The tree explains 10% of the variance in species composition.

Table 4. Indicator waterbird and shorebird species for each leaf of the MRT.

Leaf	Species	Indval	p-value	Characteristics
1	**SPSA**	**0.43**	**0.002**	WSP-05 (Beaver Pond)
2	RBGU	0.2	0.028	WSP-01, 02, 03, 04, 06 (Airport Lagoon), in the breeding season
	HEGU	0.17	0.025	
3	AMWI	0.43	0.001	WSP-01, 02, 03, 04, 06 (Airport Lagoon), in the migratory season
	MALL	0.41	0.004	
	GWTE	0.39	0.005	
	COME	0.33	0.003	
	BUFF	0.31	0.009	
	LEYE	**0.27**	**0.045**	
	RNDU	0.21	0.048	
	BAGO	0.19	0.041	
	GADW	0.17	0.04	
	LESC	0.17	0.045	

Confirmed observations of breeding waterbirds were relatively low throughout the monitoring program. Confirmed breeding was not recorded in 2014, 2015 and 2016. For other years, breeding records were limited to 1-3 observations per year. Confirmed breeding was determined based on observations of birds on the nest and by the presence of broods. Waterfowl breeding was confirmed at Airport Lagoon only and breeding species included Bonaparte's Gull, Canada Goose, Common Loon, Northern Shoveler, Trumpeter Swan and Tundra Swan.

Discussion

Both the enhanced wetland sites at Airport Lagoon and Beaver Pond were being used by waterbirds and shorebirds during the migratory and breeding periods.

Airport Lagoon

Species richness of waterbirds and shorebirds was generally higher at Airport Lagoon in the post-enhancement period; although survey effort the post-enhancement period was completed over seven years compared to the three years in the pre-enhancement period. The longer monitoring period allowed for capturing greater annual variation, which may have influenced the higher species richness. However, this longer time series provided stronger evidence of waterbird and shorebird species using the enhanced site. The data also showed higher occurrence of waterbirds and shorebirds during the migratory period, so it appeared the enhanced habitats at Airport Lagoon were being used as a stopover site for several species.

There was a diverse mix of waterfowl species using the site, including dabbling ducks, diving ducks, geese, and swans. Other water-associated birds were predominantly recorded during the post-enhancement period.

Upon closer examination, more birds were using the northern sections of Airport Lagoon. The water depths at the northern end of Airport Lagoon are typically shallower and there were likely better foraging opportunities for birds here. Riparian and aquatic vegetation were more prolific here compared to the southern areas where there was more coarse woody debris and shoreline sand. The northern sections were also typically ice-free earlier that other sections of the site during the migration period. Ice cover was recorded during several surveys in late April, but during these surveys sections of open water were present in the northern section where birds were observed.

Beaver Pond

Construction of the berm at Beaver Pond resulted in more water being impounded compared to the pre-enhancement condition, where the water feature was limited to a drainage channel. It is clear from the monitoring program that waterbirds and shorebirds are using this feature, but the occurrence of species within these subgroups was relatively lower than what was observed at Airport Lagoon. This is likely a reflection of the size of the impounded area at Beaver Pond and the lower habitat complexity, compared to Airport Lagoon.

Like Airport Lagoon, more waterbirds and shorebirds appear to be using Beaver Pond during migration, but there were similarities in the total number of birds observed between the migratory and breeding periods.

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Appendix 4

Analysis of Songbird Data

Introduction

The wetland enhancements at Airport Lagoon and Beaver Pond were designed to address the lack of riparian and wildlife habitat around the Williston Reservoir (BC Hydro 2008). The effectiveness of the enhanced wetland habitats was monitored by collecting annual data on the presence and abundance of songbird species to address the following management question:

> MQ2: Are the enhanced (or newly created) wetlands used by waterfowl and other wildlife [songbirds]?

The primary hypothesis to be tested was:

> H_3: The species composition and density of songbirds changes following enhancement.

Data collection for songbirds commenced in Year 1 (2011) of GMSMON-15 and was conducted each year to 2019. Data collection was conducted in 2020 using alternative methods presented separately.

Methods

Data collection on songbird species commenced in 2011. General survey methods for songbirds were consistent each year and followed provincial standards and established protocols (Ralph et al. 1995, RIC 1999, Bird Studies Canada 2009; MacInnis et al. 2017). Surveys were conducted at seventeen point count stations at Airport Lagoon and three point count stations at Beaver Pond (Figure 1). Three surveys (replicates) were conducted between 30 May and 15 June each year. Point count surveys were conducted during acceptable weather conditions according to modified standards (RIC 1999; Hentze and Cooper 2006). Surveys commenced at dawn and ended within four hours to capture the most stable song period (Ralph et al. 1995). At each station, counts were conducted for a duration of 5 minutes, during which all birds detected were recorded. Each detection was assigned to a temporal category based on the time of detection (0-3 and 3-5 minutes), and the species, sex, age, detection distance from the point count centre, direction to the bird, detection type, and habitat was recorded. Additional comments, such as breeding evidence, were also noted. Point count surveys were not completed in 2020 due to COVID-19 travel restrictions.

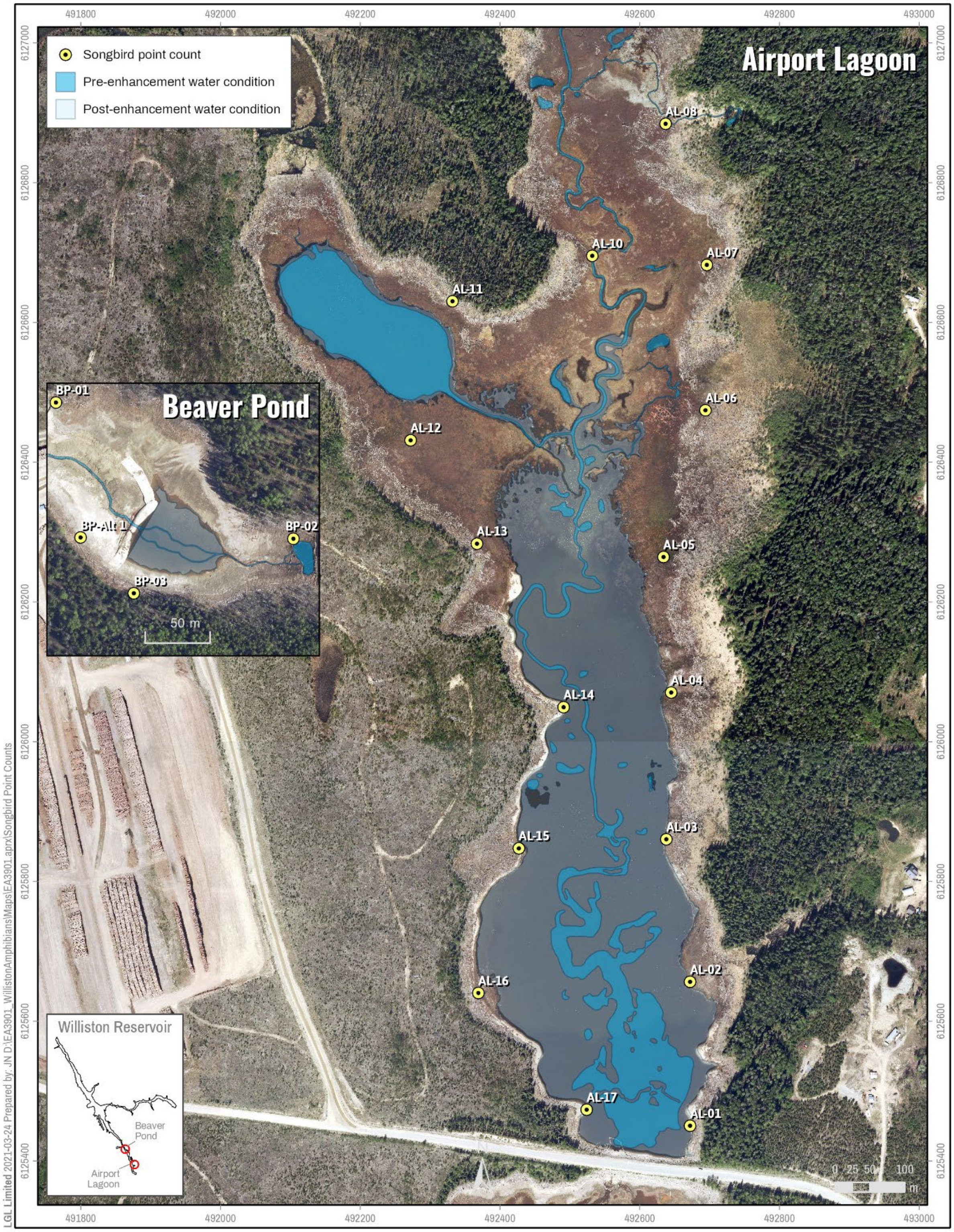

Figure 1. Songbird point count and ARU survey stations at Airport Lagoon and Beaver Pond (inset) sampled from 2011 to 2020 as part of GMSMON-15.

Dataset

This dataset was created to assess the composition, abundance, richness, diversity and habitat associations of songbird species observed during the pre-enhancement, construction and post-enhancement periods at Airport Lagoon and Beaver Pond. A total of 64 songbird (including hummingbirds and woodpeckers) species were observed during the monitoring program within the constrained dataset (see below), including 63 species at Airport Lagoon over 17 point count stations and 35 species at Beaver Pond over three point count stations.

Songbird data were summarized based on the point count station as the basic sampling unit. Point count data were constrained to passerine (i.e., "songbirds"), hummingbird and woodpecker detections. Hereafter the term "songbird" is used for this whole grouping for ease of communication, while acknowledging that it is taxonomically incorrect. Birds detected flying over a station were excluded, as these individuals are not utilizing the treatment area, with the exception of swallows and hummingbirds. Swallows were included as fly-overs as their foraging over the point count area could be related to wetland habitat enhancement as they are aerial insectivores. Point count data was further constrained to only observations within 75 m of the point count centre. This was to ensure that only individuals most associated with wetland enhancement were included and to ensure consistency among all years of data collection. We analyzed the songbird data by first computing the maximum count of individuals seen per species, per station per year over all visits.

Trends in counts and species richness were summarized over time and among periods (pre-, during, and post enhancement). A series of general linearized mixed models (GLMMs, Zuur et al. 2009) were built to assess the significance in total count (all species combined) and species richness among periods (a method similar to repeated measures ANOVAs but allowing more flexibility with highly unbalanced designs). We fit two types of models for each study area separately; both models included a fixed factor for period (with levels of before, during, and after enhancement) and a random effect for point count station to account for the repeated-measure nature of the data. The first model was a GLMM with log of total count or richness of the form: $\log(TCount) = \beta1*period + \beta0$. The other model was a GLMM with a Poisson distribution (with a log-link). We looked at diagnostic plots to assess which model performed better in terms of fit. The magnitude of effects for period was computed as the exponent of the regression coefficient for the fixed effect for both the log and the Poisson models (since they were both on a log-scale). The magnitude of effect indicates how much more (or less) the average total count or richness in the post-enhancement period was compared to the pre-enhancement period. Differences in species composition over time were assessed with Principle Coordinates Analysis (PCoAs) and Multivariate Regression Trees (MRTs) with years and plots used as explanatory variables.

We also used MRTs to look at relationships between songbirds and habitat characteristics in each site. We computed total cover of vegetation, total cover of shrubs, and total richness in vegetation species sampled at the same plots as songbirds. We included these three vegetation variables, as well as plots and years, to the MRT and assessed their influence on songbird composition. To further explore the correlation between songbird and vegetation species, we ran the Kendall W test of species concordance (Legendre 2005). The objective was to find group of songbird and vegetation species that were concordant in their association to environmental characteristics (i.e., whether species were distributed independently of one another across the study area). Species associations may be better predictors of environmental conditions than individual species because they are less subject to sampling error (Legendre 2005). We transformed species counts and covers with the Hellinger distance to make them suitable to analyses that preserve Euclidian distances (Legendre and Gallagher 2001). We then computed an overall test of independence of all species in the study and grouped the species with K-Means partitioning (after standardizing the species data). We determined which of the individual species were concordant with one or several of the other species by testing with permutations, within each group, the contribution of each species to the overall statistic (Legendre 2005). To preserve an approximately correct experiment-wise error rate, the probabilities of the tests were adjusted for multiple testing (Legendre 2005) by using the correction of Holm and 100,000 permutations. Results were shown on a Principal Component Analysis (PCA) to illustrate the correlation among species (scaling of type 2).

All analyses were performed in the R software language (version 4.0.3).

Analysis

A total of 64 songbird species were recorded within 75 m of point counts over all years at all stations (Airport Lagoon and Beaver Pond study sites combined). This included 63 species sampled from Airport Lagoon and 35 at Beaver Pond. At Airport Lagoon, between 23 (2016) and 44 (2018) species were recorded in any given year, with 15 species seen on only one year. A total of 16 species were seen on eight or nine years of the nine-year survey period. At Beaver Pond, between 11 (2015) and 23 (2019) species were recorded in any given year, with 12 species seen on only one year. A total of eight species were seen on eight or nine years of the nine-year survey period.

There was no obvious change in total counts of songbirds in Airport Lagoon before, during, or after wetland enhancement, though several point count stations showed an increase post-enhancement (Figure 2). Likewise, there was no clear trend in total counts of songbirds for Beaver Pond.

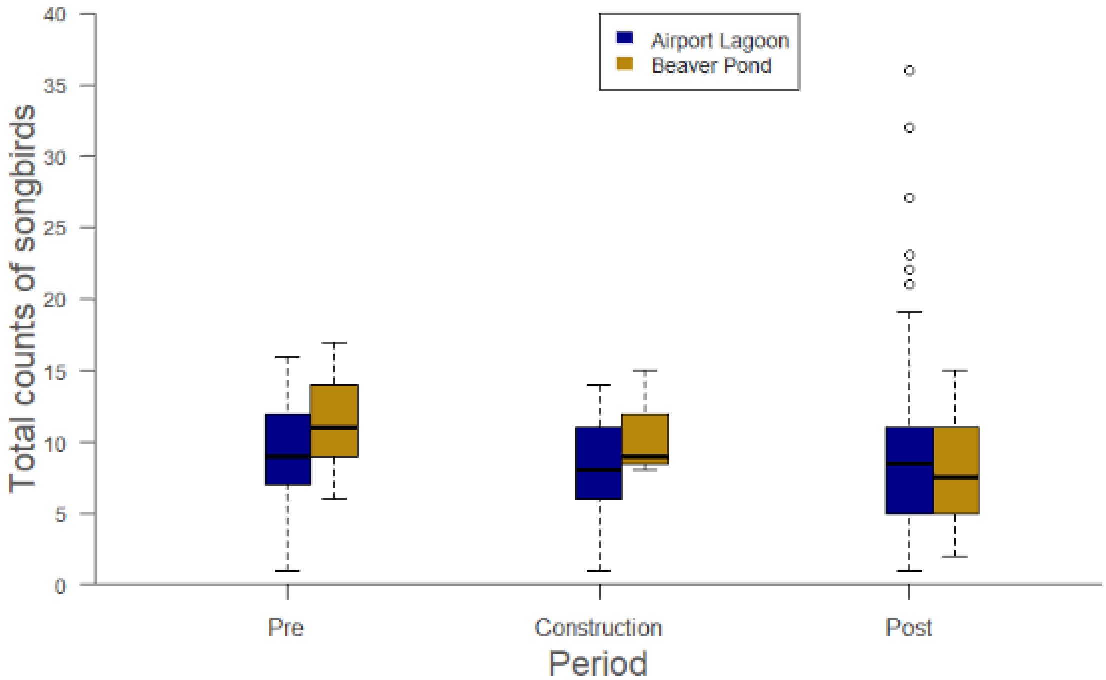

Figure 2: Total counts of songbirds across all plots sampled before, during and after construction in Airport Lagoon and Beaver Pond enhancement sites.

Total counts generally varied between a maximum of 5 to 15 individuals per point count for most years in Airport Lagoon (Figure 3) and Beaver Pond (Figure 4). Generally, total counts declined during construction in 2013 in Airport Lagoon for most point counts, before remaining rather stable from 2014 until 2017, and increasing for most point counts in 2018 (Figure 3). Point counts that saw increases in counts in 2018 showed declines in counts in 2019, whereas point counts that were stable in 2018 show an increase in counts in 2019. Highest counts of songbirds were sampled in 2018 at stations AL-7 and AL-16, followed by AL-13 in 2019. In Beaver Pond, total counts for all three point counts increased from 2011 to 2013, before decreasing during construction (2014) and following construction until 2017 for BP-1 and BP-2; total counts in both point counts increased again in 2018 (Figure 4). Counts in BP-3 reached a maximum in 2017 and decreased afterwards. Highest counts following construction (2017 and 2018) reached the same maximum (around 15 individuals) as before construction in 2013.

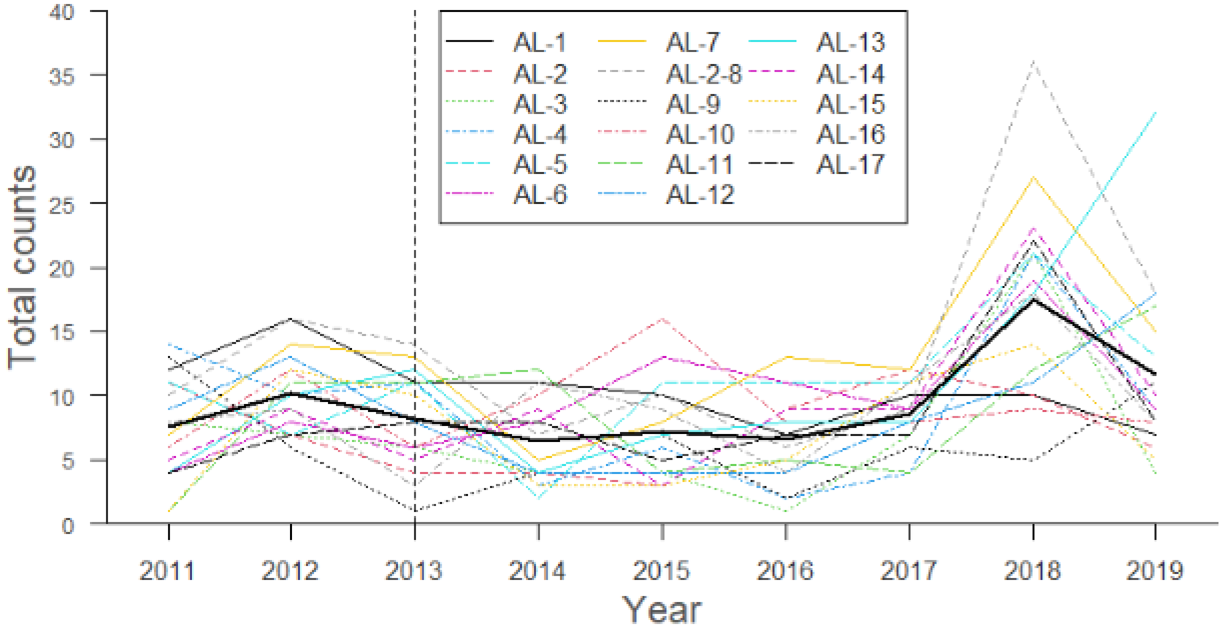

Figure 3. Variation in total counts of songbirds over time in Airport Lagoon. The vertical dotted line indicates when construction occurred, and the dark black line is the average over all plots per year.

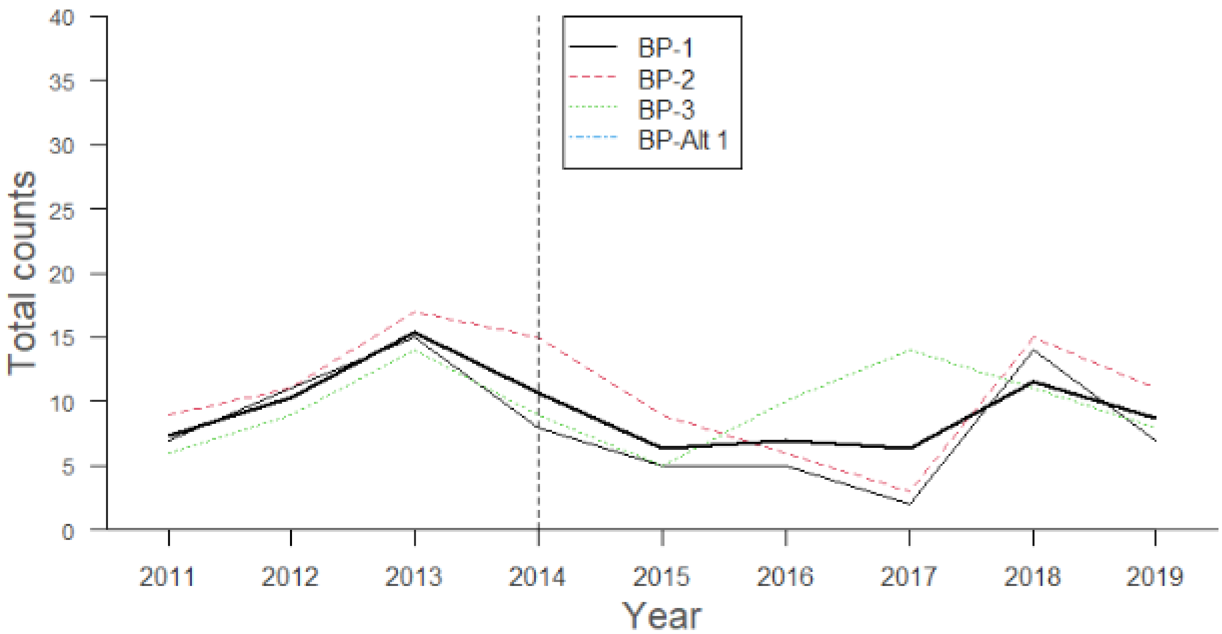

Figure 4. Variation in total counts of songbirds over time in Beaver Pond. The vertical dotted line indicates when construction occurred, and the dark black line is the average over all plots per year. Note point count BP-Alt 1 was only sampled in 2018.

Species richness appeared relatively stable over time in Airport Lagoon, with an average of about 6 species (Figure 5). Species richness was slightly higher in Beaver Pond and appeared to decline slightly on average in the post-enhancement period. Species richness varied a lot among point count stations in both sites but appeared to peak in the year before construction both in Airport

Lagoon (2012) and Beaver Pond (2013), and again in 2018 for most plots (Figure 6 Figure and Figure 7).

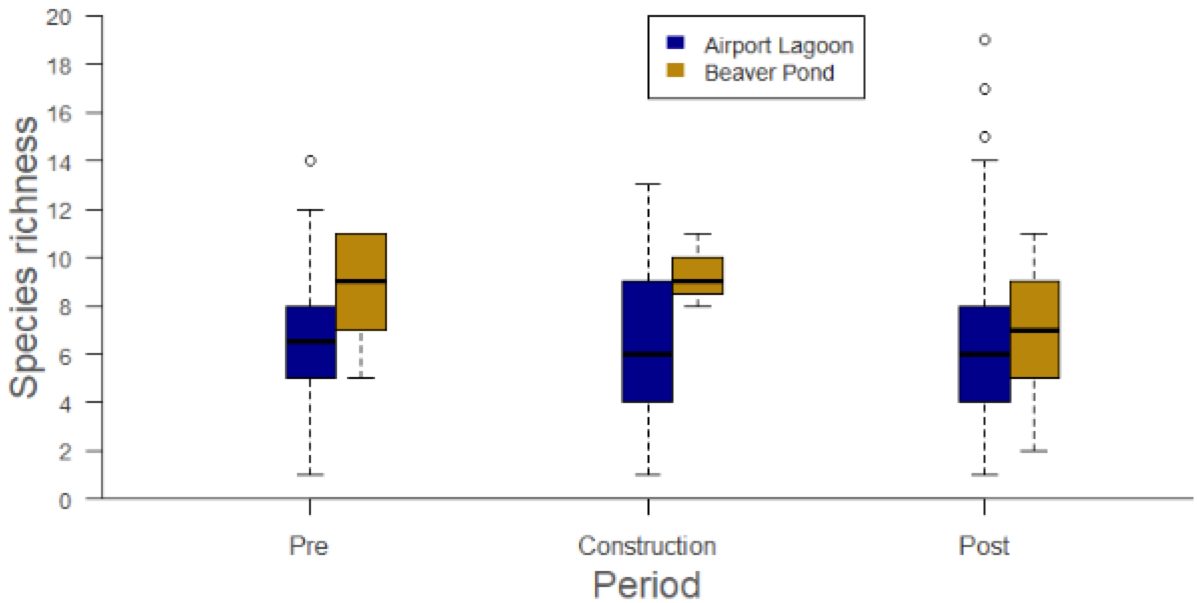

Figure 5. Richness in species of songbirds across all plots sampled before, during and after construction in Airport Lagoon and Beaver Pond.

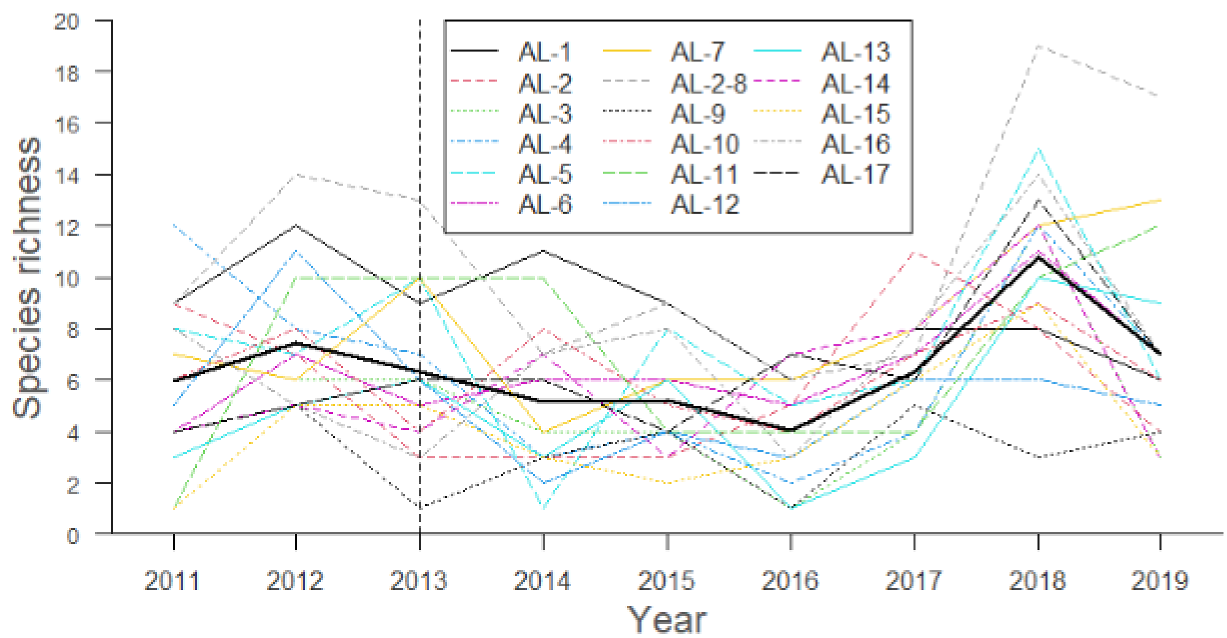

Figure 6. Variation in richness of songbird species over time in Airport Lagoon. The vertical dotted line indicates when construction occurred, and the dark black line is the average over all plots per year.

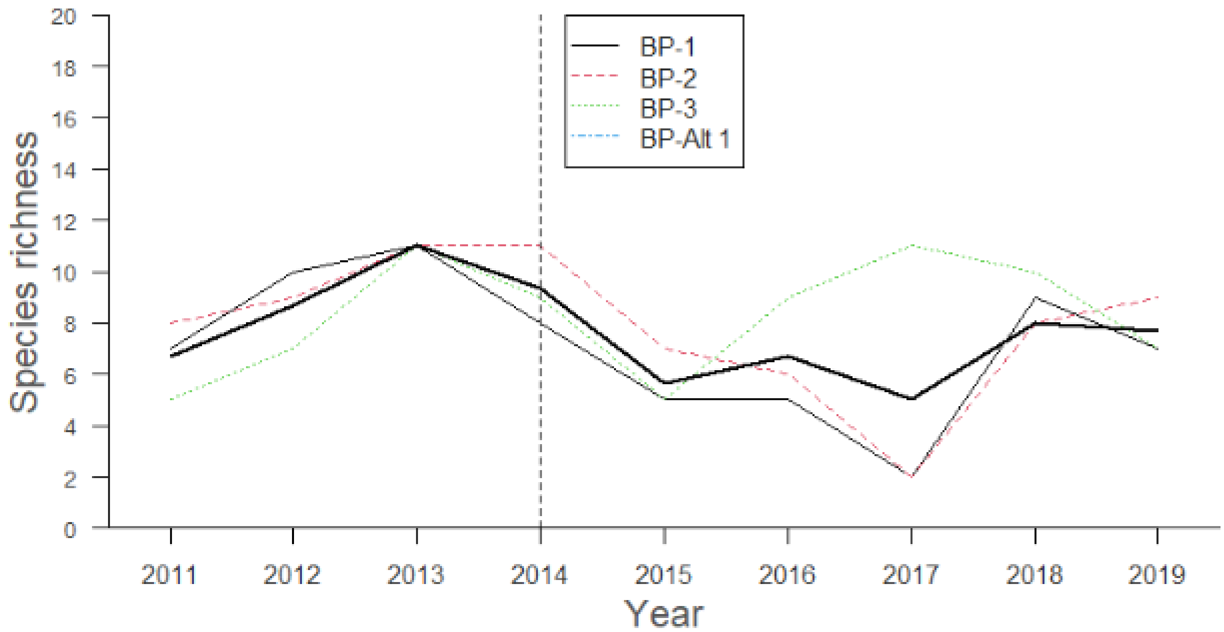

Figure 7. Variation in richness of songbird species over time in Beaver Pond. The vertical dotted line indicates when construction occurred, and the dark black line is the average over all plots per year.

There were no significant differences in total counts or species richness among the pre-, during or post-enhancement periods in Airport Lagoon (α=0.05). Diagnostic plots were generally reasonable, though not excellent, given a relatively small sample size. No model could be fit for Beaver Pond given the low number of point count stations.

Generally, species composition of some point count stations (e.g., AL-17, AL-8, AL-14) in Airport Lagoon seemed more similar in 2017 to 2019 than in other years, whereas plots from 2011 to 2013 seem to also cluster more closely together (Figure 8Figure). Results were similar for D14 and D17, suggesting abundant species did not have strong influences on the similarity among plots. No clear trends over time were obvious for species composition of songbirds at Beaver Pond (Figure 9Figure).

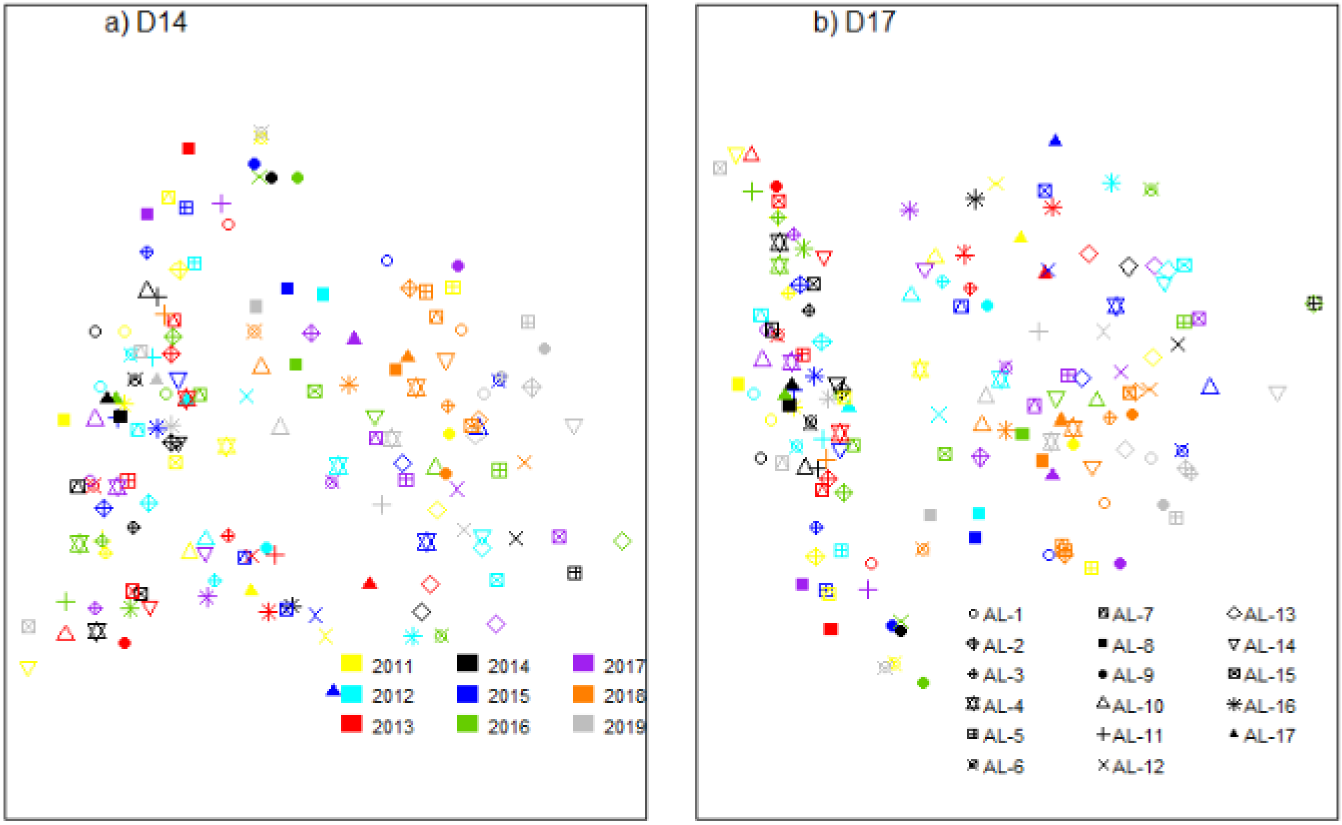

Figure 8. PCoA diagram showing the similarity in species composition of songbirds among plots over time in Airport Lagoon as computed with a) Bray-Curtis distance (D14), and b) Euclidian distance (D17). Axis X explains 16% and axis Y explains 12% of the variation in species composition for D14 and 13% and 9% for D17. Colors code for years of sampling and symbols refer to plots sampled.

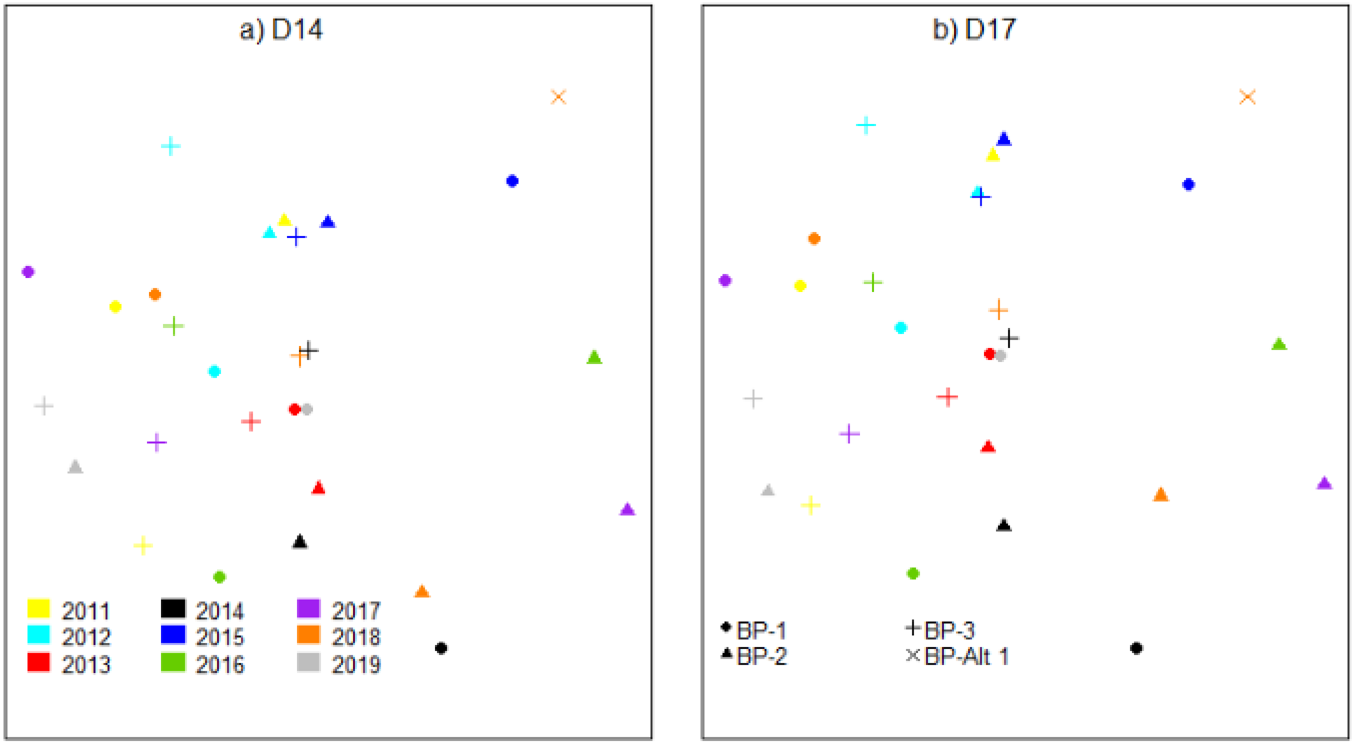

Figure 9. PCoA diagram showing the similarity in species composition of songbirds among plots over time in Beaver Pond as computed with a) Bray-Curtis distance (D14), and b) Euclidian distance (D17). Axis X explains 24% and axis Y explains 20% of the variation in species composition for D14 and 17% and 14% for D17. Colors code for years of sampling and symbols refer to plots sampled.

Species composition varied by point count station. Based on the MRT the stations AL-4 to AL-9 were most different from the other plots in terms of species composition (Figure 10). These stations were all on the eastern/northeastern section of the site and were characterized by Tennessee Warbler, Lincoln's Sparrow, and Yellow Warbler among others (Table 1). All other stations grouped together and were characterized by forest species such as Yellow-rumped Warbler, Orange-crowned Warbler and Hammond's Flycatcher. There was no influence of year on the clustering of stations or species composition.

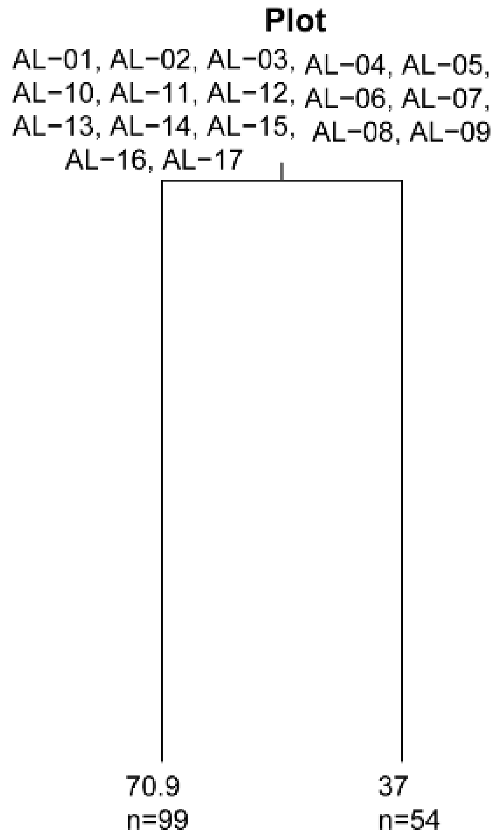

Figure 10. Multivariate regression tree (MRT) showing the partition of plots based on songbird species compositions from 2011 to 2019 in Airport Lagoon. Numbers at each leaf are relative errors and number of transects per leaf. The tree explains 4% of the variance in species composition.

Table 1. Indicator songbird species for each leaf of the MRT in Airport Lagoon.

Leaf	Species	Indval	pvalue	Characteristics
1	YRWA	0.33	0.002	AL-01, AL-02, AL-03, AL-10, AL-11, AL-12, AL-13, AL-14, AL-15, AL-16, AL-17
	OCWA	0.25	0.009	
	HAFL	0.11	0.049	
2	TEWA	0.41	0.001	AL-04, AL-05, AL-06, AL-07, AL-08, and AL-09
	LISP	0.39	0.005	
	YEWA	0.36	0.001	
	SOSP	0.24	0.001	
	SAVS	0.22	0.002	
	ALFL	0.18	0.001	
	LEFL	0.18	0.002	

At Beaver Pond, plots split in two groups (BP-02 and BP-Alt 1 on one side, and BP-01 and BP-03 on the other) with no influence of year (Figure 11). Dark-eyed Junco and Tree Swallow were indicator species for the first group, and Warbling Vireo for the latter (Table 2).

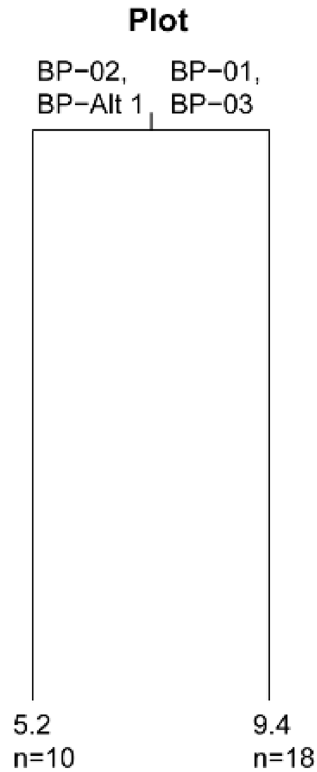

Figure 11. Multivariate regression tree (MRT) showing the partition of plots based on songbird species compositions from 2011 to 2019 in Beaver Pond. Numbers at each leaf are relative errors and number of transects per leaf. The tree explains 7% of the variance in species composition.

Table 2. Indicator songbird species for each leaf of the MRT in Beaver Pond

Leaf	Species	Indval	pvalue	Characteristics
1	DEJU	0.52	0.031	BP-02 and BP-Alt 1
	TRES	0.41	0.026	
2	WAVI	0.54	0.048	BP-01 and BP-03

To investigate species composition differences, we compared species by vegetation characteristics of the point count stations. Total cover of vegetation, total richness in vegetation species, plot and years explained 26% of the variation in songbird species composition (total cover of shrub did not influence the partition) (Figure 12). All plots sampled after 2015 were more similar in terms of songbird species composition than before, whereas the vegetation cover and richness influenced the partition of point count stations based on species composition before 2015. Tree Swallow was an indicator of leaf 2, made of stations AL-05, AL-12, AL-13, AL-14, AL-15, and AL-16 before 2015 with total vegetation cover below 14%, whereas Pine Siskin and Calliope Hummingbird were indicators of stations AL-02, AL-03, and AL-11 before 2015 (Table 3Table). Mountain Bluebird was an indicator of all plots after 2015 (leaf 6).

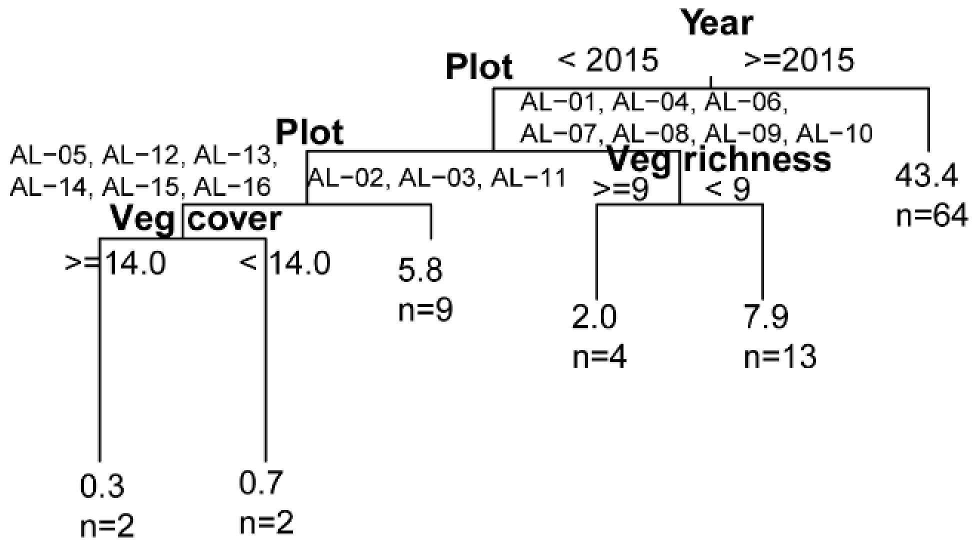

Figure 12. Multivariate regression tree (MRT) showing the partition of plots based on songbird species composition and vegetation characteristics from 2012 to 2019 in Airport Lagoon. Numbers at each leaf are relative errors and number of transects per leaf. The tree explains 26% of the variance in songbird species composition.

Table 3. Indicator songbird species for each leaf of the MRT in Airport Lagoon

Leaf	Species	Indval	pvalue	Characteristics
1	--	--	--	Plots AL-05, AL-12, AL-13, AL-14, AL-15, AL-16 before 2015 with total cover of vegetation above 14%
2	TRES	0.45	0.001	Plots AL-05, AL-12, AL-13, AL-14, AL-15, AL-16 before 2015 with total cover of vegetation below 14%
3	PISI CAHU	0.66 0.49	0.009 0.024	Plots AL-02, AL-03, AL-11 before 2015
4	--	--	--	Plots AL-01, AL-04, AL-06, AL-07, AL-08, AL-09, AL-10 before 2015 with total vegetation richness equal or above 9
5	LISP	0.33	0.025	Plots AL-01, AL-04, AL-06, AL-07, AL-08, AL-09, AL-10 before 2015 with total vegetation richness below 9
6	MOBL	0.46	0.016	All plots after 2015

Analyses of species association with the Kendall W assessed whether some vegetation and songbird species were significantly found together in plots over time. Species included were present in at least two plots (n=84 species included). The overall test was significant (W=0.37, F=3.2, p=0.0001), and the K-means analyses found that songbird and vegetation species were partitioned along two groups. Only group 2 had significant species' associations (Group 2: W = 0.046, F=3.65, p=0.00001). Results of the K-Means were superposed on a PCA (Figure 13). One songbird species (Least Flycatcher) was significantly associated with five vegetation species in group 2; Figure 13 suggests that Least Flycatcher was found with *Scirpus atrocinctus* (wool-grass) and *Salix bebbiana* (Bebb's willow).

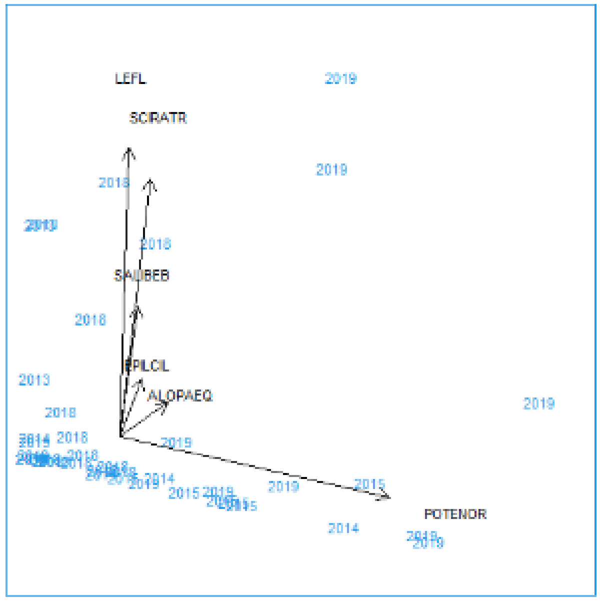

Figure 13. PCA diagram showing significant species associations between songbird and vegetation species of Airport Lagoon (scaling of type 2 represents the correlation among species). Axis X expresses 73% of the variation and axis Y, 12%.

The MRT for Beaver Pond was not very conclusive (explained only 9% of variation in songbirds composition) and only showed a difference in songbirds species composition from before and after 2019, without noted effects of total cover or richness of vegetation, plots or years (Figure 14). Only three species of songbirds were indicative of plots in or after 2019: Savannah Sparrow (0.67, p=0.015), Swainson's Thrush (0.73, p=0.01), and Wilson's Warbler (0.88, p=0.001).

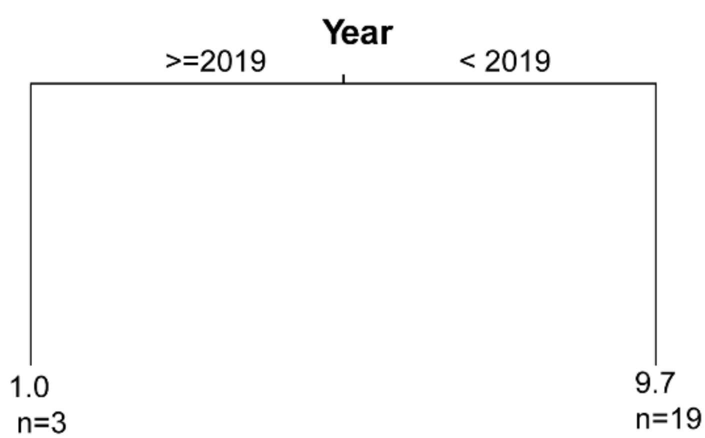

Figure 14. Multivariate regression tree (MRT) showing the partition of plots based on songbird species composition and vegetation characteristics from 2012 to 2019 in Beaver Pond. Numbers at each leaf are relative errors and number of transects per leaf. The tree explains 8.7% of the variance in songbird species composition.

Analyses of species association with the Kendall W assessed whether some vegetation and songbird species were significantly found together in plots over time in Beaver Pond. Species included were present in at least two plots (n=32 species included).

The overall test was barely significant (W=0.0.049, F=1.6, p=0.083), and the K-means analyses found that songbird and vegetation species were partitioned along two groups. Both groups had significant species' associations, but none included songbird species (Group 1: W = 0.29, F=2.8, p=0.003, Group 2: W = 0.14, F=3.67, p=0.00006; (Figure 15).

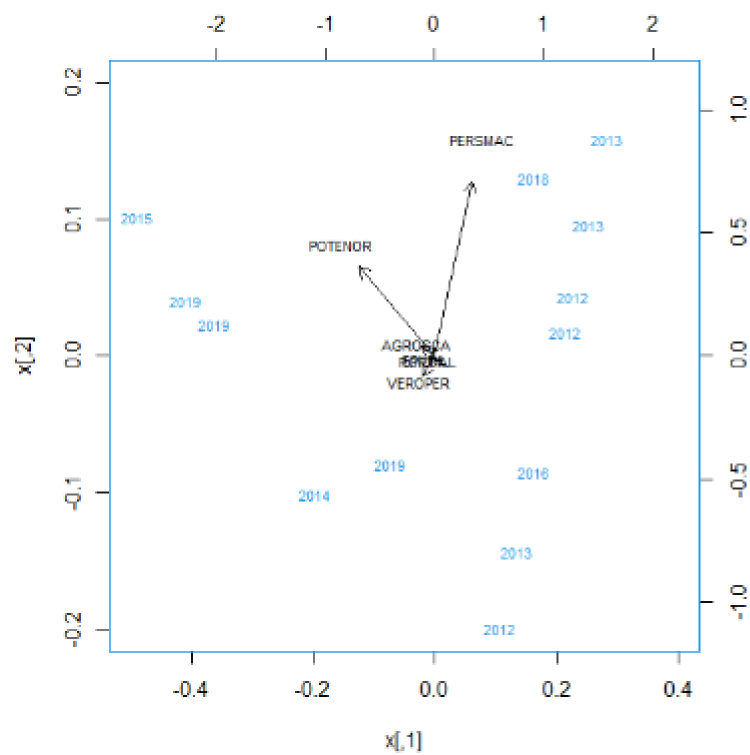

Figure 15. PCA diagram showing significant species associations between songbird and vegetation species of Beaver Pond (scaling of type 2 represents the correlation among species). Axis X expresses 75% of the variation and axis Y, 12%.

As the vegetation results in association with bird species composition were not that informative, analyses were re-run using broader habitat classifications of drawdown zone, shrub and tree. Only birds with those habitat associations recorded were included in analyses. Species richness varied over time. At Airport Lagoon, richness appeared to increase in drawdown zone habitat in the post-enhancement period, while remaining fairly stable in shrub habitats (Figure 16). Forest habitat had an increase in richness in 2018 relative to other years. Beaver Pond had few data points (so is shown as a dot plot rather than boxplot), but richness appeared to increase in drawdown zone and decrease in forest habitats post-enhancement.

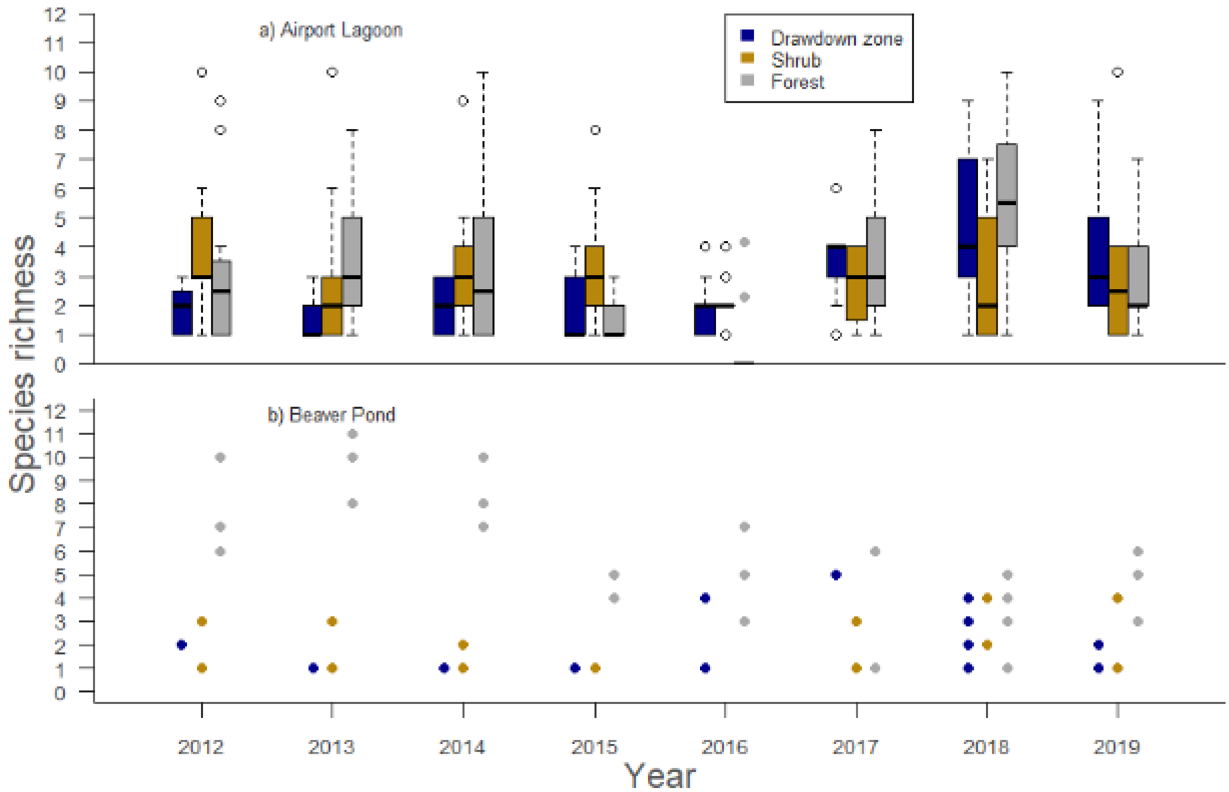

Figure 16. Variation in species richness over time in the drawdown zone, shrub, and forest habitats of a) Airport Lagoon, and b) Beaver Pond.

At Airport Lagoon, songbird species composition was most different between forest/shrub and drawdown zone habitats (Figure 17). Within the drawdown zone, species composition different in years prior to 2017 and those from 2017 onwards. Prior to and during enhancement, as well as the first several years post-enhancement, American Robin, Mountain Bluebird, American Crow and Savannah Sparrow were weakly associated with the drawdown zone (Table 4). After 2017 there was a stronger association of swallows and Lincoln's Sparrow with the drawdown zone. Species such as Yellow-rumped Warbler, American Redstart, and Yellow Warbler were more strongly associated with shrub and forest habitats.

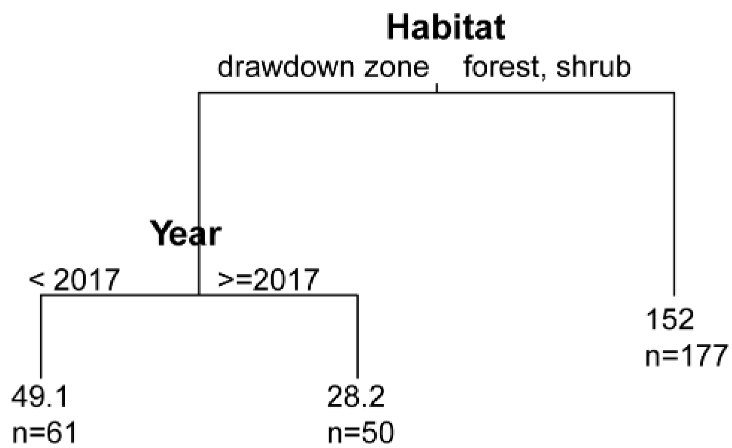

Figure 17. Multivariate regression tree (MRT) showing the partition of plots based on songbird species composition and habitats from 2012 to 2019 in Airport Lagoon. Numbers at each leaf are relative errors and number of transects per leaf. The tree explains 9% of the variance in songbird species composition.

Table 4. Indicator songbird species for each leaf of the MRT in Airport Lagoon.

Leaf	Species	Indval	pvalue	Characteristics
1	AMRO	0.23	0.002	Drawdown zone before 2017
	MOBL	0.15	0.001	
	AMCR	0.11	0.003	
	SAVS	0.09	0.011	
2	TRES	0.63	0.001	Drawdown zone in and after 2017
	LISP	0.41	0.001	
	BARS	0.28	0.001	
	VGSW	0.12	0.001	
	BHCO	0.1	0.003	
	CORA	0.07	0.006	
	BANS	0.06	0.006	
	NRWS	0.06	0.005	
3	YRWA	0.24	0.001	Forest and shrub habitats on all years
	AMRE	0.17	0.001	
	YEWA	0.17	0.001	
	NOWA	0.15	0.002	
	OCWA	0.15	0.003	
	SWTH	0.14	0.002	
	TEWA	0.14	0.005	
	WAVI	0.1	0.01	
	RCKI	0.095	0.012	
	WIWA	0.08	0.029	
	ALFL	0.07	0.031	
	HAFL	0.07	0.026	

At Beaver Pond, songbird species composition was most different between forest and drawdown zone/shrub habitats (Figure 18).There was no influence of year. No species were particular associated with the drawdown zone/shrub habitats at Beaver Pond. Forest habitats were associated with species such as American Redstart, Yellow-rumped Warbler, Warbling Vireo and Swainson's Thrush (Table 5).

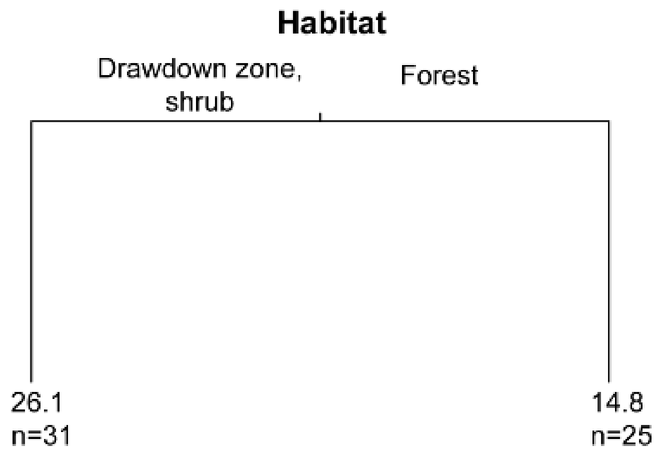

Figure 18. Multivariate regression tree (MRT) showing the partition of plots based on songbird species composition and habitats from 2012 to 2019 in Beaver Pond. Numbers at each leaf are relative errors and number of transects per leaf. The tree explains 9% of the variance in songbird species composition.

Table 5. Indicator songbird species for each leaf of the MRT in Beaver Pond.

Leaf	Species	Indval	pvalue	Characteristics
1	--	--	--	Drawdown zone and shrub habitat
2	AMRE	0.65	0.001	Forest habitat
	YRWA	0.6	0.001	
	WAVI	0.49	0.001	
	SWTH	0.44	0.001	
	OCWA	0.36	0.006	
	MAWA	0.2	0.015	

Discussion

Songbirds are utilizing the suite of habitats available at and near the enhanced wetland sites at Airport Lagoon and Beaver Pond.

Airport Lagoon

Species richness and total counts of songbirds at Airport Lagoon did not appear to significantly differ in the post-enhancement period relative to pre-enhancement; although survey effort in the post-enhancement period was completed over six years compared to the three years in the pre- and during enhancement period. There was a diverse mix of songbird species utilizing the Airport Lagoon study area, and the area seems to support open-country (e.g., drawdown zone associated), forest edge, and forest-associated species. In particular, the drawdown zone bird community is different from the shrub and forest bird community. In addition, the bird community may differ slightly in the northeast section of the study area relative to other areas. However, in general differences were slight or insignificant. The enhancement activities were not designed to benefit songbirds. Overall, the songbird community appeared relatively stable over time, with overall no enhancement impact on overall species abundance or richness.

Beaver Pond

Construction of the berm at Beaver Pond resulted in more water being impounded compared to the pre-enhancement condition, where the water feature was limited to a drainage channel. As with at Airport Lagoon, there was no clear impact of this enhancement activity on songbird abundance or richness. Forest bird communities clustered apart from drawdown zone and shrub communities, but no trends were apparent over time. The lower number of point count stations at Beaver Pond limit statistical extrapolation.

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Appendix 5

Analysis of Songbird Data: Autonomous Recording Units

Introduction

The wetland enhancements at Airport Lagoon and Beaver Pond were designed to address the lack of riparian and wildlife habitat around the Williston Reservoir (BC Hydro 2008). The effectiveness of the enhanced wetland habitats was monitored by collecting annual data on the presence and abundance of songbird species to address the following management question:

> MQ2: Are the enhanced (or newly created) wetlands used by waterfowl and other wildlife [songbirds]?

The primary hypothesis to be tested was:

> H_3: The species composition and density of songbirds changes following enhancement.

Data collection for songbirds commenced in Year 1 (2011) of GMSMON-15 and was conducted each year to 2019. However, due to access restrictions, songbird data in 2020 was collected via autonomous recording units (ARUs). Details of ARU data are presented in this appendix.

Methods

Acoustic autonomous recording units (Wildlife Acoustics Song Meter 4 [SM4]) were temporarily set-up at each point count station (Table 1). Units were deployed as close to the point count stations previously surveys as possible: 17 at Airport Lagoon and 3 at Beaver Pond. Units were deployed at Airport Lagoon on 15 June 2020 and collected 22 June 2020 and deployed at Beaver Pond from 23 June to 07 July 2020. A single 10-minute recording was reviewed from the first hour after sunrise on two dates from each unit (June 16 and 17 for Airport Lagoon stations, and June 24 and 25 for Beaver Pond stations). Only a single date was available for station AL-12 due to ARU malfunction. Acoustic data were manually reviewed, with the species and minute of first detection recorded for each unique species detected. Due to limitations of reviewing data from single recording units, no attempt was made to quantify the number of individuals, and no habitat or distance data could be quantified.

Table 1. Date and locations of ARUs deployed at Airport Lagoon and Beaver Pond in 2020. Deviation from Point Count indicates the distance in metres from the point count station surveyed in 2011-2019 that the ARU was positions. Negative values indicate deviations to the west (if in "East" column) or to the south (if in "North" column).

Station	Date Deployed	Date Retrieved	UTM		Deviation from Point Count (m)	
			Easting	Northing	East	North
Airport Lagoon						
AL-01	15-Jun-20	22-Jun-20	492671	6125451	3	4
AL-02	15-Jun-20	22-Jun-20	492671	6125657	1	6
AL-03	15-Jun-20	22-Jun-20	492637	6125861	6	-3
AL-04	15-Jun-20	22-Jun-20	492644	6126071	0	13
AL-05	15-Jun-20	22-Jun-20	492633	6126265	14	-3
AL-06	15-Jun-20	22-Jun-20	492693	6126475	-8	7
AL-07	15-Jun-20	22-Jun-20	492695	6126683	-1	6
AL-08	15-Jun-20	22-Jun-20	492636	6126885	0	31
AL-09	15-Jun-20	22-Jun-20	492554	6127065	-10	-24
AL-10	15-Jun-20	22-Jun-20	492531	6126696	-10	-4
AL-11	15-Jun-20	22-Jun-20	492331	6126631	-6	5
AL-12	15-Jun-20	22-Jun-20	492271	6126432	4	-22
AL-13	15-Jun-20	22-Jun-20	492366	6126284	54	-51
AL-14	15-Jun-20	22-Jun-20	492490	6126050	-5	-2
AL-15	15-Jun-20	22-Jun-20	492426	6125848	-3	-5
AL-16	15-Jun-20	22-Jun-20	492368	6125641	-4	1
AL-17	15-Jun-20	22-Jun-20	492523	6125474	-22	-3
Beaver Pond						
BP-01	23-Jun-20	07-Jul-20	479204	6148354	0	-1
BP-02	23-Jun-20	07-Jul-20	479387	6148249	-4	8
BP-03	23-Jun-20	07-Jul-20	479264	6148207	-12	2

Dataset

This dataset was created to assess the species composition and richness at the point count stations in 2020 when no surveys were possible due to COVID-19 restrictions. Comparisons were made between 2020 and pre-2020 years (Table 2). Because no visual information is presented, it was not possible to exclude fly-overs or include habitat associations with ARU detections. The dataset includes 20 minutes of recordings reviewed for each ARU (10 minutes each on two dates), excepting the ARU at AL-12 which malfunctioned and only a single date of recordings was reviewable.

Table 2. Number of species detected on songbird point counts in each year from 2011-2019, and maximum, minimum, and average species counts over that time period. Species are presented for ARUs based on a full 10-minutes per recording, and 5-minutes per recording.

Station	Year (20xx)													
	'11	'12	'13	'14	'15	'16	'17	'18	'19	Max	Min	Avg	ARU (10 min)	ARU (5 min)
ALL BIRDS														
AL-01	20	16	10	17	14	15	18	14	16	20	10	15.6	25	20
AL-02	22	20	15	20	11	17	17	22	23	23	11	18.6	24	20
AL-03	16	20	11	18	11	8	13	20	19	20	8	15.1	35	28
AL-04	20	18	11	13	10	16	15	21	24	24	10	16.4	31	28
AL-05	17	14	19	16	20	20	18	23	27	27	14	19.3	25	22
AL-06	16	12	17	11	17	16	17	21	19	21	11	16.2	25	20
AL-07	15	15	14	14	20	18	19	22	24	24	14	17.9	32	25
AL-08	19	19	19	17	15	17	16	28	25	28	15	19.4	24	21
AL-09	18	14	11	14	13	14	14	16	19	19	11	14.8	28	23
AL-10	11	12	7	21	12	12	16	20	18	21	7	14.3	29	26
AL-11	7	19	13	14	10	14	15	20	22	22	7	14.9	26	21
AL-12	7	17	16	13	16	20	18	23	20	23	7	16.7	19	16
AL-13	5	12	11	17	14	18	16	25	24	25	5	15.8	28	24
AL-14	9	10	8	18	8	16	15	17	14	18	8	12.8	29	26
AL-15	11	13	8	14	12	14	13	13	16	16	8	12.7	33	27
AL-16	12	8	8	15	15	10	10	18	16	18	8	12.4	23	21
AL-17	9	9	8	14	9	16	12	18	14	18	8	12.1	29	22
BP-01	11	14	15	11	15	7	10	11	20	20	7	12.7	24	20

BP-02	11	11	14	13	11	9	7	19	26	26	7	13.4	17	15
BP-03	12	11	15	11	8	11	17	13	20	20	8	13.1	20	19
"SONGBIRDS"														
AL-01	9	12	9	11	9	6	8	8	11	12	6	9.2	19	17
AL-02	9	7	3	3	3	5	11	8	12	12	3	6.8	19	18
AL-03	7	6	6	4	4	1	4	12	10	12	1	6.0	29	25
AL-04	12	8	7	3	4	2	4	12	11	12	2	7.0	26	26
AL-05	8	7	10	1	8	5	6	15	15	15	1	8.3	23	21
AL-06	4	7	5	6	6	5	7	11	14	14	4	7.2	21	18
AL-07	7	6	10	4	6	6	8	12	20	20	4	8.8	28	23
AL-08	9	14	13	7	9	6	7	19	23	23	6	11.9	21	19
AL-09	4	5	1	3	4	1	5	3	10	10	1	4.0	24	21
AL-10	6	8	4	8	5	4	7	9	11	11	4	6.9	25	23
AL-11	1	10	10	10	4	4	4	10	14	14	1	7.4	23	18
AL-12	5	11	6	2	4	3	6	6	9	11	2	5.8	17	16
AL-13	3	5	6	3	6	1	3	10	12	12	1	5.4	22	21
AL-14	4	5	4	7	3	7	8	12	10	12	3	6.7	25	23
AL-15	1	5	5	3	2	3	6	9	12	12	1	5.1	29	25
AL-16	8	5	3	7	8	3	8	14	10	14	3	7.3	21	20
AL-17	4	5	6	6	4	7	6	13	10	13	4	6.8	25	21
BP-01	7	10	11	8	5	5	2	9	15	15	2	8.0	21	18
BP-02	8	9	11	11	7	6	2	8	15	15	2	8.6	15	13
BP-03	5	7	11	9	5	9	11	10	13	13	5	8.9	17	16

Analysis

A total of 62 bird species were detected from ARU recordings (Table 3), of which 50 were passerines, hummingbirds and woodpeckers (collectively “songbirds”) as analysed for 2011-2019 data. The number of species (both all species and songbirds) was typically higher than the maximum value recorded during point count surveys when compared with 10-minute recording durations. Fewer species were recorded when reviewing only the first five minutes of each ARU recording. Under this scenario more stations have point counts at or below the recorded maximum based on point count surveys for all birds, though the species totals for only songbirds remains higher than previously recorded maximums even based on just the first five minutes of recordings.

Species not previously detected during point count surveys were identified from all ARU stations except one. One to eight new species were identified per station. At Airport Lagoon there were no species detected from ARU recordings that were not previously detected during point count surveys in that study area. At Beaver Pond there was only one species recorded on ARUs not previously recorded from any point at Beaver Pond (Western Tanager).

Table 3. Birds detected from ARU recordings at each station at Airport Lagoon and Beaver Pond study sites in 2020.

Code	Common Name	Airport Lagoon																	Beaver Pond		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	1	2	3
CANG	Canada Goose	✓								✓											
MALL	Mallard													✓							
RUGR	Ruffed Grouse																		✓		✓
-	Hummingbird sp.							✓													
WISN	Wilson's Snipe	✓	✓	✓												✓		✓	✓	✓	✓
SPSA	Spotted Sandpiper	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SOSA	Solitary Sandpiper	✓	✓	✓																	
LEYE	Lesser Yellowlegs			✓	✓	✓	✓					✓		✓							
BOGU	Bonaparte's Gull		✓		✓		✓	✓			✓	✓	✓	✓	✓	✓		✓			
COLO	Common Loon	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓				
OSPR	Osprey			✓																	
RTHA	Red-tailed Hawk							✓	✓	✓	✓										
BEKI	Belted Kingfisher	✓	✓	✓														✓			
HAWO	Hairy Woodpecker	✓	✓	✓			✓														
NOFL	Northern Flicker	✓	✓			✓	✓	✓			✓	✓		✓	✓				✓	✓	✓
PIWO	Pileated Woodpecker		✓	✓	✓	✓				✓		✓		✓	✓	✓	✓	✓			
-	Sapsucker sp.			✓															✓		✓
OSFL	Olive-sided Flycatcher							✓	✓	✓			✓								
WEWP	Western Wood-Pewee																				
ALFL	Alder Flycatcher				✓	✓	✓		✓			✓		✓	✓		✓				
LEFL	Least Flycatcher						✓	✓	✓	✓	✓										
HAFL	Hammond's Flycatcher	✓		✓	✓		✓	✓			✓		✓			✓	✓				✓
DUFL	Dusky Flycatcher																	✓			
WAVI	Warbling Vireo	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
REVI	Red-eyed Vireo																	✓	✓		
AMCR	American Crow	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓			
CORA	Common Raven			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TRES	Tree Swallow	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Code	Common Name	Airport Lagoon																	Beaver Pond		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	1	2	3
NRWS	Northern Rough-winged Swallow									✓				✓					✓		
BCCH	Black-capped Chickadee			✓																	
RBNU	Red-breasted Nuthatch	✓	✓	✓	✓	✓		✓	✓		✓				✓	✓	✓	✓			
PAWR	Pacific Wren	✓	✓	✓	✓	✓	✓								✓	✓	✓	✓			
GCKI	Golden-crowned Kinglet				✓	✓		✓			✓										
RCKI	Ruby-crowned Kinglet	✓		✓	✓			✓	✓	✓	✓	✓			✓	✓		✓			✓
SWTH	Swainson's Thrush	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
HETH	Hermit Thrush												✓		✓	✓	✓	✓			
AMRO	American Robin		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
VATH	Varied Thrush				✓									✓	✓	✓					
CEDW	Cedar Waxwing	✓		✓	✓	✓	✓	✓			✓			✓	✓	✓	✓		✓	✓	
EVGR	Evening Grosbeak			✓	✓										✓						
PUFI	Purple Finch																		✓		
PISI	Pine Siskin	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CHSP	Chipping Sparrow	✓	✓	✓				✓		✓	✓	✓	✓	✓		✓		✓			
DEJU	Dark-eyed Junco	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓		
WCSP	White-crowned Sparrow												✓			✓					
WTSP	White-throated Sparrow	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
SAVS	Savannah Sparrow							✓	✓	✓	✓			✓	✓						
SOSP	Song Sparrow					✓			✓	✓	✓					✓				✓	
LISP	Lincoln's Sparrow	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
BHCO	Brown-headed Cowbird															✓					
OVEN	Ovenbird				✓														✓	✓	✓
NOWA	Northern Waterthrush		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓			✓
TEWA	Tennessee Warbler			✓		✓		✓	✓	✓	✓							✓			
OCWA	Orange-crowned Warbler	✓	✓	✓		✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
MGWA	MacGillivray's Warbler	✓	✓		✓		✓					✓			✓	✓		✓			
COYE	Common Yellowthroat			✓		✓		✓		✓								✓			
AMRE	American Redstart	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓
MAWA	Magnolia Warbler																		✓	✓	✓
YEWA	Yellow Warbler			✓	✓											✓					
YRWA	Yellow-rumped Warbler				✓						✓	✓	✓		✓				✓	✓	✓

Discussion

ARU recordings served as a proxy songbird occurrence during 2020 when point count surveys could not be conducted. Reviewing recordings indicated that most species had already been documented during multiple years of point count surveys, and only one new species was detected from Beaver Pond where the fewest number of point count stations occurred. However, at the level of individual point count stations several species not previously documented were recorded from almost every station. As most ARUs were installed relatively close to the point count survey locations, it is unlikely that differences in sampling location can explain this trend. This may in part be due to observer differences (the biologist reviewing recordings had not previously done point count surveys at these locations) or recording attributes (birds flying over or recorded from a distance may not have been as evident to ground-based observers focusing on birds within 100 m of the station). Recordings also offer the benefit of being able to replay sounds as often as desired or reviewing entire blocks of time. It was not possible to get habitat use details or quantify the number of individual birds or distance from the recording location to the bird. ARUs also offer the disadvantage of relying 100% on bird sounds in order to detect presence. With these considerations aside, ARUs have proven to be useful for confirming species occurrence in the vicinity of point count stations.

References

BC Hydro. 2008. Peace River Water Use Plan, Monitoring Program Terms of Reference, GMSMON-15 Reservoir Wetland Habitat. BC Hydro and Power Authority, Burnaby, BC. 11 pp.

Appendix 6

Analysis of Amphibian Data

Introduction

Amphibians were identified as a target species group for GMSMON-15 to provide some indication of wildlife response to the wetland enhancement. Reconnaissance surveys for amphibians were completed in 1998 and 1999 to document the presence and distribution of amphibian species suspected to reside in the watersheds (Hengeveld 1999, 2000). Monitoring of amphibians will also provide an opportunity to improve the knowledge of this species groups as little data is presently available about them in Williston Reservoir.

The key management question pertaining to amphibian is:

> MQ-2: Are the enhanced (or newly created) wetlands used by waterfowl and other wildlife?

The primary hypothesis to be tested was:

> H_4: Amphibian abundance and diversity in the wetland changes following wetland enhancement.

Four species of amphibians were expected to occur along the impounded waters of the Peace River in northern BC (Table 1). All species are pond-breeding amphibians, that congregate in small wetlands and lakes in the spring to breed (Matsuda et al. 2006). Western Toad (Anaxyrus boreas), the most likely species to occur in the Williston Reservoir, is currently listed as Special Concern (SARA Schedule 1) and is considered to be at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). There are records of Boreal Chorus Frogs (*Pseudacris maculata*) in the Peace River Valley, but this species has not been documented in the Williston Reservoir area to date (BC CDC 2021).

Table 1. Provincial and federal status of species of amphibian species that occur in the northern B.C. (BC CDC 2021).

		Status†	
Species	**Species Code**	**CDC**	**COSEWIC***
Columbia Spotted Frog (*Rana luteiventris*)	A-RALU	Y	
Wood Frog (*Lithobates sylvatica*)	A-LISY	Y	
Western Toad (*Anaxyrus boreas*)	A-ANBO	Y	SC
Long-toed Salamander (*Ambystoma macrodactylum*)	A-AMMA	Y	
Boreal Chorus Frog (*Pseudacris maculata*)	A-PSMA	Y	

Methods

Systematic surveys were used to record amphibian species at both wetland sites across all years of study (RISC 1998) and allowed for using a single, repeatable method to provide diversity and relative abundance measures for all species detected. Amphibian surveys occurred over two to four sampling intervals (i.e., replicates) between April and June each year to coincide with the active period of amphibians (Table 2). Weather and site access constraints (e.g., reservoir still covered in ice) prevented the completion of surveys in all months in several years of study. For example, most often the April field survey was not conducted due to ice on reservoir.

Table 2. Number of wetland site visits to Airport Lagoon and Beaver Pond in Williston Reservoir as part of GMSMON-15, 2011 to 2020.

	Airport Lagoon (11 transects)				Beaver Pond (1 transect)			
		# of Visits				# of Visits		
Year	**Phase**	Apr	May	June	**Phase**	Apr	May	June
2011	Pre		1	1	Pre			2
2012	Pre		4		Pre		1	3
2013	Pre		4	1	Pre		2	1
2014	Post		3	1	Pre		1	1
2015	Post		4		Post		2	2
2016	Post	1	3		Post	1	2	1
2017	Post		3		Post		2	
2018	Post	1	1	1	Post		1	1
2019	Post	1	2		Post		1	1
2020	Post		2	1	Post		1	1

At Airport Lagoon 11 transects distributed along the periphery of the inundated areas were sampled; whereas, at Beaver Pond the entire site was considered a single transect (Figure 1, Figure 2). Transect start and end points (and survey tracks) were recorded using GPS units to allow for repeat surveys and for calculations of detections per unit distance. A photograph was taken at each transect start point, oriented towards the end point (Table 3). Environmental conditions were recorded at the start and end of each transect. The search area for each transect included shallow water (< 1 m deep), the shorelines, and areas within 3 m of the shoreline (ponds, streams, riparian areas). A zig-zag search pattern was applied to areas above the waterline and a linear pattern directly adjacent to the water (i.e., shoreline) to ensure complete coverage of the area. Habitat was visually scanned and in some cases a dip-net sweep was used in the shallow water zone in a standardized fashion and at a regular interval. Searchers on the shore and shoreline overturned pieces of woody debris and other potential cover objects to search for amphibians sheltering underneath. All pieces of woody debris and cover were returned to their original position after determining if amphibians were present.

Table 3. Start and end locations of the amphibian survey transects at to Airport Lagoon and Beaver Pond in Williston Reservoir as part of GMSMON-15.

Site	Transect	UTM_E_start	UTM_N_start	UTM_E_end	UTM_N_end
Airport Lagoon	AL-2	492471	6125557	492307	6125618
Airport Lagoon	AL-3	492399	6125331	492374	6125722
Airport Lagoon	AL-7	492461	6126003	492427	6126101
Airport Lagoon	AL-10	492381	6126294	492316	6126362
Airport Lagoon	AL-14	492150	6126556	492097	6126618
Airport Lagoon	AL-25	492440	6126928	492494	6126951
Airport Lagoon	AL-32	492657	6126520	492607	6126443
Airport Lagoon	AL-35	492704	6126443	492744	6126265
Airport Lagoon	AL-37	492656	6126120	492627	6126027
Airport Lagoon	AL-38	492619	6126888	492609	6126803
Airport Lagoon	AL-40	492688	6125739	492660	6125819
Beaver Pond	BP-1	479404	6148212	479194	6148313

Completion of the wetland enhancements (Airport Lagoon in 2013, Beaver Pond 2014) at both sites resulted in increased water levels that required the adjustment of eight of the original transects at Airport Lagoon and modifications to the Beaver Pond transect following construction of the berm. The modification (i.e., moving of transect by a few meters) of some transects after project construction was anticipated during development of the monitoring program (MacInnis et al. 2015, MacInnis et al. 2016); however, transects were directly compared pre- and post-enhancement as the modifications were deemed negligible in distance from each other.

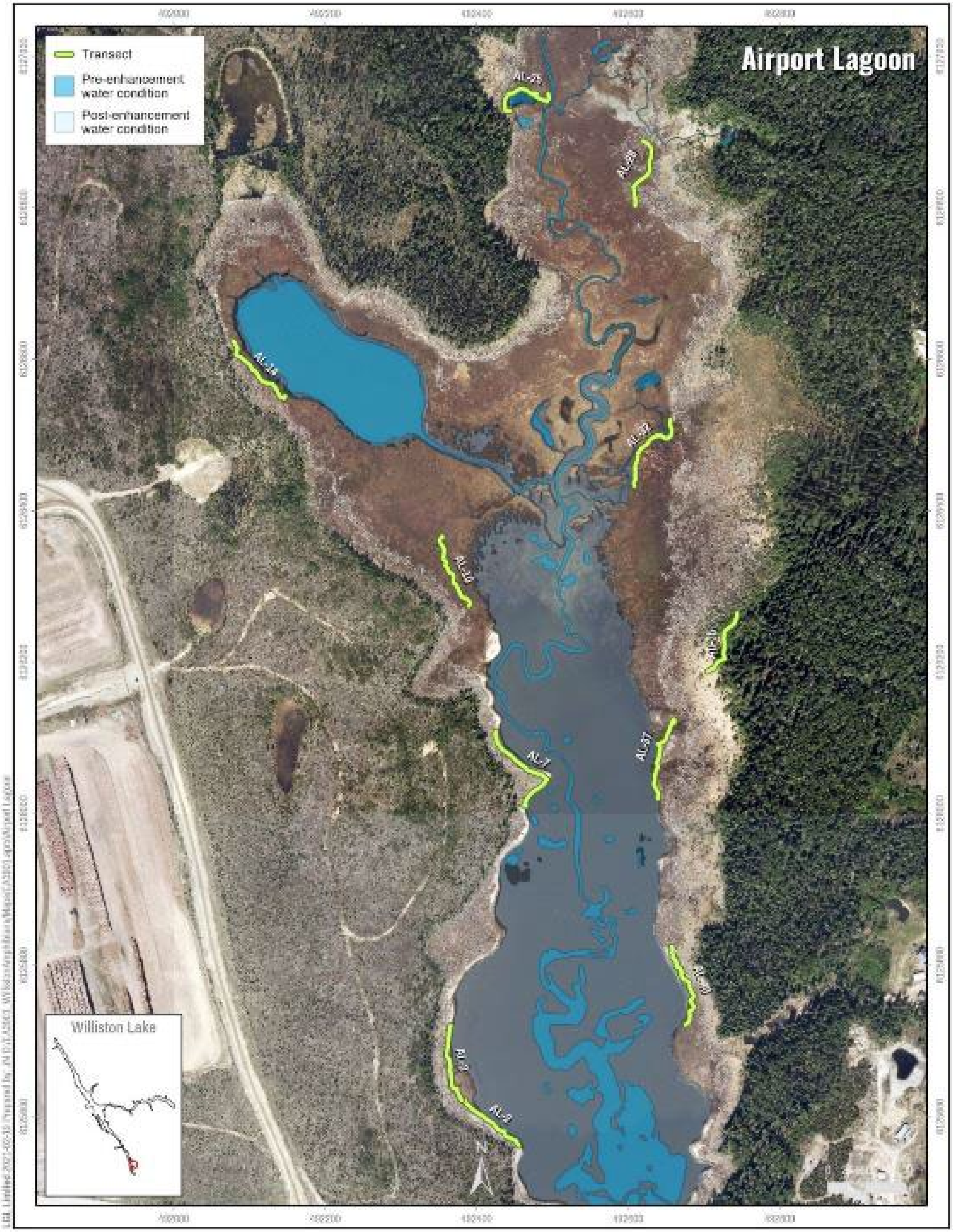

Figure 1. Amphibian survey transect locations at Airport Lagoon sampled from 2011 to 2020, Williston Reservoir

Figure 2. Amphibian survey transect locations at Beaver Pond sampled from 2011 to 2020, Williston Reservoir.

General BC Wildlife Permits were granted for each year of work (see LGL Limited annual reports for specific permit numbers from 2018 to 2020). The Resources Inventory Standards Committee (RISC) protocols for sampling and handling of amphibians (RISC 1998) were followed; see previous annual reports for descriptions of any morphometric data collected (e.g., weight, size, sex). Amphibians were only captured if identification was not possible during the initial sighting; all individuals were released immediately upon identification. Species, developmental stage, and approximate size were recorded for each observation on animal observation forms modified from RISC (1998). Species, developmental stage, behavior and habitat variables were recorded for each adult, larvae and egg mass observed. In some years (2011 to 2017), where it was not possible to exactly count large numbers of tadpoles (>100), they were simply recorded as 'tadpoles', in other years (2018 to 2020) aggregations of tadpoles and metamorph amphibians were treated as a single detection and the total number of individuals was estimated.

A few amphibian observations of Boreal Chorus Frog (*Pseudacris maculata*) were made in earlier years of the study (MacInnis et al. 2012); however, the authors reported these as misidentifications (in subsequent years) as this species is not known to occur in the area

(Hengeveld 2000, Matsuda et al. 2006). For analyses and reporting, these observations were classified as 'unknown frog'.

Dataset

This dataset was created to summarize the presence–absence (i.e., detection or non-detection) of amphibian species in the drawdown zone of Williston Reservoir by wetland site (i.e., Airport Lagoon and Beaver Pond). Data pooled across all years of sampling were used in most analyses and these data assisted in answering MQ2. From this dataset, several measures were extracted, including species-specific site presence, species richness, species diversity, and abundance and detection rates (catch per unit effort [CPUE]). This data set was also used to examine differences in amphibian abundance and occupancy between pre-enhancement, construction and post enhancement years.

Site Presence – For the purposes of this report, site presence (or occupancy) was defined simply as the location where amphibians were documented during each year of study (i.e., the naïve occupancy rate; MacKenzie et al. 2006). Likewise, detection probabilities were not calculated. This dataset contained 64 surveys at the two wetland sites during which 549 detections across multiple life stages of four species were made. In total ~200,200 amphibians were observed, including 32 egg masses, ~200,000 tadpoles, ~200 metamorphs or juveniles, and 237 adults of the four amphibian species (not including unidentified amphibians; n = 18; Table 4). Approximately 106 hours were spent over 64 days surveying the study sites between April and June 2011 to 2020 (Table 5).

Table 4. Summary of amphibian raw observation data by life stage at wetland sites in Williston Reservoir from 2011 to 2020. A-AMMA = Long-toed Salamander, A-ANBO = Western Toad, A-LISY = Wood Frog, A-RALU = Columbia Spotted Frog, UNKN = unknown amphibian species, () = aggregations of tadpoles were recorded as single detection.

Site	Species	Life Stage				Total
		Egg Mass	Tadpole / Larvae	Juvenile	Adult	
Airport Lagoon	A-AMMA	7			7	14
	A-ANBO		4608 (18)	52	136	4796 (206)
	A-LISY		100 (1)		1	101 (2)
	A-RALU		10 (1)		3	13 (4)
	UNKN		5		1	6
Beaver Pond	A-AMMA	18	1		21	40
	A-ANBO	7	194996 (66)	132	43	195178 (247)
	A-LISY			6	23	29
	UNKN		23 (6)	4	2	29 (12)
Airport Lagoon		7	4723 (20)	52	148	4930 (227)
Beaver Pond		25	195020 (72)	142	89	195276 (328)
Total		**32**	**199743 (92)**	**194**	**237**	**200206**

Table 5. Survey effort (hours, days) by year and month and the number of days at wetland sites in Williston Reservoir from 2011 to 2020. Year of enhancement = light grey rows.

Site	Year	Survey Effort (hrs; [Number of Days])			Total	
		April	May	June	Hours	Days
Airport Lagoon	2011	0	1.42 (1)	3.70 (1)	5.12	2
	2012	0	9.45 (4)	0	9.45	4
	2013	0	6.63 (4)	2.67 (1)	9.30	5
	2014	0	6.98 (3)	1.92 (1)	8.90	4
	2015	0	8.75 (4)	0	8.75	4
	2016	1.50 (1)	5.78 (3)	0	7.28	4
	2017	0	4.02 (3)	0	4.02	3
	2018	2.40 (1)	2.80 (1)	2.68 (1)	7.88	3
	2019	2.33 (1)	3.35 (2)	3.27 (2)	8.95	5
	2020	0	5.95 (2)	3.07 (1)	9.02	3
	Total	6.23 (3)	55.13 (27)	17.31 (7)	78.67	37
Beaver Pond	2011	0	0.83 (1)	0.38 (1)	1.21	2
	2012	0	1.15 (1)	1.88 (3)	3.03	4
	2013	0	2.28 (2)	0.7 (1)	2.98	3
	2014	0	1.23 (1)	1.75 (1)	2.98	2
	2015	0	2.83 (2)	1.55 (2)	4.38	4
	2016	0.8 (1)	1.42 (1)	2.12 (2)	4.34	4
	2017	0	1.62 (2)	0	1.62	2
	2018	0	0.5 (1)	0.5 (1)	1	2
	2019	0	0.97 (1)	1.43 (1)	2.4	2
	2020	0	1.58 (1)	1.85 (1)	3.43	2
	Total	0.8 (1)	14.41 (13)	12.16 (13)	27.37	27

Analysis

Diversity – Annual differences in species richness, diversity, and evenness were assessed. Species richness was defined as the number of species of amphibians recorded at each site. Species diversity and evenness were computed as Shannon's Entropy and corresponded to a measure of species composition, combining both the number of species and their relative abundances (Legendre and Legendre 1998). For each wetland site, diversity was computed as:

$$\sum_i p_i \log \frac{1}{p_i}.$$

where p_i is the relative proportion of species i.

A value of 0 means that the sampling unit contained only one species; species diversity then increases along with the number of species recorded in the sampling unit. A high value of species diversity means that many species were recorded.

Abundance and detection rates – We assessed the abundance of amphibians by species, wetland site, and year. To assess species-by-site relationships, we pooled all life stages and examined species observations to identify sites where the detection of a given species was the highest regardless of age class. Clusters of egg masses and aggregations of tadpoles or metamorphs were treated as a single observation per location, so as not to skew numbers. For example, estimates of 199,743 tadpoles were observed; however, when these tadpole aggregations were treated as single detections, the number of times tadpoles were observed was 98. We analyzed abundance through the calculation of detection rates. We calculated detection rates for each amphibian species at each monitoring site by dividing the number of observations per site and per species by survey effort in hours. Survey effort was calculated as the number of hours surveyed multiplied by the number of surveyors conducting the survey. Mean detection rates were calculated for each site (pooling data from all years) and by year.

Wetland Enhancement Effects – This data set was also used to examine differences in amphibian abundance and occupancy between pre-enhancement, construction and post-enhancement years. To assess the data for differences between pre- and post-construction detection rates, boxplots were produced and one-way ANOVAs with 9999 permutations were performed in R (version 4.0.3).

Results

Since the inception of GMSMON-15, four species of amphibians were detected at the wetland enhancement sites: Western Toad, Wood Frog, Columbia Spotted Frog, and Long-toed Salamander. Western Toad was by far the most encountered amphibian in the drawdown zone at both sites across all study years (83% of all detections). Wetland enhancements occurred in 2013 for Airport Lagoon and 2014 for Beaver Pond, both of which led to an increase in available aquatic habitat. In theory, this potentially would have benefited amphibians by providing an increased amount of aquatic habitat available for breeding, foraging, or overwintering (for some species); however, the abundance data only marginally support this for Western Toad in the years immediately following to construction. For example, there was an initial spike in Western Toad detections in both years following enhancement (2013 for Airport Lagoon, 2014 for Beaver Pond), followed by lower detections for Airport Lagoon. Too few detections were made for the other three species to support any evidence of change in amphibian use post-enhancement.

Overall, Airport Lagoon had 41% of the species detections and the highest species richness (n = 4), although not all species were consistently observed across the years (e.g., Wood Frog detected only in 2011 and 2016). Western Toad was the most abundant species (91% of all detections), with tadpoles, metamorphs and adults observed in multiple years. Breeding was confirmed in Airport Lagoon for all amphibian species by observations of egg masses, tadpoles/larvae, or metamorphs. The most productive area for amphibians appeared to be transects 25 and 28 in the northeastern section of the enhanced wetland area, although observations of Western Toads were made at 10 of the 11 transects.

Despite being a smaller site and having only one survey transect, Beaver Pond had 59% of the individual detections over the 10 years, but only three species were observed. Similar to Airport

Lagoon, Western Toad was the most abundant species (78% of all detections), with all life stages observed in multiple years. Breeding was also confirmed for Long-toed Salamander (egg masses and tadpole) at this site.

Site Presence (i.e., Occupancy)

Over the 10 years of monitoring, four species of amphibian were recorded in or near the two wetland sites in Williston Reservoir. Species richness and assemblages differed between wetlands with four species detected at Airport Lagoon (Long-toed Salamander, Western Toad, Wood Frog, and Columbia Spotted Frog) and three at Beaver Pond (Long-toed Salamander, Western Toad, and Wood Frog; Table 6).

Table 6. Amphibian species detected by year of study during systematic surveys of Williston Reservoir wetlands from 2011 to 2020. A-AMMA = Long-toed Salamander, A-ANBO = Western Toad, A-LISY = Wood Frog, A-RALU = Columbia Spotted Frog. Enhancement construction year = grey columns.

		Catch										
Site	**Species**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**
Airport Lagoon	A-AMMA	0	2	3	8	1	0	0	0	0	0	14
	A-ANBO	20	7	11	118	29	6	1	2	1	2	197
	A-LISY	1	0	0	0	0	1	0	0	0	0	2
	A-RALU	0	0	0	1	0	0	0	0	3	0	4
Beaver Pond	A-AMMA	0	0	1	22	8	3	6	0	0	0	40
	A-ANBO	4	2	3	15	97	56	21	2	18	27	245
	A-LISY	9	1	1	0	4	2	1	0	5	6	29
	A-RALU	0	0	0	0	0	0	0	0	0	0	0
Total by Species	A-AMMA	0	2	4	30	9	3	6	0	0	0	54
	A-ANBO	24	9	14	133	126	62	22	4	19	29	442
	A-LISY	10	1	1	0	4	3	1	0	5	6	31
	A-RALU	0	0	0	1	0	0	0	0	3	0	4
Total by Year	**All Spp.**	**34**	**12**	**19**	**164**	**139**	**68**	**29**	**4**	**27**	**35**	**531**

Transects AL-25 at Airport Lagoon and BP-01 at Beaver Pond were the two areas with the highest species richness and species observations (Table 7). Transects AL-14 and AL-32 did not show high amphibian observations despite there being wetland or pond habitat nearby. Transect AL-02 had no amphibian observations from 2011 to 2020, AL28 had a one-day observation of 28 adult toads, and the remainder of the transects (AL-03, AL-07, AL-10, AL-14, AL-35, AL-37, and AL-40) all had under 10 observations during the entire study.

Table 7: Amphibian species observations by life stage in Airport Lagoon and Beaver Pond transects in Williston Reservoir from 2011 to 2020. A-AMMA = Long-toed Salamander, A-ANBO = Western Toad, A-LISY = Wood Frog, A-RALU = Columbia Spotted Frog, UNKN = unknown frog; EM = egg mass; L = larvae; T = tadpole; J = juvenile (including metamorph); A = adult. Data for tadpoles was pooled.

Transect	A-AMMA				A-ANBO				A-LISY				A-RALU				UNKN	Total
	EM	**L**	**J**	**A**	**EM**	**T**	**J**	**A**	**EM**	**T**	**J**	**A**	**EM**	**T**	**J**	**A**		
Airport Lagoon	7			7		18	52	127		1		1		1		3	6	**218**
AL02																		**0**
AL03							1											**1**
AL07				1		3		1				1						**6**
AL10							3	2										**5**
AL14						4	2											**6**
AL25	6			2		9	36	78		1				1		2	4	**139**
AL28								28										**28**
AL32				1		1	3	17								1	1	**24**
AL35								1										**1**
AL37				1			6											**7**
AL40				3		1	1										1	**6**
Beaver Pond	18	1		21	4	66	132	43			6	23					12	**326**
Total	**24**	**1**		**29**	**4**	**84**	**184**	**170**		**1**	**6**	**24**		**1**		**3**	**18**	**549**

Figure 3. Photos of Beaver Pond (BP01) transect in May 2019, including the enhanced wetland habitat above the berm (bottom photos) and existing wetland habitat including beaver dam (above the Williston Reservoir drawdown zone; top photos).

Western Toad was the most frequently encountered amphibian species at both Airport Lagoon (91% of observations) and Beaver Pond (78% of observations) sites across all study years. Columbia Spotted Frog and Wood Frog were observed during this study with Wood Frog detected at both sites and Columbia Spotted Frog only at Airport Lagoon. Adult Wood Frog individuals were observed on multiple occasions at Beaver Pond and one individual was noted at Airport Lagoon. The only evidence of breeding in this species was a single tadpole was documented at AL-25. Overall, Columbia Spotted Frog had very few observations, with only four individuals documented at two transects in Airport Lagoon (three of four at the small wetland located along transect AL-25) during the 10 years. Long-toed Salamanders were present at both wetland areas, with BP01 having the most observations (n = 40). Most observations were of adults and egg masses: 18 egg masses were observed at Beaver Pond and 6 egg masses on transect AL-25 at Airport Lagoon. A single Long-toed Salamander was captured incidentally at the Beaver Pond during minnow trapping in 2011.

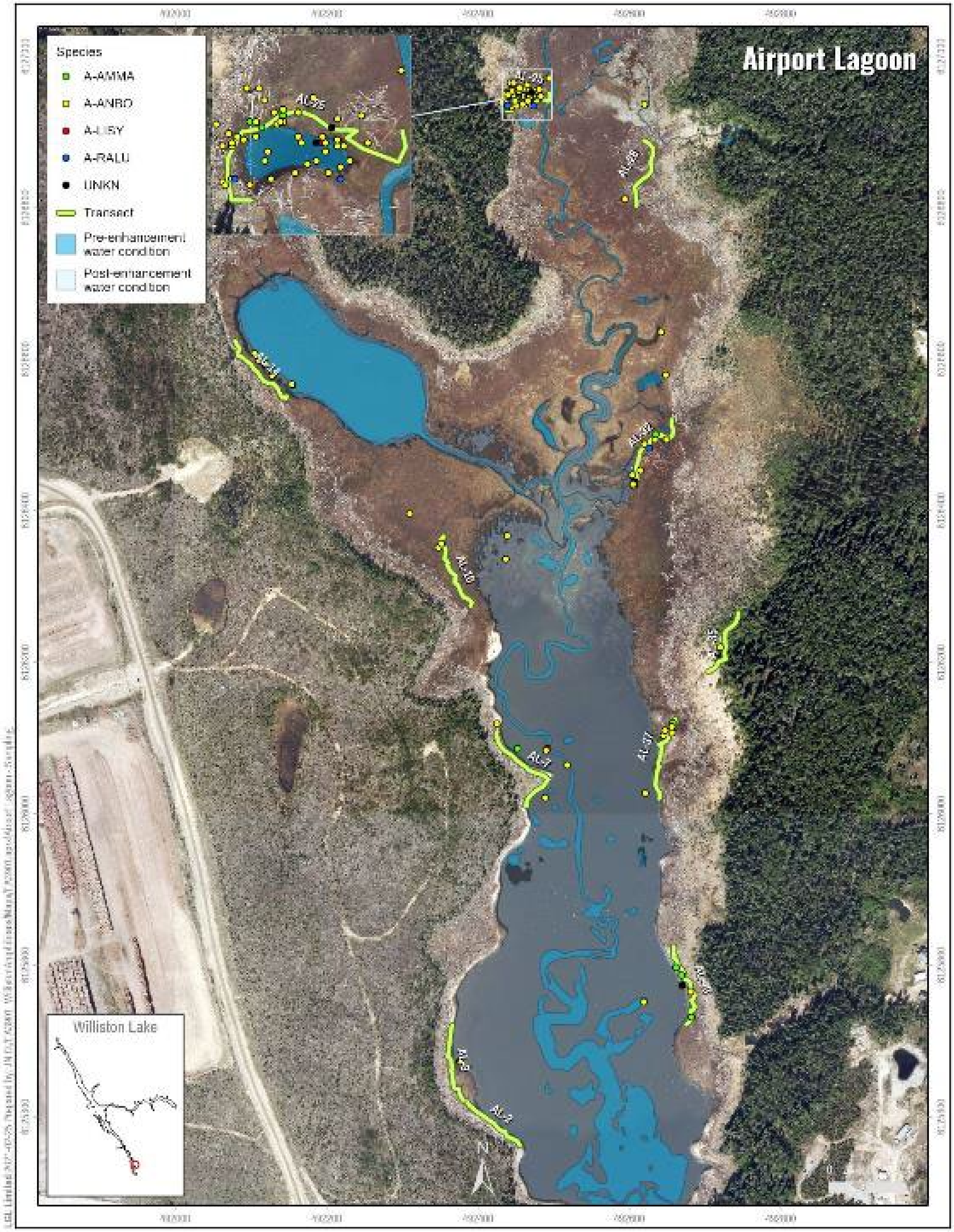

Figure 4. Overall detections of amphibian species (all life stages pooled) in Airport Lagoon transects, Williston Reservoir between 2011 – 2020. A-AMMA = Long-toed Salamander, A-ANBO = Western Toad, A-LISY = Wood Frog, A-RALU = Columbia Spotted Frog.

Figure 5. Overall detections of amphibian species (all life stages pooled) at Beaver Pond, Williston Reservoir between 2011 – 2020. A-AMMA = Long-toed Salamander, A-ANBO = Western Toad, A-LISY = Wood Frog, A-RALU = Columbia Spotted Frog.

Diversity

Overall species diversity ranged from 0 to 0.39 on Shannon's Index (Table 8). The average species diversity was 0.11 at Airport Lagoon and 0.23 at Beaver Pond. In other words, Beaver Pond showed a greater consistency across the years of observing the three species detected there, whereas Airport Lagoon had several years where only one species was detected (e.g., Western Toad in 2017, 2018, and 2020), thereby reducing diversity values. By transect, species diversity was highest at transect AL-07 at Airport Lagoon with 0.38, followed by AL-40 and BP-01 with 0.29, respectively (Table 9). Although species richness was highest at transect AL-25, the skewed number of detections resulted in a lower index of diversity.

Table 8. Species diversity (Shannon's Entropy) by year and wetland site at Williston Reservoir (transects pooled). Enhancement construction year = grey cells.

	Species Diversity		
Year	Airport Lagoon	Beaver Pond	Overall
2011	0.08	0.27	0.26
2012	0.23	0.28	0.31
2013	0.23	0.41	0.31
2014	0.12	0.29	0.22
2015	0.06	0.18	0.16
2016	0.18	0.15	0.39
2017	0	0.31	0.28
2018	0	0	0
2019	0.24	0.23	0.24
2020	0	0.21	0.20
Average	**0.11**	**0.23**	**0.24**
Minimum	**0**	**0**	**0**
Maximum	**0.24**	**0.41**	**0.39**

Table 9. Species diversity (Shannon's Entropy) by transect at Williston Reservoir (years pooled).

Transect	Species Diversity	Species Richness
AL02	N/A	0
AL03	0	1
AL07	0.38	3
AL10	0	1
AL14	0	1
AL25	0.16	4
AL28	0	1
AL32	0.15	3
AL35	0	1
AL37	0.18	2
AL40	0.29	2
BP01	0.29	3

Abundance

Amphibian abundances (detection rates) varied from year to year and by species, with the highest overall detection rates occurring in 2014 at Airport Lagoon and 2015 at Beaver Pond for Western Toad followed by Long-toed Salamander (Table 10). Both of these years were immediately following construction, and in general post-enhancement surveys recorded higher numbers of Western Toad than in the pre-enhancement surveys at both sites. There were no other consistent patterns in other amphibian species detection rates by year, site, or enhancement condition.

Table 10. Detection rate by amphibian species and wetland site at Williston Reservoir from 2011 to 2020. A-AMMA = Long-toed Salamander, A-ANBO = Western Toad, A-LISY = Wood Frog, A-RALU = Columbia Spotted Frog, detection rate = the number of observations per wetland site and per species (all life stages pooled) divided by the survey effort, Enhancement construction year = grey columns.

		Detection Rate										
Site	**Species**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**
Airport Lagoon	A-AMMA	0	0.21	0.32	0.90	0.11	0	0	0	0	0	0.18
	A-ANBO	3.91	0.74	1.18	13.26	3.31	0.82	0.25	0.25	0.11	0.22	2.50
	A-LISY	0.20	0	0	0	0	0.14	0	0	0	0	0.03
	A-RALU	0	0	0	0.11	0	0	0	0	0.34	0	0.05
Beaver Pond	A-AMMA	0	0	0.34	7.38	1.83	0.69	3.70	0	0	0	1.46
	A-ANBO	3.31	0.66	1.01	5.03	22.15	12.90	12.96	2.00	7.50	7.87	8.95
	A-LISY	7.44	0.33	0.34	0	0.91	0.46	0.62	0	2.08	1.75	1.06
	A-RALU	0	0	0	0	0	0	0	0	0	0	0
Total by Species	A-AMMA	0	0.16	0.33	2.53	0.69	0.26	1.06	0	0	0	0.51
	A-ANBO	3.79	0.72	1.14	11.20	9.60	5.34	3.90	0.45	1.67	2.33	4.17
	A-LISY	1.58	0.08	0.08	0	0.30	0.26	0.18	0	0.44	0.48	0.29
	A-RALU	0	0	0	0.08	0	0	0	0	0.26	0	0.04
Total by Year	**All Spp.**	**5.37**	**0.96**	**1.55**	**13.80**	**10.59**	**5.85**	**5.14**	**0.45**	**2.38**	**2.81**	**5.01**

Reproduction in amphibians was not studied under GMSMON-15; however, egg masses and tadpoles in three species were observed in Airport Lagoon and Beaver Pond during surveys. Large aggregations of Western Toad tadpoles were observed in multiple years in Beaver Pond, and to a slightly lesser extent in Airport Lagoon (Figure 6, Figure 7, Figure 8).

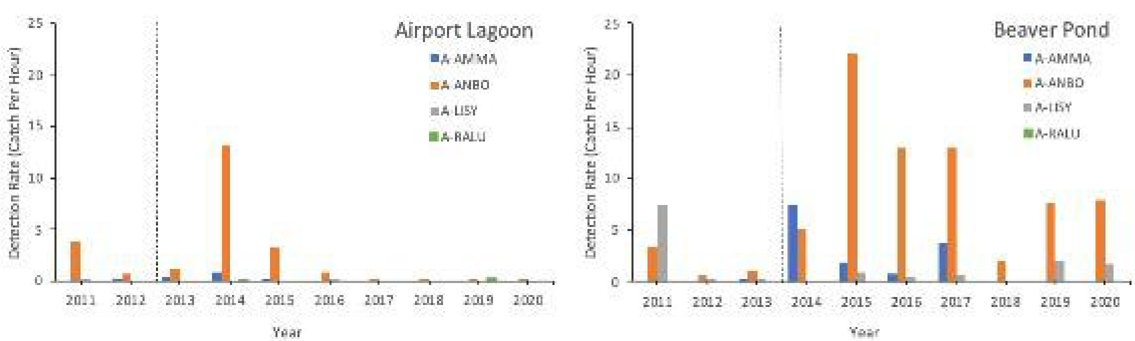

Figure 6. Annual variation in detection rate for amphibians (by species) at Airport Lagoon (left) and Beaver Pond (right) from 2011 to 2020. A-AMMA = Long-toed Salamander, A-ANBO = Western Toad, A-LISY = Wood Frog, A-RALU = Columbia Spotted Frog, detection rate = the number of observations per wetland site and per species (all life stages pooled) divided by the survey effort, black vertical dashed line = the beginning of the year of construction at each respective site.

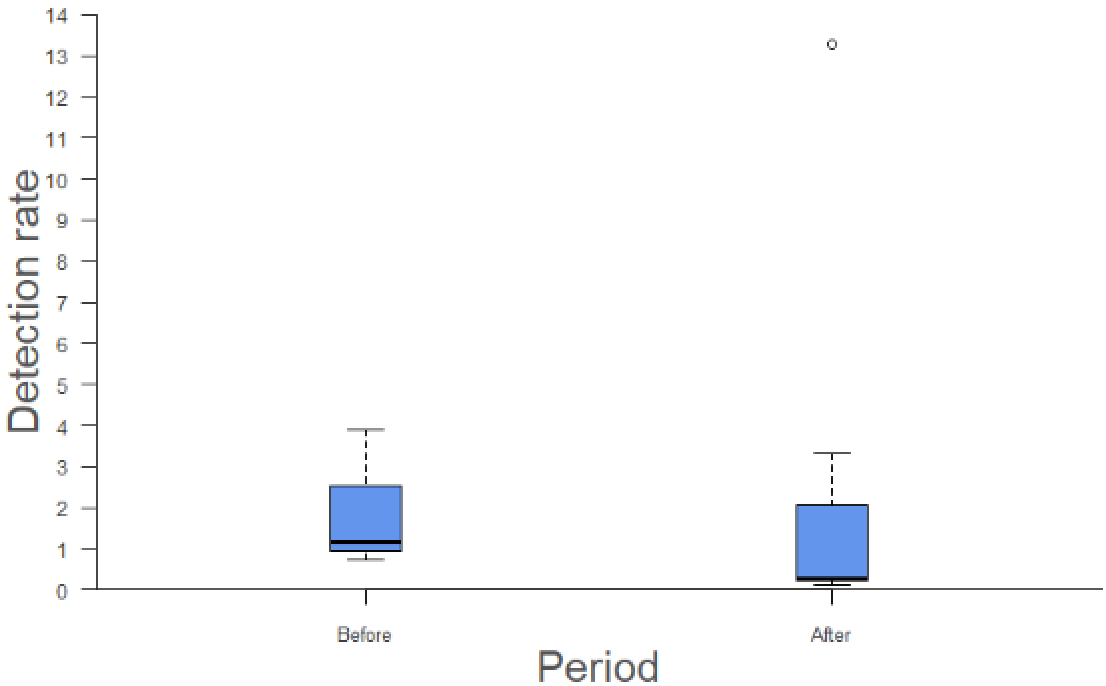

Figure 7. Detection rate of Western Toad (ANBO) in Airport Lagoon before (2011-2013) and after (2014-2020) treatment. Differences in average detection rates were not statistically significant ($p > 0.05$).

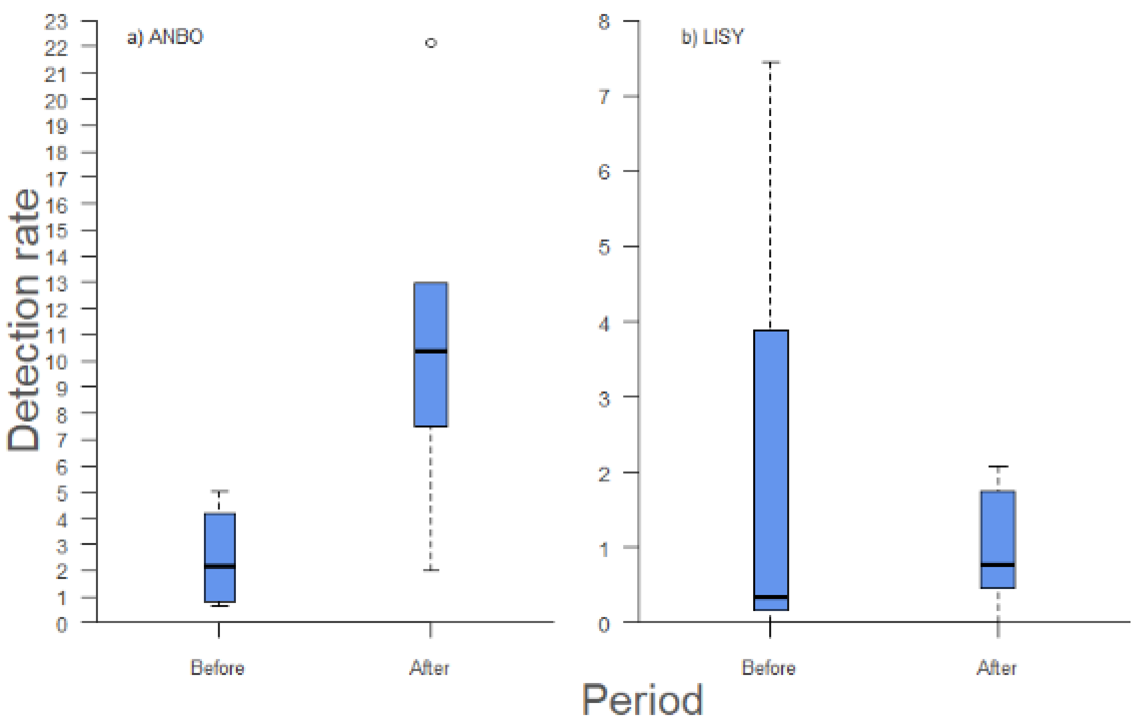

Figure 8. Detection rate of a) Western Toad (ANBO) and b) Wood Frog (LISY) in Beaver Pond before (2011-2014) and after (2015-2020) treatment. Differences in average detection rates were statistically significant for ANBO ($F = 5.5$, $p = 0.04$) but not for LISY ($p > 0.05$).

Long-toed Salamander showed no significant differences between the before and after period in Airport Lagoon or Beaver Pond ($p > 0.05$; Figure 9); however, when the outlier with high detection rate from 2014 for the post-construction period at Airport Lagoon was removed, there was a significant difference ($F = 5.5$, $p = 0.03$).

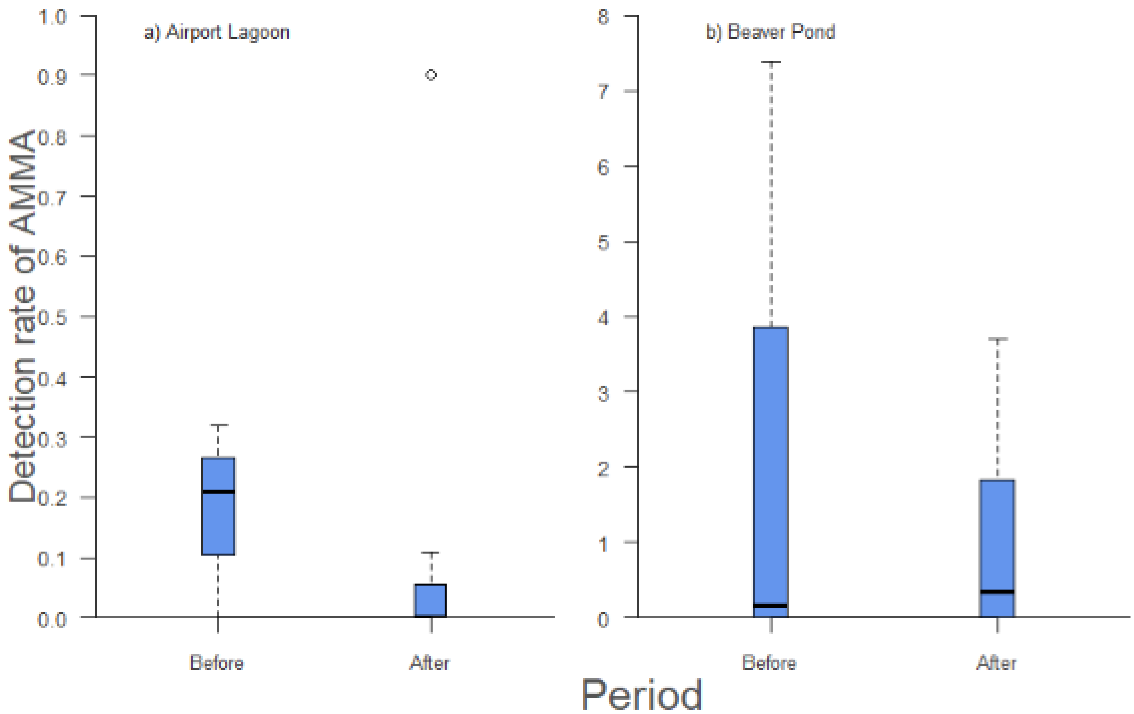

Figure 9. Detection rate of Long-toed Salamander (AMMA) in a) Airport Lagoon and b) Beaver Pond before and after treatment.

Neither analysis of detection rates pooled for all amphibians showed statistically significant differences in the rate of detection between pre- and post-construction (Figure 10, Figure 11).

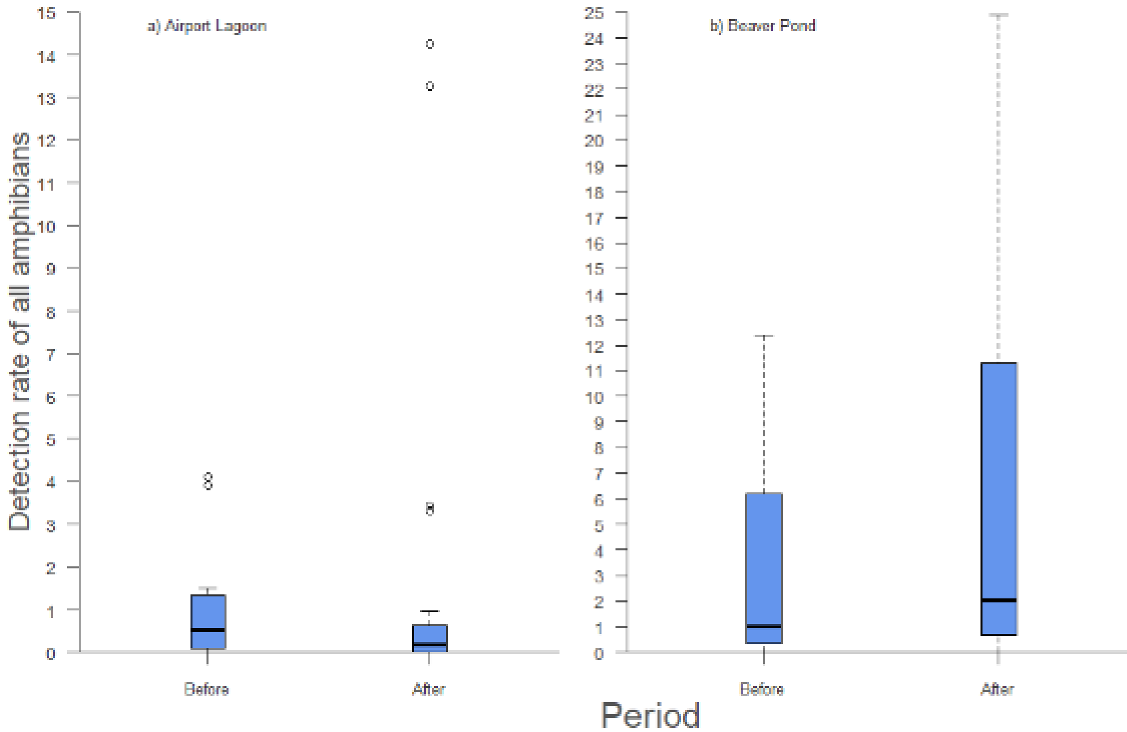

Figure 10. Detection rate of all amphibians (pooled) using "raw" data (all species and years as replicates) at a) Airport Lagoon and b) Beaver Pond before and after treatment.

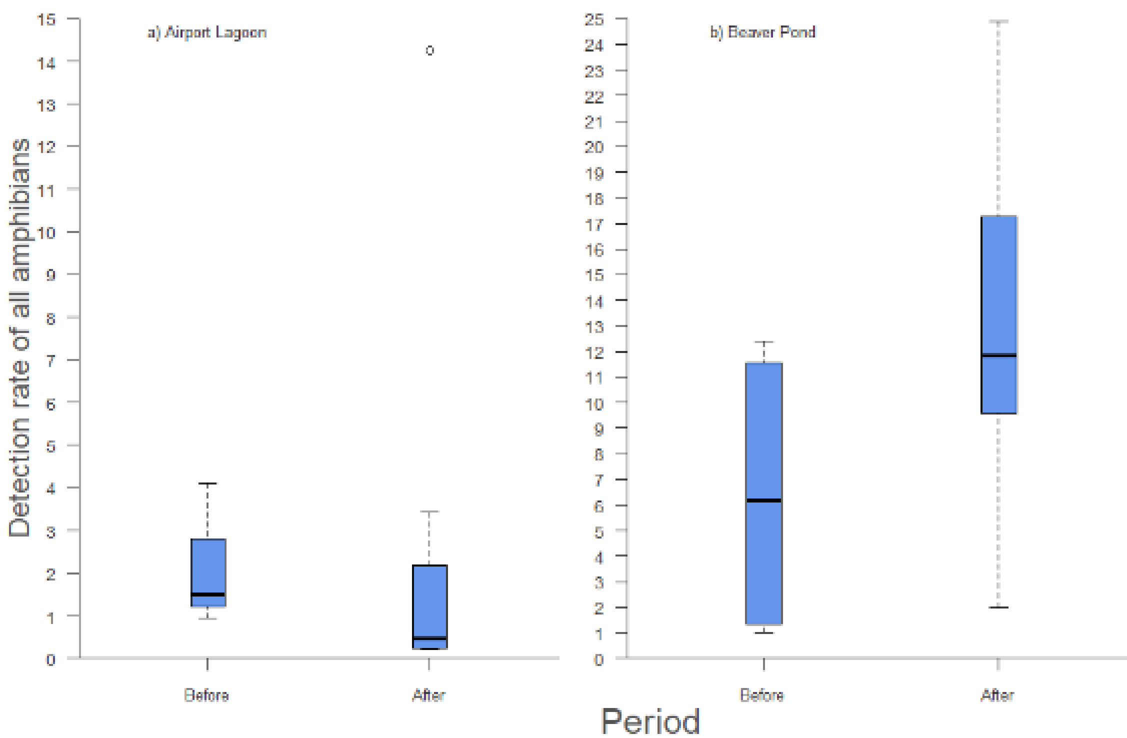

Figure 11. Detection rate of all amphibians (pooled) using "summed" data (total detection rate summed up over all species per year) at a) Airport Lagoon and b) Beaver Pond before and after treatment.

Discussion

Overall, the amphibian survey results were generally consistent with other inventory work that has been completed in the area (Hengeveld 2000; Hawkes et al. 2006), showing the same species assemblages across the region. Amphibian populations (e.g., abundance, productivity) are known to vary considerably from year to year (RIC 1998, US EPA 2002); therefore, species with only a few detections in this study (e.g., Columbia Spotted Frog, Wood Frog) would require further study to confirm occupancy and summarize life history information (e.g., productivity, foraging habits, overwintering sites).

The high species richness and observations at AL-25 and BP-01 was likely due to the presence of existing wetland habitat (i.e., wetted habitat) along or immediately adjacent to the transect itself, whereas many of the other transects in Airport Lagoon were not close the wetland (or pond-like) features. Transects AL-14 and AL-32 did had wetted patches (i.e., wetland or pond habitat nearby) but did not necessarily show high amphibian observations. The habitat at the other transects (Appendix 7), where amphibian detection was relatively low, was typical of most of the areas in lower portion in Airport Lagoon reach (i.e., closer to the main reservoir, at the south end), and was generally sandy or peat substrate, void of vegetation, and steeply-sloped into the reservoir. These areas were not ideal for amphibian breeding and were also unlikely to be used as foraging areas due to the lack of vegetative cover. For the most part, amphibian species occurring in the Peace Region hibernate in upland forested habitats (Matsuda et al. 2006), and amphibian observations in the lower portion of the reach were likely animals migrating in search of breeding habitat in the early spring, although this was not tested. Additional study involving a radiotelemetry component would shed light on the movements of amphibians in and out of the Williston Reservoir drawdown area.

Intact natural wetland habitat, extending northeast from the top end of Beaver Pond in the drawdown zone, appeared to be the highest quality aquatic habitat at the study sites and was likely the source population for most amphibian species occurring there, although this was not explicitly tested. Extensive surveys of this (above Williston Reservoir) wetland were not possible due to time and study constraints (e.g., only one transect at Beaver Pond which did not extend into upland wetland habitat), and surveys were conducted mainly around the beaver dam that separated the wetland from the lower portion of the pond in the enhancement area, and the pond near the sand berm installed in 2014.

Western Toad was the most frequently encountered amphibian species at both Airport Lagoon (91% of observations) and Beaver Pond (78% of observations) across all study years. This species is widespread throughout BC and uses a variety of pond types as well as nearby upland habitat to fulfill its life history requirements. Evidence of breeding was observed at both wetland sites, with egg masses detected in May and tadpoles detected from May 18 (earliest observation) to the end of June. No surveys were conducted in July although tadpoles would likely still have been present. The timing of metamorphosis of these population is unknown, as only the previous year's metamorphs were detected in the wetland areas (i.e., no surveys were conducted during summer months when metamorph emergence would have occurred). Adults were observed throughout April to June. Toad observations were made at most transects with most of the observations occurring near AL-25 and BP-01, both of which had wetland areas immediately nearby.

Columbia Spotted Frog and Wood Frog are also both pond-breeding amphibians and widely distributed in northern BC, although to a lesser extent than Western Toad. Both species were observed during this monitoring program with Wood Frog detected at both sites and Columbia Spotted Frog only at Airport Lagoon. Adult Wood Frog individuals were observed on multiple occasions at Beaver Pond and one individual was noted at Airport Lagoon. The only evidence of breeding in this species was a single tadpole was documented at AL-25; however, this species is typically an early breeder, and it is possible that the window for egg laying was missed in most years of study. Overall, Columbia Spotted Frog had very few observations, with only four individuals documented at two transects in Airport Lagoon (three of four at the small wetland located along transect AL-25) during the 10 years. Spotted frogs are more tied to pond habitat for breeding, foraging, and overwintering (than Wood Frogs that typically migrate upland for foraging and winter; Matsuda et al. 2006), which might explain their low occupancy values, as permanent wetland habitat occurred only on a few transects. Additionally, tadpoles of this species are more difficult to locate due to their preference for feeding and hiding under vegetation (Patla and Keinath 2005).

Long-toed Salamanders were present at both wetland areas, with BP-01 having the most observations (n = 40). Most observations were of adults and egg masses: 18 egg masses were observed at Beaver Pond and six egg masses on transect AL-25 at Airport Lagoon. A single Long-toed Salamander was captured incidentally at the Beaver Pond during minnow trapping in 2011. This species is often cryptic in nature (e.g., harder species to observed than the other three more conspicuous anurans) as it has an early breeding season, lays eggs individually under submerged vegetation, its larvae are often cryptic and solitary, and adults migrate away from ponds to upland habitats to overwinter.

Western Toads are a highly conspicuous amphibian species, both in the typically large numbers of adults that congregate (and often call) in breeding areas in the spring, and the large aggregations of tadpoles that are often visible throughout their development stages from egg string to metamorph (Matsuda et al. 2006). These species are also habitat generalists and will use a variety of aquatic environments to breed including lakes, open water ponds, vegetated wetlands, and ditches of varying sizes. Hawkes et al. (2020) found large populations of Western Toad using multiple habitats for breeding in large reservoirs over a ten-year period; and the same is likely for the Williston Reservoir, as evidence by this multiple life stages of this species observed at transects for both study sites over the ten-year period (Figure 4, Figure 5). Although not observed in this study, both Wood Frog and Columbia Spotted Frog can be locally abundant at breeding areas (Matsuda et al. 2006). The shorter and earlier breeding season for Long-toed Salamander (and possibly Wood Frog) made it unlikely that surveys coincided with peak breeding and migration periods for these species.

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Appendix 7

Habitat Classification of Vegetation Communities

Introduction

The primary focus of GMSMON-15 was on the effectiveness of wetland enhancement to improve fish and wildlife habitat as well as maintain this habitat over the life of the project. Terrestrial vegetation community structure and their distribution over time were identified as metrics to track the changes to the enhancement sites.

Methods

Ecological communities were originally delineated and classified at each site in 2011 using a combination of air photo interpretation and terrestrial ecosystem ground sampling (Province of British Columbia 2010, FLNRO 2011). Air photo interpretation was originally completed in 2-D softcopy using ArcGIS (version 9.3, ESRI 2008). Digital ortho-rectified 1:5000 air photos provided by BC Hydro were used as the background layer for delineating polygons (MacInnis et al. 2012). Since both sites were influenced by reservoir operations and not naturally recurring and stable wetlands, the BC wetland classification scheme (Mackenzie and Moran 2004) was not followed. Rather, habitat classes were first determined from an overview of the study area, following standard protocols (FLNRO 2011) to identify the larger vegetation features. Field notes on vegetation composition and structure from inspections of the study sites assisted with establishing the initial habitat classes based on a common plant species assemblage and elevation position within the drawdown zone (MacInnis et al. 2012).

The habitat classifications and their spatial distribution were reassessed in Years 2 and 3 and the classifications and mapping refined as additional information was collected. As result, the original 19 classes were reduced to 16 in Year 3 and some of the habitat class names were revised to reflect the expected annual vegetation cover and location (MacInnis et al. 2014). A high resolution orthomosaic (5 cm pixel resolution) was provided by JR Canadian Mapping for Airport Lagoon in Year 4 (2014), which along with field notes on vegetation composition and structure allowed for further interpretation and updating of habitat classes (MacInnis et al. 2015). Habitat classes were refined to 12 at Airport Lagoon and six at Beaver Pond and their spatial distribution was reassessed in Years 5 and 6 (MacInnis et al. 2017).

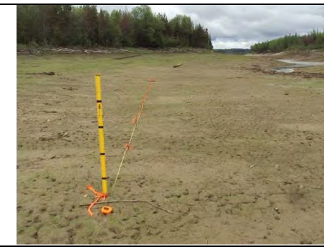
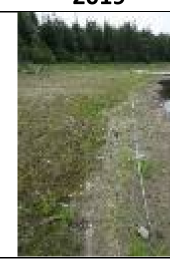
Updated high resolution orthomosaic imagery of Airport Lagoon and Beaver Pond were obtained in May 2018 (Teri Neighbour, pers. comm.). The habitat class polygons delineated in 2014 were updated using a heads up (i.e., on screen) approach where each polygon was assessed relative to the 2018 imagery. Based on the visual comparison of 2014 to 2018, polygons delineated in 2014 were either left unchanged, modified to fit the extent of vegetation cover on the 2018 images, or deleted. Imagery interpretation was completed in QGIS (Version 3.4.1).

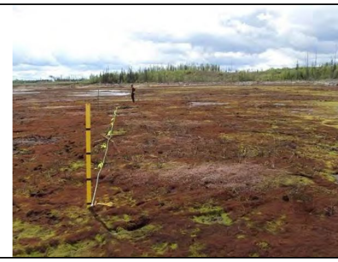
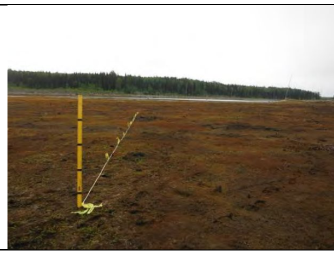
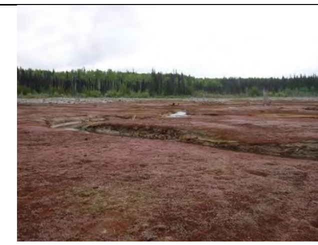
Dataset

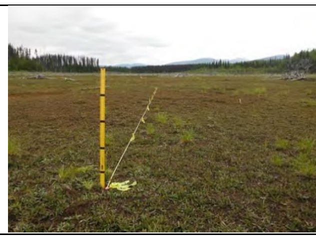
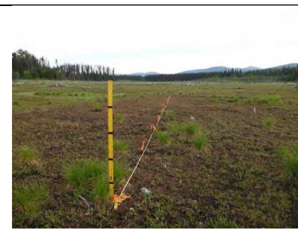
This dataset is comprised of habitat class descriptions, their spatial extent and area of coverage from data collected in 2011 (pre-enhancements), 2014 (post-enhancements), and 2018 (latter years of monitoring program). As GMSMON-15 progressed, updates to habitat classes were noted, which included the identification of new classes or the merging of two or more habitat classes into a new class. The original habitat classes defined in 2011 were reviewed and updated to ensure consistency of the description of habitat classes across the three years in this dataset.

One habitat class (floating island) that was added in 2014 was excluded from this dataset since it only accounted for <0.1% of the habitat coverage and decreased in size in subsequent year until it was not longer evident in 2018. The total area of and spatial extent habitat classes was compared across years.

Descriptions of the habitat classes and representative photographs from Year 1 to Year 9 are provided below.

Habitat Class	Representative Photographs (Beaver Pond)		
BC	**2011**	**2012**	**2013**
			
	2014	**2015**	**2016**
			
	2017	**2018**	**2019**
	Picture Not Available		
	Description		
	Basin Cryptantha (BC): Moderate herbaceous perennial cover with negligent coarse woody debris and low coarse rock cover (5%) on a plain to gentle sloping surface expression. Common species includes Torrey's cryptantha (*Cryptantha torreyana*), purslane speedwell (*Veronica peregrina* var. *xalapensis*), red sand-spurry (*Spergularia rubra*) and Arctic pearlwort (*Sagina saginoides*). Soils are composed of a deep clay mineral layer; organic layer is absent. Groundwater is the main water source; soils are very poorly drained and reservoir flooding is expected to occur annually.		

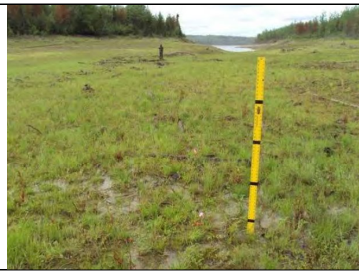
Habitat Class	Representative Photographs (Airport Lagoon)		
BM	**2011**	**2012**	**2013**
			
	2014	**2015**	**2016**
		Picture Not Available	
	2017	**2018**	**2019**
	Picture Not Available		
	Description		
	Basin Moss (BM): Moderate to high bryophyte and low to moderate herbaceous perennial cover; low coarse woody debris cover on a plain to hummock surface depression. Dominating species include common hook-moss, lady's thumb (*Persicaria maculosa*), water smartweed (*Persicaria amphibia*), common mare's-tail (*Hippularis vulgaris*) and Norwegian cinquefoil (*Potentilla norvegica*). Soils are composed of a shallow to moderate organic layer (at least 30 cm) overlying a clay mineral layer. Groundwater is the main water source; soils are very poorly drained. Reservoir flooding is expected to occur annually.		

<table>
<tr><th>Habitat Class</th><th colspan="3">Representative Photographs (Airport Lagoon)</th></tr>
<tr><td rowspan="7">BS</td><td>2011</td><td>2012</td><td>2013</td></tr>
<tr><td></td><td>Picture Not Available</td><td></td></tr>
<tr><td>2014</td><td>2015</td><td>2016</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>2017</td><td>2018</td><td>2019</td></tr>
<tr><td>Picture Not Available</td><td>Picture Not Available</td><td></td></tr>
<tr><td colspan="3">Description
Basin Smartweed (BS): High cover of water smartweed and sedge (Carex spp.), with low to high coarse wood debris cover (0-50%) on a plain to hummock surface expression. Other species present may include lady’s thumb and common hook-moss. Soils are composed of shallow to moderate organic layer (approx. 25 cm depth) overlying a clay mineral layer. Groundwater is the main water source; soils are imperfectly drained and reservoir flooding is expected to occur annually.</td></tr>
</table>

Habitat Class	Representative Photographs (Airport Lagoon)		
FI			
			
	Description		
	Floating Island (FI): Large, persistent, floating masses of organic matter, coarse woody debris and mineral soil. High bryophyte cover and low to moderate perennial herb cover. Common species include common hook-moss, lady's thumb, water smartweed and spring water-starwort (*Callitriche palustris*), purple-leaved willowherb (*Epilobium ciliatum* ssp. *ciliatum*) and a variety of sedges. The elevation of these islands is expected to rise and fall with water levels. Over time, shrubs, such as willow (*Salix* spp.), have become well established on the islands.		

Habitat Class	**Representative Photographs (Beaver Pond)**		
SC			
	2014	**2015**	**2016**
	Picture Not Available	Picture Not Available	Picture Not Available
	2017	**2018**	**2019**
	Picture Not Available		
	Description		
	Shoreline Clay (SC): Sparse herbaceous vegetation cover with low coarse woody debris and coarse rock cover on gentle to moderate sloping surface expression. The most common species present are lady's thumb, lamb's quarters (*Chenopodium album* ssp. *striatum*) common horsetail (*Equisetum arvense*) and Norwegian cinquefoil. Water source is precipitation and flooding is expected to be annual to frequent (every 2 to 5 years).		

Habitat Class	Representative Photographs (Airport Lagoon)		
	2011	2012	2013
			
	2014	2015	2016
SD			
	2017	2018	2019
	Picture Not Available		
	Description		
	Shoreline Driftwood (SD): Low to Moderate, grass dominated vegetation cover with high coarse woody debris cover (ranging from 20-50%) on a gently sloping (3 to 15°) surface expression. Common species include bluejoint (*Calamagrostis canadensis*), common horsetail, water smartweed (*Persicaria amphibia*), uplifting suncress (*Boechera divaricarpa*) and reed canarygrass (*Phalaris arundinacea*). A diversity of bryophytes such as marsh thread moss (*Bryum pseudotriquetum*), tree moss (*Climancium dendroides*) and purple horn-toothed moss (*Ceratodon purpureus*) may be present. Soils consist of a shallow (1-10 cm depth) organic layer overlying a moderate (11-30 cm) sandy mineral layer. Precipitation is the main water source; soils are rapidly drained and reservoir flooding expected to be annual to frequent.		

Habitat Class	**Representative Photographs (Beaver Pond)**		
SE	**2011**	**2012**	**2013**
			
	2014	**2015**	**2016**
	Picture Not Available	Picture Not Available	Picture Not Available
	2017	**2018**	**2019**
	Picture Not Available		
	Description		
	Stream Sedge (SE): Moderate to high sedge and bryophyte cover with negligible coarse woody and low water cover on a plain to gently sloping surface expression. Common species include sedges sp., bluejoint, lady's thumb, Torrey's cryptantha and spring water-starwort. Soil are composed of a minor organic layer (10 cm depth) overlying a clay and sand mineral layer. Surface and groundwater are the main water sources, soils are very poorly drained and annual flooding is expected to occur.		

Habitat Class	Representative Photographs (Airport Lagoon)		
SG	**2011**	**2012**	**2013**
			Picture Not Available
	2014	**2015**	**2016**
	Picture Not Available	Picture Not Available	Picture Not Available
	2017	**2018**	**2019**
	Picture Not Available		
	Description		
	Shoreline Grassland (SG): Very high grass dominated vegetation cover with low coarse woody debris cover on a gently sloping surface expression. Common species may include bluejoint, common horsetail, reed canarygrass, large-leaved avens (*Geum macrophyllum* ssp. *perincisum*) and a few unidentified grasses.		

Habitat Class	Representative Photographs (Airport Lagoon & Beaver Pond)		
SP	**2011**	**2012**	**2013**
			
	2014	**2015**	**2016**
			
	2017	**2018**	**2019**
	Picture Not Available		
	Description		
	Streams and Ponds (SP): Areas of open water and perennial water flow. Emergent or submergent vegetation identified include lady's thumb, white water-buttercup (*Ranunculus aquatilis*), spring water-starwort, common mare's-tail, water smartweed, fennel-leaved pondweed (*Stuckenia pectinata*), variegated yellow pond-lily (*Nuphar variegata*), common hornwort (*Ceratophyllum demersum*), verticillate water-milfoil (*Myriophyllum verticillatum*), wavy water nymph (*Najas flexilis*) and closed-leaved potamogeton (*Potamogeton foliosus*).		

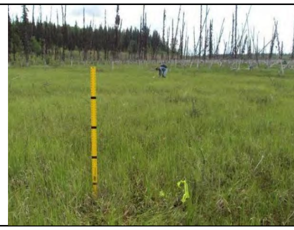
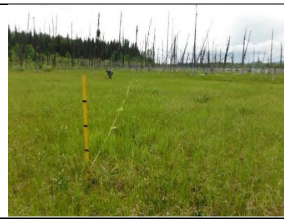
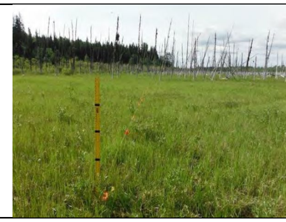
<table>
<tr><th>Habitat Class</th><th colspan="3">Representative Photographs (Beaver Pond)</th></tr>
<tr><td rowspan="8">SR</td><td>2011</td><td>2012</td><td>2013</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>2014</td><td>2015</td><td>2016</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>2017</td><td>2018</td><td>2019</td></tr>
<tr><td>Picture Not Available</td><td></td><td></td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">Shoreline Gravel (SR): Low to moderate grass dominated vegetation cover with negligent coarse woody debris and moderate coarse rock cover on a gently to moderate sloping surface expression. Dominant species include bluejoint, bronze sedge (Carex aenea), purslane speedwell, red sand-spurry and Norwegian cinquefoil. Soils are composed of a deep sand and gravel mineral layer; organic layer is absent. Precipitation is the main water source; soils are rapidly drained and reservoir flooding is expected to be rare (only during extreme events).</td></tr>
</table>

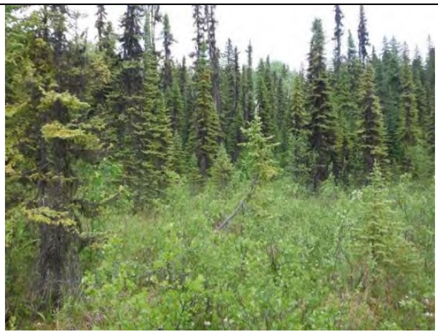
Habitat Class	Representative Photographs (Airport Lagoon)		
	2011	2012	2013
			
	2014	2015	2016
SS			
	2017	2018	2019
	Picture Not Available		
	Description		
	Shoreline Sand (SS): Sparse herbaceous vegetation cover with low (5 to 15%) coarse woody debris cover on a gentle to moderate (15 to 26°) sloping surface expression. Common species include bluejoint, lady's thumb, Norwegian cinquefoil, bronze sedge (*Carex aenea*), marsh yellow cress (*Rorippa palustris*) and pink corydalis (*Corydalis sempervirens*). Soils are composed of a deep (30-50 cm) sandy mineral layer; organic layer is absent. Precipitation is the main water source; soils are rapidly drained and reservoir flooding is expected to be annual to frequent.		

Habitat Class	Representative Photographs (Airport Lagoon & Beaver Pond)		
	2011	**2012**	**2013**
			
	2014	**2015**	**2016**
			
SW	**2017**	**2018**	**2019**
	Picture Not Available		
	Description		
	Shoreline Willow (SW): High grass and shrub dominated vegetation cover with high coarse woody debris cover on a gently to moderate sloping surface expression. Common species include common horsetail, fireweed, bluejoint, Norwegian cinquefoil, and small bedstraw (*Galium trifidum*) with patches of live and dead willow (e.g., Alaska willow [*Salix alaxensis*], Barclay's willow [*Salix barclayi*]. Soils are composed of a shallow organic layer overlying a clay mineral layer. Precipitation is the main water source; soils are moderately well drained, and flooding is expected to be frequent to rare.		

<table>
<tr><th>Habitat Class</th><th colspan="3">Representative Photographs (Airport Lagoon)</th></tr>
<tr><td rowspan="8">WD</td><td>2011</td><td>2012</td><td>2013</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>2014</td><td>2015</td><td>2016</td></tr>
<tr><td></td><td>Picture Not Available</td><td>Picture Not Available</td></tr>
<tr><td>2017</td><td>2018</td><td>2019</td></tr>
<tr><td>Picture Not Available</td><td></td><td></td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">Wetland Dead Trees (WD): High herbaceous perennial and low dead standing tree (snag) cover with low to moderate coarse woody debris cover on a gently sloping surface expression. Common species include swamp horsetail, water smartweed, buckbean, sedges and slender cottongrass (Eriophorum gracile). A low cover (approximately 15%) of standing dead black spruce (Picea mariana) trees is present as well as a variety of bryophytes. Groundwater is the main water source (surface and subsurface seepage), soils are very poorly drained, and flooding is expected to be annual to frequent.</td></tr>
</table>

Habitat Class	Representative Photographs (Airport Lagoon)		
	2011	**2012**	**2013**
			
	2014	**2015**	**2016**
			
WH	**2017**	**2018**	**2019**
	Picture Not Available	Picture Not Available	
	Description		
	Wetland Horsetail (WH): High horsetail and bryophyte dominated vegetation cover with low to moderate coarse woody debris cover on a plain to gently sloping surface expression. Common species include swamp horsetail, Norwegian cinquefoil, buckbean, small bedstraw, willows, and a diversity of bryophytes (marsh thread moss, giant calliergon moss, glow moss, and purple horn-toothed moss). Soils are composed of a moderate organic layer; mineral layer is absent. Groundwater is the main water source surface and subsurface seepage), soils are very poorly drained, and flooding is expected to be annual to frequent		

Habitat Class	Representative Photographs (Airport Lagoon)		
	2011	**2012**	**2013**
			
	2014	**2015**	**2016**
			
WS	**2017**	**2018**	**2019**
	Picture Not Available	Picture Not Available	
	Description		
	Wetland Sedge (WS): High sedge and bryophyte dominated vegetation cover with negligible coarse woody debris cover on a plain to depressed surface expression. Common species include hook moss, marsh thread moss, giant calliergon moss, common cattail, bronze sedge (along with 2 to 3 other species of sedges [*Carex* spp.]), swamp horsetail (Equisetum fluviatile), small bedstraw (*Galium trifidum*), water smartweed (*Persicaria amphibia*), common mare's-tail (*Hippuris vulgaris*) and buckbean (*Menyanthes trifoliata*). Soils are composed of a deep organic layer either overlying a clay mineral layer or mineral layer absent. Groundwater is the main water source (surface and subsurface seepage), soils are very poorly drained and reservoir flooding is expected to be annual to frequent.		

<table>
<tr><th>Habitat Class</th><th colspan="3">Representative Photographs (Airport Lagoon)</th></tr>
<tr><td rowspan="6">WW</td><td>2014</td><td>2015</td><td>2016</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>2017</td><td>2018</td><td>2019</td></tr>
<tr><td>Picture Not Available</td><td></td><td></td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">Wetland Willow (WW): Moderate shrub and high grass/sedge dominated vegetation cover with negligible coarse woody debris cover and a gentle sloping surface expression. Species present consisted of a variety of willows, sedges, grasses and bryophytes. Flooding is expected to be frequent to rare.</td></tr>
</table>

Analysis

The vegetation data collected at each site was used to determine whether the species composition of those communities changed over time.

Airport Lagoon

A total of 13 habitat classes describing vegetation communities at the Airport Lagoon site were identified and mapped in Year 1 of the study (MacInnis et al. 2012; Figure 1). The habitat classifications and their spatial distribution were reassessed in Years 2, 3, and 4 and the classifications and mapping refined as additional information was collected. As result, the original 13 classes were reduced to 12 in Year 4 (MacInnis et al. 2015). Some of the habitat class names were also revised to more accurately reflect the observed vegetation cover and location. These classifications remained relatively stable over time, with little change in species composition of each community (i.e., the same dominant species can be used to define each community); however, the area and coverage of these communities has changed between 2016 and 2018 (Table 1; Figure 2).

The plant species assemblages identified within habitat classes consisted mostly of herbaceous perennials (grasses and herbs) and bryophytes with minimal woody shrubs and no live tree cover (with the exception of occasional paper birch [*Betula papyrifera*] and trembling aspen [*Populus tremuloides*] seedlings). A few classes had a high percentage of coarse woody debris (≥50%) from driftwood accumulation.

The biggest changes were a reduction in the area coverage for Basin Moss (BM) by approximately 23% over the course of the monitoring program. The amount of Shoreline Driftwood was also reduced; by approximately 7%. These reductions were the result of an increase in surface water (i.e., Streams and Ponds habitat class) within Airport Lagoon. The other habitat classes remained relatively stable over the course of the program.

Beaver Pond

A total of eight habitat classes describing vegetation communities at the Beaver Pond sites were identified and mapped in Year 1 of the study (MacInnis et al. 2012; Figure 1). The habitat classifications and their spatial distribution were reassessed in Years 2, 3, and 4 and the classifications and mapping refined as additional information was collected. As result, the original eight classes were reduced to six in Year 4 (MacInnis et al. 2015) and some habitat class names were also revised. Habitat class descriptions and their spatial distribution were again reviewed in Year 5 and 6. No substantial changes in the distribution and abundance of habitat classes were observed, resulting in the total number of classes remaining at six (MacInnis et al. 2017; Figure 2).

Similar to Airport Lagoon, the plant species assemblages identified within habitat classes consisted mostly of herbaceous perennials (grasses and herbs). Shrub cover was sparse, with the exception of the habitat class located at the edge of the forest cover and there was no tree cover.

One class had a high percentage of coarse woody debris (27%; Table 7) from driftwood accumulation.

Basin Cryptantha and Stream Sedge was reduced by about 11% and 7%, respectively. Conversely, Shoreline Clay and the amount of surface water (Steams and Ponds) increase by approximately 9% and 8%, respectively. The other habitat classes at Beaver Pond remained relatively stable over the course of the program.

Table 1. Area and proportion of habitat classes at Airport Lagoon and Beaver Pond measured at time series intervals during the GMSMON-15 monitoring period.

			2011		2014		2018	
Airport Lagoon	**Code**	**Habitat Classification**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
	BM	Basin Moss (Cattail Thread Rush, Cinquefoil Moss, Cinquefoil Fireweed)	30.13	45.5%	17.98	27.6%	14.58	22.3%
	BS	Basin Smartweed (Smartweed Moss)	4.03	6.1%	4.82	7.4%	3.06	4.7%
	SD	Shoreline Driftwood	16	24.2%	8.08	12.4%	10.99	16.8%
	SG	Shoreline Grassland	-	-	0.43	0.7%	2.19	3.4%
	SP	Streams and Ponds	7.28	11.0%	26.1	40.1%	27.02	41.3%
	SS	Shoreline Sand	0.74	1.1%	1.18	1.8%	0.72	1.1%
	SW	Shoreline Willow	2.94	4.4%	3.63	5.6%	3.91	6.0%
	WD	Wetland Dead Trees	0.45	0.7%	0.17	0.3%	0.17	0.3%
	WH	Wetland Horsetail	1.97	3.0%	0.75	1.2%	0.75	1.1%
	WS	Wetland Sedge	1.54	2.3%	1.06	1.6%	1.06	1.6%
	WW	Wetland Willow	1.1	1.7%	0.92	1.4%	0.92	1.4%
			66.18	*100.0%*	*65.12*	*100.0%*	*65.37*	*100.0%*

			2011		2014		2018	
Beaver Pond	**Code**	**Habitat Classification**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
	BC	Basin Cryptantha (Cryptantha Speedwell, Cinquefoil Bluegrass)	1.7	38.7%	1.32	32.0%	1.18	27.5%
	SC	Shoreline Clay (Shoreline Cinquefoil)	1.25	28.5%	1.6	38.7%	1.62	37.8%
	SE	Stream Sedge (Stream Bluejoint)	0.32	7.3%	0.04	1.0%	0.01	0.2%
	SR	Shoreline Gravel	0.15	3.4%	0.07	1.7%	0.15	3.5%
	SP	Streams and Ponds	0.03	0.7%	0.15	3.6%	0.38	8.9%
	SW	Shoreline Willow	0.94	21.4%	0.95	23.0%	0.95	22.1%
			4.39	*100.0%*	*4.13*	*100.0%*	*4.29*	*100.0%*

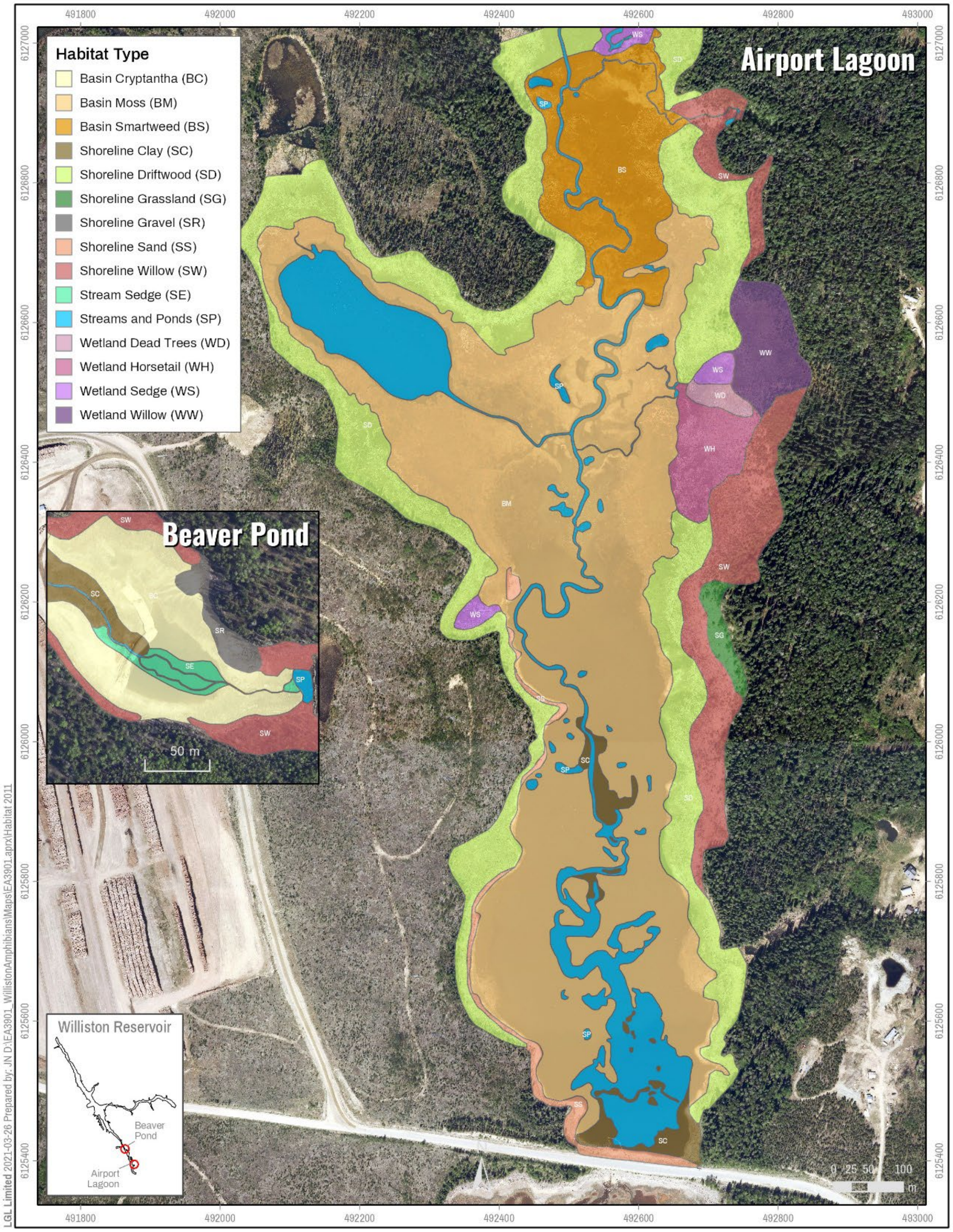


Figure 1. Spatial extent of habitat classes delineated at Airport Lagoon and Beaver Pond in Year 1 (2011) of GMSMON-15.

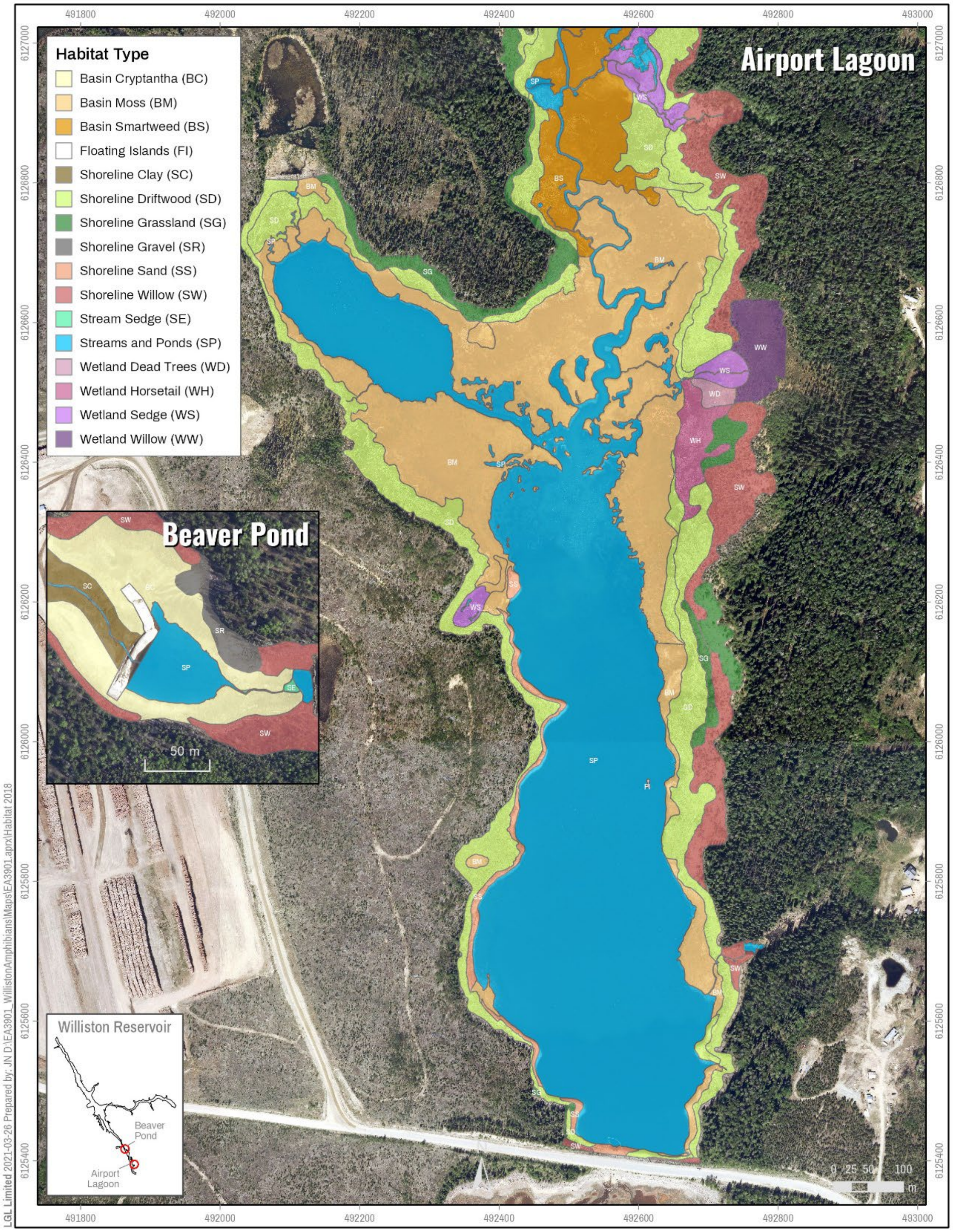


Figure 2. Spatial extent of habitat classes delineated at Airport Lagoon and Beaver Pond in Year 8 (2018) of GMSMON-15.

Discussion

The habitat classes at both sites have responded to the wetland enhancements and to annual flooding events. The amount of surface water (e.g., pond) has appeared to have increased at both sites leaving a varied shoreline/riparian area. At Airport Lagoon, the general pattern of riparian habitat from the water's edge starts with either mineral soil (sand) or mosses and perennials that transitions into a band of coarse woody debris (driftwood) followed by graminoid-dominated areas and then shrub habitats. Tree seedlings were documented in Years 9 and 10, but it may be too early to determine if these trees can become established.

At Beaver Pond, mud and clay remains present at the water's edge, but perennial species are becoming established. The partitioning of communities observed along these gradients suggests that succession to stable wetland/riparian communities will require additional time, but that this successional trajectory is occurring.

Vegetation development and establishment can be a relatively slow ecological process, so the longer time series (i.e., 10 years) is necessary and the conditions under which the vegetation communities persist will become evident with the proceeding results.

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Appendix 8

Analysis of Terrestrial Vegetation Data

Introduction

The wetland enhancements at Airport Lagoon and Beaver Pond were designed to create larger areas of permanently flooded habitat and reduce water level changes during reservoir drawdown. The stable water level was anticipated to allow for colonization of the drawdown zone by riparian vegetation. As such, terrestrial vegetation was identified as an indicator group for determining the effectiveness of the wetland enhancement projects. (BC Hydro 2008). Annual measurements of vegetation were collected to address the following management question:

> MQ3: Is there a change in the abundance, diversity and extent of vegetation in the enhancement area?

The primary hypothesis to be tested was:

> H_2: The density, diversity, and spatial extent of riparian and aquatic vegetation changes following enhancement.

Data collection for terrestrial vegetation commenced in Year 1 (2011) of GMSMON-15 and was conducted each year until 2020.

Methods

Ground sampling of terrestrial (i.e., riparian) vegetation was typically conducted in June or July along belt-transects. Sampling commenced as early as June 1 (2016) and was completed as late as July 7 (2020). Initially 10 transects were established at Airport Lagoon and five transects at Beaver Pond, but data collection for these varied throughout the program as access to transects changed as a result of water infiltration during the post-enhancement period and as reservoir levels fluctuated (Table 1). During post-enhancement, new transects were established in close proximity to ones that were no longer accessible.

Table 1. Ground sampling of terrestrial vegetation throughout the GMSMON-15 monitoring program.

Year	Julien date	Res. Elev.	Airport Lagoon		Beaver Pond	
			Phase	# of Transects	Phase	# of Transects
2011	171	655.418	Pre	10	Pre	5
2012	154	663.475	Pre	10	Pre	5
2013	160	665.967	Construction	7	Pre	5
2014	167	665.989	Post	9	Construction	3
2015	156	668.108	Post	8	Post	2
2016	152	667.687	Post	7	Post	3
2017	N/A	N/A	Post	N/A	Post	N/A
2018	187	666.716	Post	12	Post	5
2019	179	664.500	Post	12	Post	5
2020	188	669.691	Post	10	Post	4

Belt-transects were 20 m in length and consisted of ten 2 m by 0.5 m quadrats to allow for sub-sampling and to increase the accuracy of vegetation cover estimates (Figure 1). Each transect was laid out using a 30 m measuring tape and a 2 m measuring rod. Transect start and end coordinates were recorded, and photographs were taken at both the start and end points. Within each quadrat, all vegetation within or overhanging each quadrat was identified to species and the percent cover (vertical crown projection) of each species was visually estimated and rounded as follows: <1% - traces; 1-10% - rounded to nearest 1%; 11-30% - rounded to nearest 5%; 31-100% - rounded to nearest 10%.

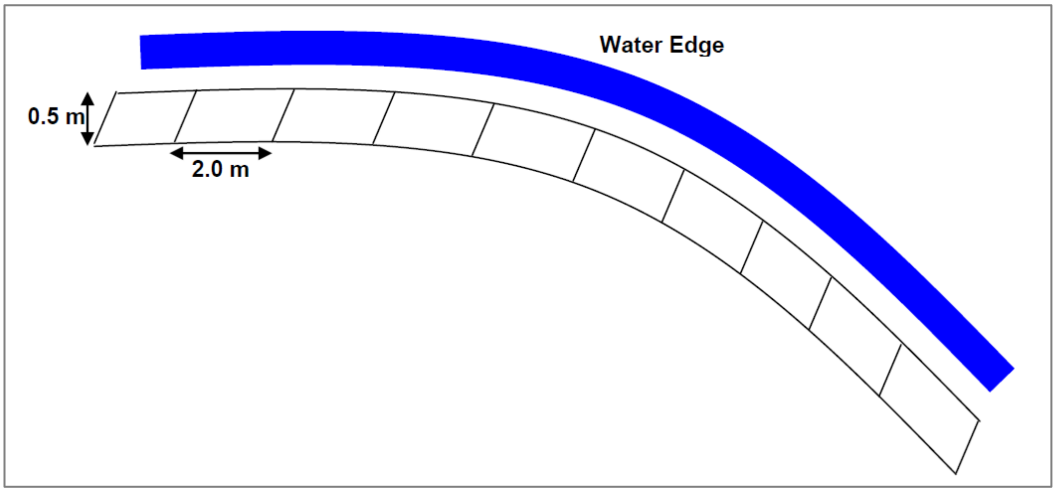

Figure 1. Schematic of belt transect survey design for the ground sampling of terrestrial vegetation at Airport Lagoon and Beaver Pond.

Site and soil characteristics for each transect were recorded on provincial ecosystem field forms (Province of British Columbia 2010). The ground cover (per cent area) of each quadrat was apportioned among substrate classes as follows: organic matter, coarse woody debris, rock, mineral soil, and water (standing and flowing). These data are presented in annual reports for the project.

Dataset

The terrestrial vegetation dataset was the compiled presence/not detected data that was used to measure diversity and abundance of terrestrial vegetation species. The average percent cover of terrestrial species across the 10 quadrats in each transect was calculated. These averages were used to calculate an average per cent cover by vegetation layer (e.g., moss, herb, shrub, tree) for each transect during each year of the monitoring program. In summary, this dataset was comprised of 1259 records for 130 individual species.

Differences in cover and species richness by vegetation layer were assessed with general linear mixed models (GLMMs), which included a fixed factor for period (before, during, and after enhancements) and a random effect for transect, to account for the repeated-measure nature of the data. Three types of GLMMs were run. The first model was a general linear mixed model with log of cover: log(cover)= β1*period + β0. The two other models were generalized linear mixed models with either a gamma distribution (and an inverse-link) or a beta regression (with a log-link) (Zuur et al. 2009).

The magnitude of effects was computed as either the exponent of the regression coefficients for the log and the beta models (since they were both on a log scale), or as the difference between the inverse of the two regression coefficients for the gamma model (e.g. (1/(β1+β0))/(1/β0). The magnitude of effects indicated how much more or less vegetation cover there was (on average) in the post-enhancement period as compared to the pre-enhancement period. We used principal component ordinations (PCoAs) and multivariate regression trees (MRTs) to look into changes in species composition over time and across transects.

Analysis

Airport Lagoon

The cover of herbs increased slightly on average during and after construction at Airport Lagoon, whereas the cover of moss generally decreased (likely because of one transect, see Figure 3 below), and the cover of shrubs stayed very minimal if not absent (Figure 2).

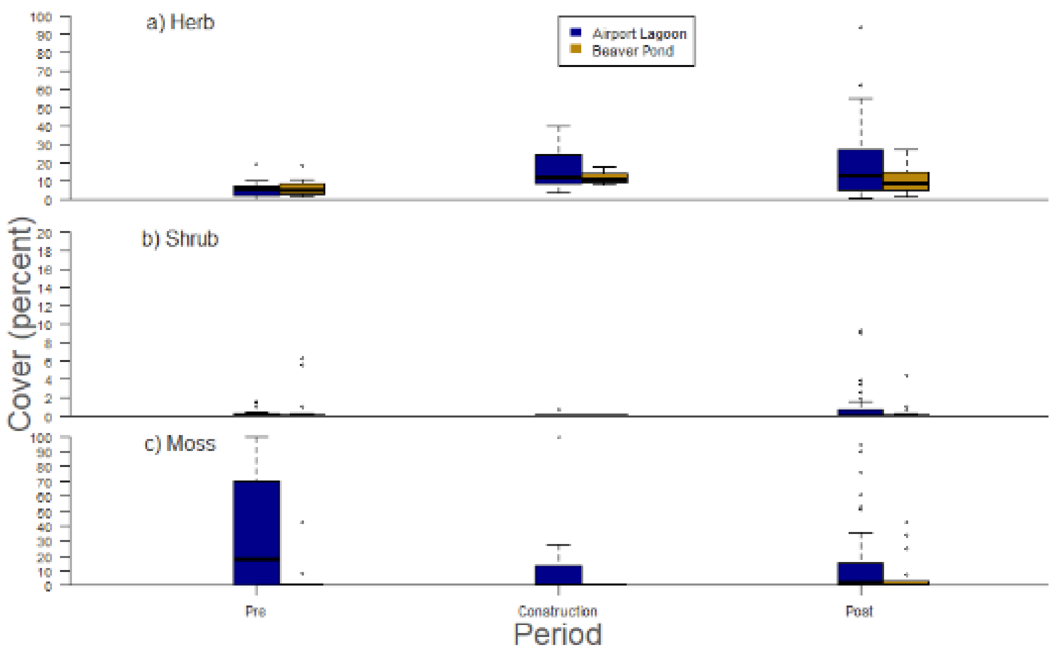

Figure 2. Cover (per cent) of a) herbs, b) shrubs, and c) moss across all transects before, during and after construction in Airport Lagoon and Beaver Pond (Note that the y-axis are different).

After the enhancement construction at Airport Lagoon in 2013, there was no clear trend in herb cover over time. While cover did increase at some transects after 2013 (e.g., AL-6, AL-7, except in 2018), many transects showed reduced cover up to 2018. Results from 2019 and 2020 showed an improvement in cover. Overall, there was an average increase in percent cover after 2012, except for 2018 when percent cover was as low as in the pre-enhancement years.

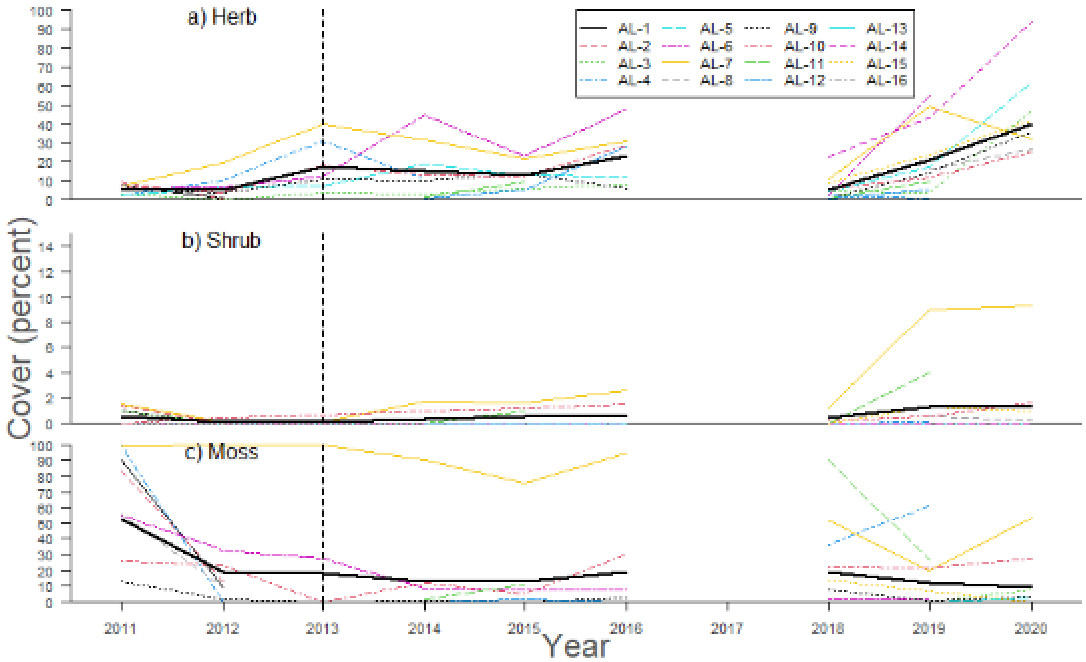

Figure 3. Variation in cover of a) herb, b) shrub, and c) moss over time in Airport Lagoon. Note no data were available for 2017. The vertical dotted line indicates when construction occurred, and the dark black line is the average over all transects per year. (Note that the y-axis are different).

Throughout the monitoring of terrestrial vegetation at Airport Lagoon, there was very low coverage of shrubs, except for one transect (AL-7) in 2019-2020 where cover was around 10% (Figure 3.b). Cover of moss was high in 2011 but declined sharply in 2012, and stayed low afterwards, except for AL-7 where it was high all years but declined sharply in 2018 and 2019 (Figure 3.c). No trees species were present on any transects before or during construction. Very little cover appeared in one transect in 2015 (AL-10) and three transects in 2019 and 2020 (0.01-0.1%, in transects Al-3, AL-11, and AL-15).

Results for Airport Lagoon showed that cover of herb vegetation was, on average, 2.5 to 3.8 greater during construction (i.e., in 2013) and 2.3 to 3.3 greater in the post-enhancement period (2014-2020) compared to the pre-enhancement period (2011-2012) (Table 2). Goodness of fit was better for the log model.

Table 2. Results of GLMM models assessing differences in cover of terrestrial vegetation in the herb layer before, during and after enhancements at Airport Lagoon.

Site	Model	Fixed effect	Coefficients	Significance	Magnitude of effect	Diagnostic plots
Herb	log(cover)	During	1.33	t= 2.66; p=0.01	3.8	ok, not great but ok (decent goodness of fit)
		After	1.19	t= 3.9; p=0.00019	3.3	
		Intercept	1.0893	t=3.54; p=0.001	--	
	gamma	During	-0.124	t=-2.9; p=0.004	2.9	Good enough too though quite low goodness of fit; qq plot better than for log model, but other plots look better for log. . ** not one outlier at high cover was removed
		After	-0.126	t=-3.3; p=0.001	3.0	
		Intercept	0.1905	t=4.96; p=0.000007	--	
	beta	During	0.911	t=02.43; p=0.015	2.5	not bad but not great; worst than for the other two models (not great goodness of fit, nor normality of residuals. ** also removed outlier at high cover
		After	0.841	t=3.35; p=0.001	2.3	
		Intercept	-2.534	t=-9.5; p=0	--	

Models for shrub cover either did not converge or did not yield significant changes in cover during or after enhancements (at α-0.1). Moss cover was best modelled with the log model, which had good enough diagnostic plots and goodness of fit, and significant changes in cover during and after the enhancements. The gamma model did not converge, and the beta model had poor fit (note that the presence of 0 forced adding 0.005 to all cover values, which is not ideal but necessary for the model). The log model predicted declines in moss cover for both during (0.02X smaller) and after (0.2X smaller) enhancement compared to the pre-enhancement period, which is likely due to the sharp declines in cover noted in transects AL-7 and AL-11.

Species richness was highest for herbs at Airport Lagoon with an average around five species before enhancement, to averages closer to 10 species after enhancements. Species richness for shrubs and mosses was generally low (1-2 species), though five species of moss were record in the post-enhancement period at Airport Lagoon.

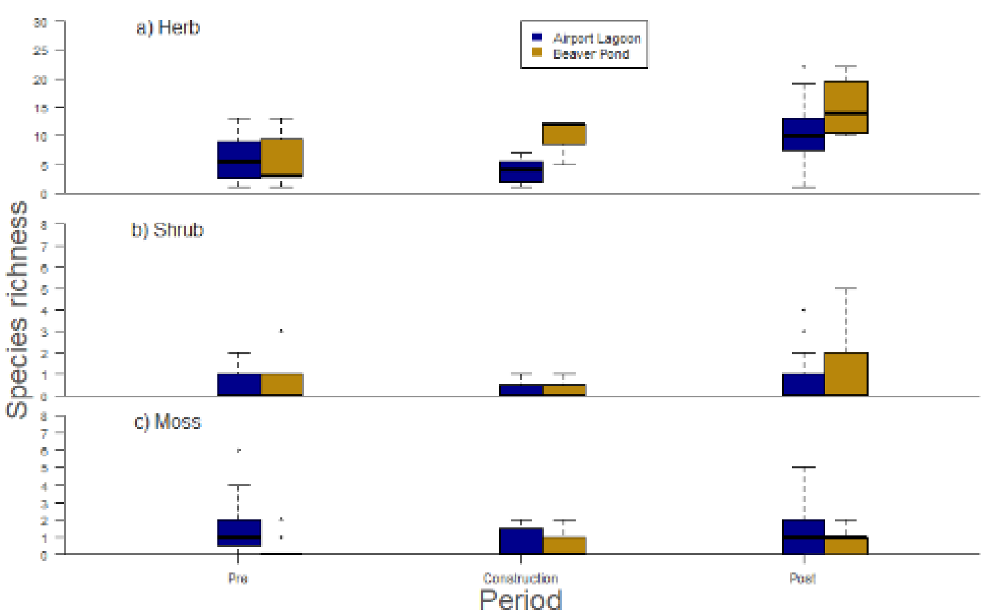

Figure 4. Richness (# of species) of a) herbs, b) shrubs, and c) moss across all transects before, during and after construction in Airport Lagoon and Beaver Pond. (Note that the y-axis are different).

Species richness of herbs decreased in most transects at Airport Lagoon between 2011 and 2012 but started increasing afterwards (Figure 5). Richness in shrub species was very low until 2018 when it increased for most transects. Richness in moss species remained relatively low throughout the monitoring program.

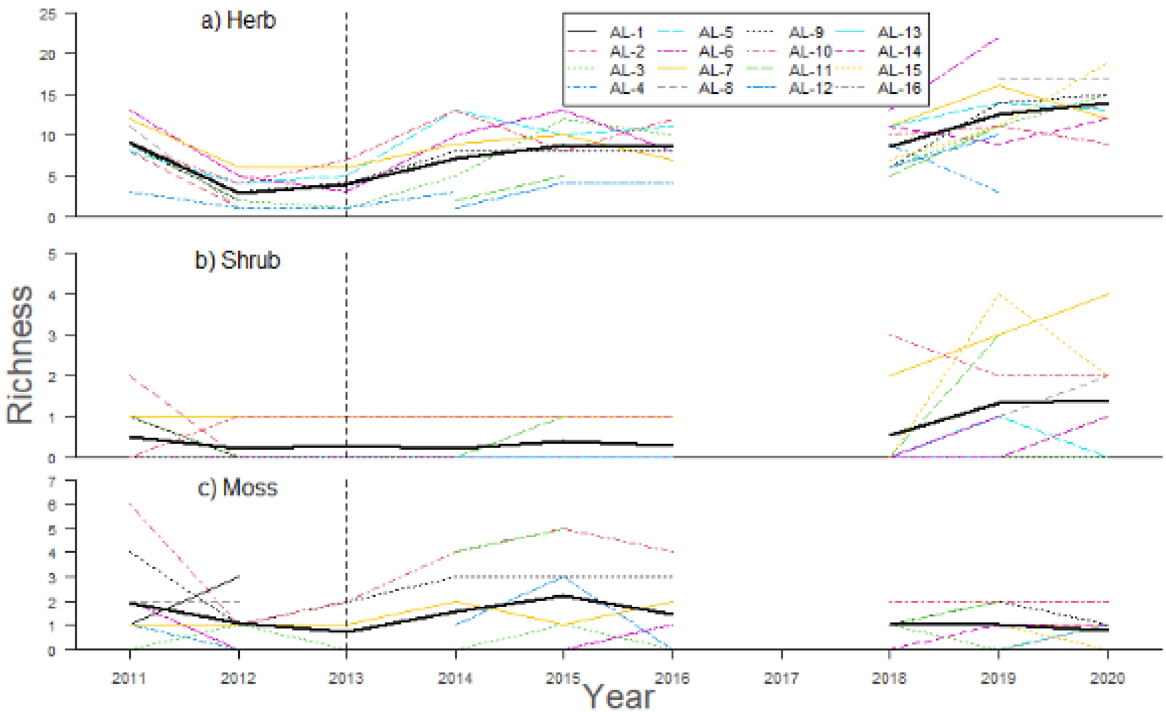

Figure 5. Variation in species richness of a) herb, b) shrub, and c) moss over time in Airport Lagoon. Note no data were available for 2017. The vertical dotted line indicates when construction occurred, and the dark black line is the average over all transects per year. (Note that the y-axis are different).

The general linear mixed models found a significant decrease in herb richness during construction (0.7X) and a significant increase (1.6 to 2.1X) in richness in the post-enhancement period at Airport Lagoon (Table 3). The log and Poisson models did not show a significant change in richness of shrub species during or after enhancements (at alpha=0.05), but fit was not great (diagnostic plots not great, residuals not really normal), so the results are not shown (gamma model was not run since presence of zeros made it less relevant). Richness of moss species was also low, but the log model had a much better fit and yielded a significant decrease in moss species richness during construction (0.15X, t=-2.006, p=0.048), but not in the post-enhancement period (Poisson model did not have a good enough fit to report results).

Table 3. Results of GLMM models assessing differences in richness of herb species before, during and after treatments in Airport Lagoon.

Site	Model	Fixed effect	Coefficients	Significance	Magnitude of effect	Diagnostic plots
Herb	log(cover)	During	-0.3958	t=-1.59; p=0.117	0.7	Generally ok, a bit underspecified at high values and overspecified at low values; more variation in residuals in before period; residuals fairly normal
		After	0.7254	t=4.79; p=0.0000075	2.1	
		Intercept	1.4441	t=9.3, p=0	--	
	gamma	During	0.088	t=41.65; p=0.099	0.7	Goodness of fit low; also more variation in residuals in before period; residuals more normal
		After	-0.07	t=-3.45; p=0.00055	1.6	
		Intercept	0.18	t=7.9; p=0	--	
	beta	During	-0.4034	z=-1.875; p=0.0608	0.7	Fit similar to gamma model; residuals look normal
		After	0.5819	z=5.57, p=0	1.8	
		Intercept	1.6903	z=13.97; p=0	--	

A total of 130 species were recorded over the monitoring program at both sites combined. Twenty species were recorded in 2012, in the pre-enhancement period; all of which were recorded again in the post-enhancement period. Likewise, no species were unique to 2013 and 2014 and only a few were unique to 2015 and 2016. The highest number of species was recorded in 2019 (n=90 species), and 35 of these were unique to 2019. Seven species were recorded in all years: *Drepanocladus aduncus* (common hook moss), *Persicaria amphibia* (water smartweed), *Calamagrostis canadensis* (bluejoint), *Equisetum fluviatile* (swamp horsetail), *Equisetum arvense* (common horsetail), *Eleocharis palustris* (common spikerush), and *Menyanthes trifoliata* (buckbean). A total of 59 species were seen in only one year.

Potentilla norvegica (Norwegian cinquefoil) was most frequently the dominant species in the herb layer (i.e., it had the highest cover in 10 transects), followed by *Calamagrostis canadensis* (bluejoint; 6 transects), and *Carex* sp. (sedge), *Cryptantha torreyana* (Torrey's cryptantha) and *Equisetum arvense* (common horsetail) (5 transects each). Salix species (willow) were dominant in the shrub layer, especially *Salix bebbiana* (Bebb's willow) and *Salix barclayi* (Barclay's willow). Only three tree species were documented, and only with less than 1% of cover in 2019 and 2020 (*Pinus contorta* [lodgepole pine], *Populus tremuloides* [trembling aspen], and *Populus balsamifera* [balsam poplar]). Finally, in the moss layer, *Drepanocladus aduncus* was by far the most dominant species, followed by *Climacium dendroides* (tree-moss).

Individual transects at Airport Lagoon were more similar in terms of species composition to themselves over time, than to other transects from the same year of sampling, except for five transects from 2012 that clustered rather close together (AL-8, AL-2, AL-1, AL-10, AL-6; Figure 6). Most transects sampled in 2019 and 2020 seem to be in the same general area in the bottom left of the ordination, suggesting they were more similar together than to transects sampled in other years. However, some transects changed quite a bit over time (e.g., AL-4, AL-2, AL-9, AL-10), while others remained quite stable over time (e.g., AL-6, AL-5, AL-10, AL-7, AL-12). Results were similar for Bray-Curtis (D14) and Euclidian distance (D17) coefficients, although results were more temporally delineated with the Euclidian distance (light blue [2012] to the right of the ordination, orange [2018] as a bit of a transition year in the middle, and grey/pink [2019, 2020] to the left of the ordination). This suggests that differences for abundant species contributed more to the similarity among transects over time than differences in rare species (as D17 gives more weight to abundant species while D14 gives equal weight to abundant and rare species).

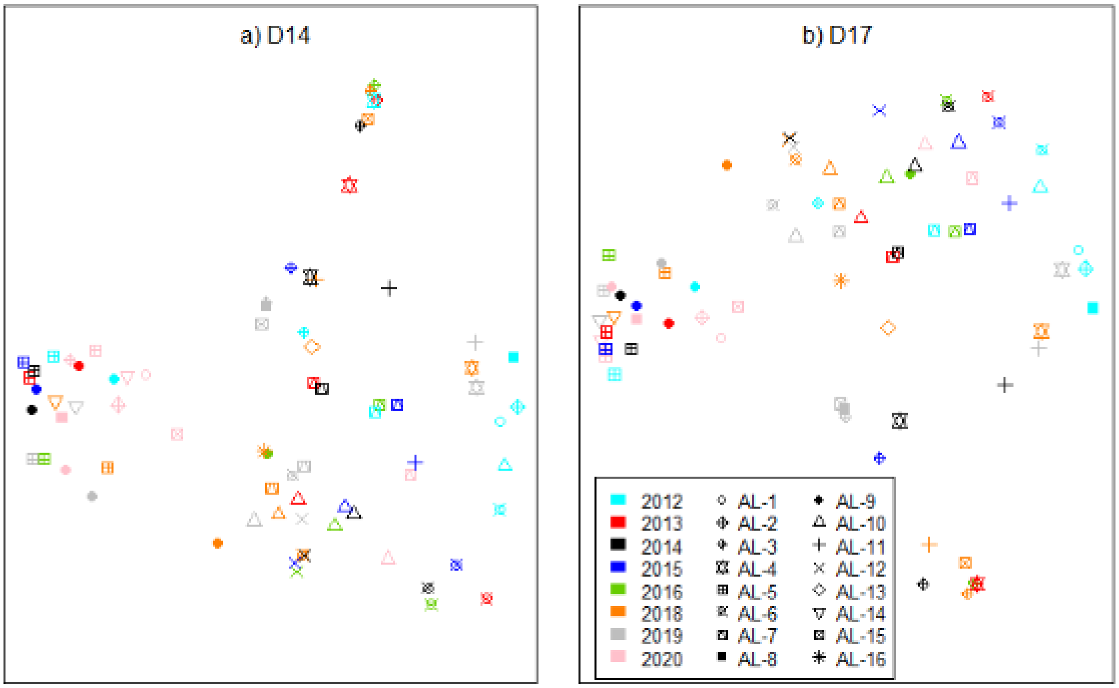

Figure 6. PCoA diagram showing the similarity in species composition of terrestrial vegetation among transects over time in Airport Lagoon as computed with a) Bray-Curtis distance (D14), and b) Euclidian distance (D17). Axis X explains 17% and axis Y explains 12% of the variation in species composition for D14 and 22% and 16% for D17. Colors code for years of sampling and symbols refer to transect sampled.

Based on the multivariate regression tree (MRT), transects AL-5, AL-9 and AL-14 were most different from the other transects in terms of species composition (Figure 7); their differences were also noticeable on the principal component analysis (PCoA; Figure 6). These species were characterized by *Calamagrostis canadensis* and *Equisetum arvense* (Table 4). Transects AL-1, AL-2, AL-3, AL-4, AL-8, AL-11, AL-13, and AL-15 were most similar, and their species composition was different before 2020 than in 2020. Several species were indicative of the species composition in 2020 (see Table 4), while *Persicaria maculosa* (lady's thumb) represented the same transects before 2020. Transects AL-6, AL-10, AL-12, and AL-16 clustered together, while transect AL-7 stood alone.

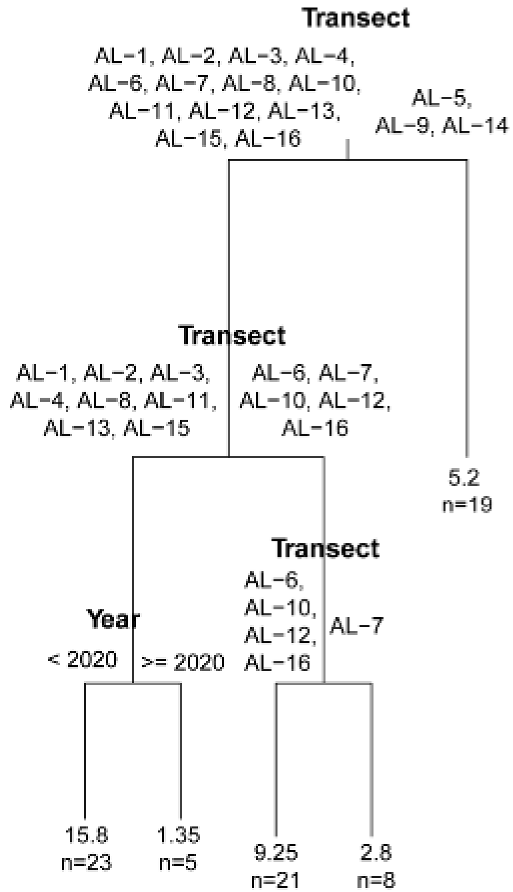

Figure 7. Multivariate regression tree (MRT) showing the partition of transects based on vegetation species compositions from 2012 to 2020 in Airport Lagoon. Numbers at each leaf are relative errors* and number of transects per leaf. The tree explains 38% of the variance in species composition.

* Relative error at each leaf= sum of squared distances of all objects in the cluster to their common centroid (= same as “error” in ANOVA). If all data points have same coordinates in the multidimensional space, error is 0, so higher error means groups are less tight.

Table 4. Indicator species for each leaf of the MRT in Airport Lagoon.

Leaf	Species	Indval	p-values	Characteristics
1	PERSMAC	0.79	0.001	Transects AL-1, AL-2, AL-3, AL-4, AL-8, AL-11, AL-13, and AL-15 before 2020
2	CAREAEN	0.96	0.001	Transects AL-1, AL-2, AL-3, AL-4, AL-8, AL-11, AL-13, and AL-15 in 2020
	CHAMANG	0.96	0.001	
	POA PAL	0.65	0.001	
	EPILCIL	0.6	0.001	
	RHINMIN	0.58	0.002	
	CREPCAP	0.52	0.003	
	AGOSTR	0.51	0.002	
	TARAOFF	0.51	0.003	
	POTENOR	0.46	0.003	
	SALIBAR	0.45	0.005	
	RANUPEN	0.33	0.029	
	SALIALA	0.18	0.035	
3	EQUIFLU	0.52	0.003	Transects AL-6, AL-10, AL-12, and AL-16
	PERSAMP	0.39	0.006	
	CARDPEN	0.31	0.016	
	CAREVIR	0.19	0.047	
4	MENYTRI	0.98	0.001	Transect AL-7
	ELEOPAL	0.82	0.001	
	CALLGIG	0.68	0.001	
	COMAPAL	0.6	0.002	
	CAREUTR	0.32	0.013	
	SALIPED	0.27	0.021	
	CAREAQU	0.25	0.044	
5	EQUIARV	0.62	0.001	Transects AL-5, AL-9, and AL-14
	CALACAN	0.47	0.003	

Beaver Pond

At Beaver Pond, the cover of herbs also increased slightly during and after construction, though at lower percent covers than at Airport Lagoon. Herb cover along most transects increased until 2014 and then remained stable or declined (Figure 8.a). By 2018, cover had reduced to approximately 5%, which was similar to the cover before the enhancement; however, in 2019 and 2020 percent cover of herbs began to increase again.

There was barely any cover of shrubs or moss at Beaver Pond before, during or after construction. Trace amounts of shrub cover (approximately 3%) were present in Year 1 (2011) but reduced to mostly nil throughout the monitoring program, and then reappeared again in 2020 (Figure 8.b).

Similarly, cover of moss was nil in all years except for 2011 and 2020 (Figure 8.c). Tree species were only present on the transect in 2019 (0.01% on BP-2) and 2020 (0.1% on BP-3).

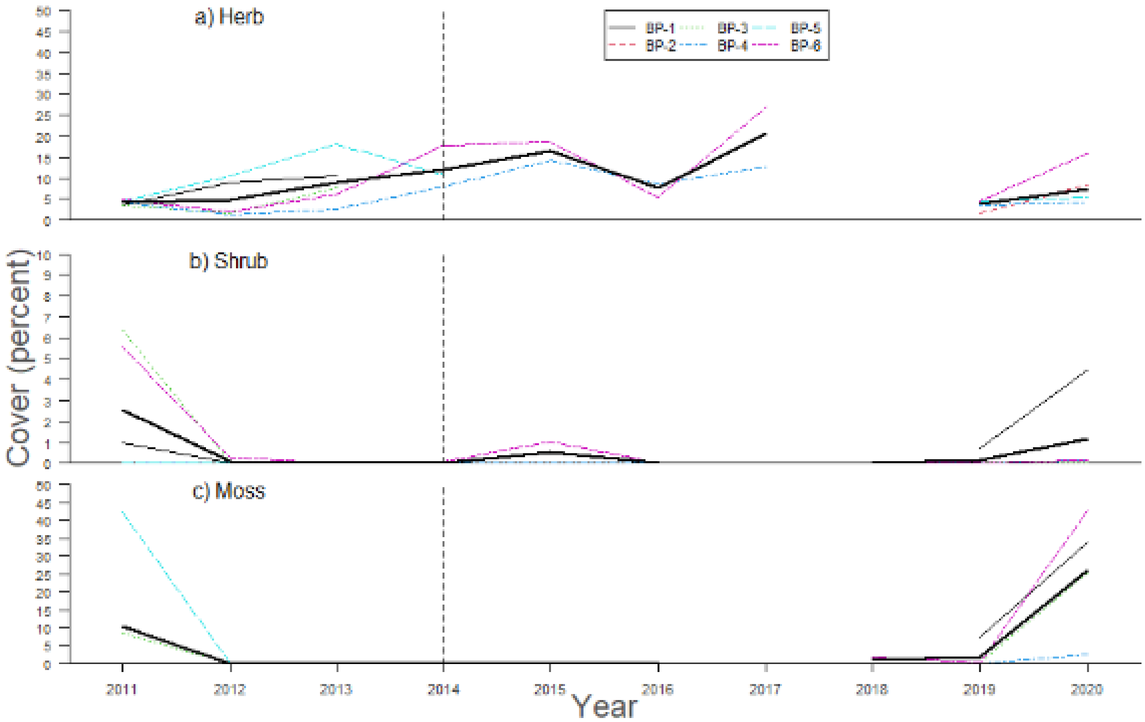

Figure 8.Variation in cover of a) herb, b) shrub, and c) moss over time in Beaver Pond. Note no data were available for 2017. The vertical dotted line indicates when construction occurred, and the dark black line is the average over all transects per year. (Note that the y-axis are different).

At Beaver Pond, the cover of herbs increased significantly during and after enhancements, by a factor of 1.6 to 2.2X (Table 5). Note however that diagnostic plots were not great, so caution should be taken with interpreting results. A log model could not be fit. Similarly, no model could be fit for the cover of shrubs or mosses at Beaver Pond. The poorer fits can likely be explained by the small sample size and limited presence and low cover of vegetation (especially shrub and moss) overall in Beaver Pond.

Table 5. Results of GLMM models assessing differences in cover of terrestrial vegetation in the herb layer before, during and after treatments in Beaver Pond.

Site	Model	Fixed effect	Coefficients	Significance	Magnitude of effect	Diagnostic plots
Herb	gamma	During	-0.084	t=5.54; p=0	2.0	Not great plots; not great goodness of fit but residuals normal; maybe small sample size and generally low cover limits performance of model
		After	-0.0703	t=-1.99; p=0.0466	1.7	
		Intercept	0.1696	t=-2.2; p=0.03	--	
	beta	During	0.7699	z=13.62; p=0	2.2	Not great plots; not great goodness of fit but residuals normal; maybe small sample size and generally low cover limits performance of model
		After	0.4433	z=2.04; p=0.042	1.6	
		Intercept	-2.6623	z=1.89; p=0.06	--	

Species richness was generally low for shrub and mosses (1-2 species, generally, though up to 5 species of shrub were sampled after treatments in Beaver Pond and 5 species of moss were seen after treatments in Airport Lagoon) (Figure 4).

Like at Airport Lagoon, species richness was highest for herbs, with an average around five species before enhancement, to averages and 15 species after enhancement. Species richness at Beaver Pond followed similar trajectories to what was documented at Airport Lagoon (Figure 9), with a decreased richness of herbs between 2011 and 2012, followed by an increase in richness until 2014, a period of stable richness until 2018, and an increase again until 2020. The number of shrub species remained relatively low after 2011 until an increase was recorded between 2018 and 2020. Species richness of moss varied between 1-2 species only.

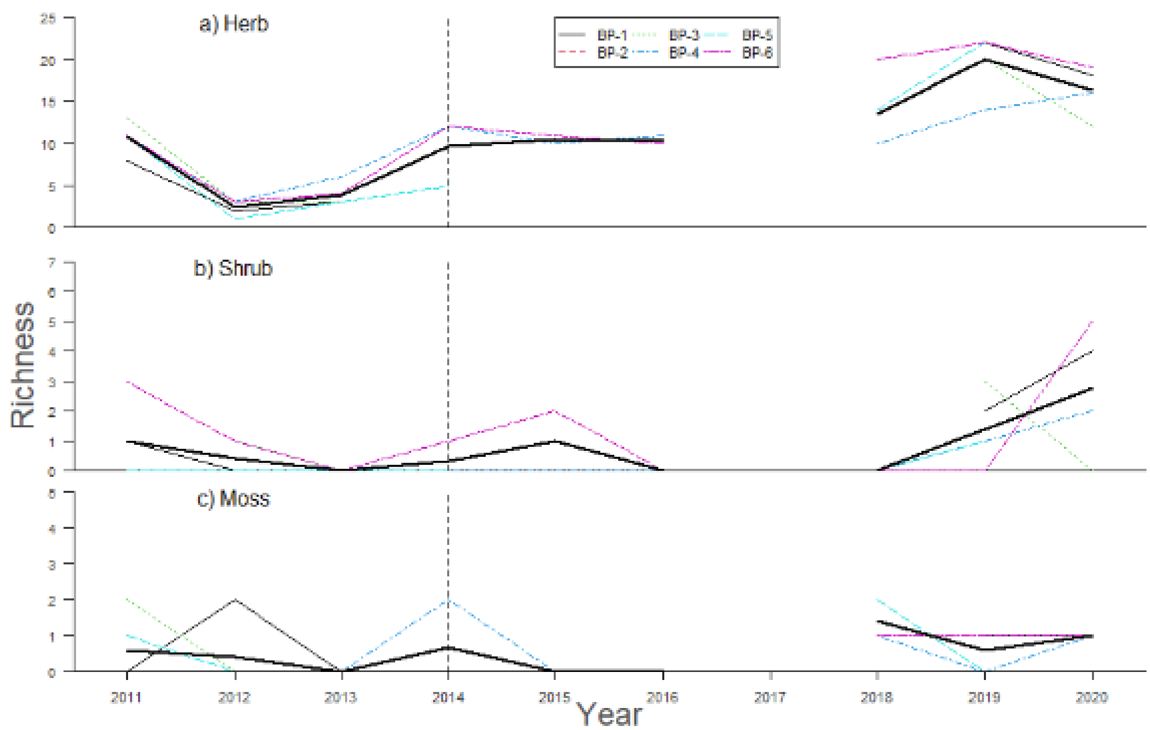

Figure 9. Variation in species richness of a) herb, b) shrub, and c) moss over time in Airport Lagoon. Note no data were available for 2017. The vertical dotted line indicates when construction occurred, and the dark black line is the average over all transects per year. (Note that the y-axis are different).

No models could be fit for richness of herb, shrub or moss species at Beaver Pond; the goodness of fit were not good at all, and no significant effects were noted.

Species composition in all transects at Beaver Pond transitioned over time with transects sampled in 2012 (light blue) clustering on the left (BP-1, BP-2, and BP-4) or top of the diagram (BP-3 and BP-5) and transects sampled in 2019 and 2020 (grey and pink) clustering more tightly together at the bottom right of the ordination (Figure 10). Transects BP-5 and BP-3 both showed two clusters with species composition most similar in 2012, 2013, 2016 and 2018, and most similar in 2014 (the construction year), 2015, 2019 and 2020. Transects BP-1, BP-2, BP-3, and BP-4 all show a clear trend over time from 2012 to 2020. Results were similar for both distance coefficients, indicating little influence of abundant species.

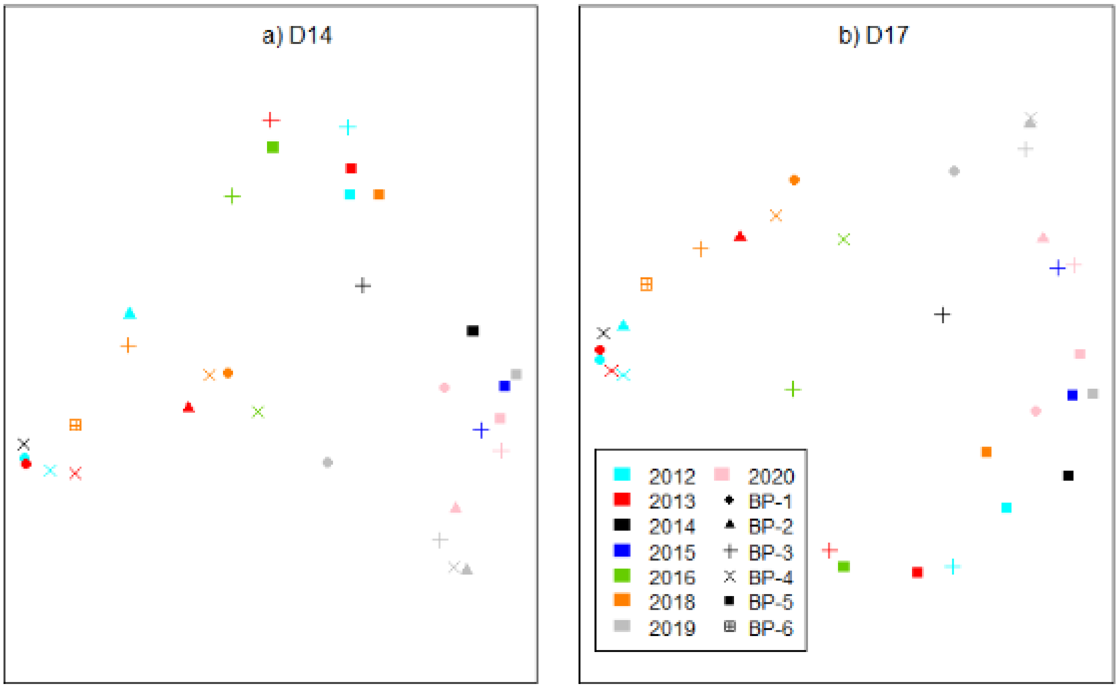

Figure 10. PCoA diagram showing the similarity in species composition of terrestrial vegetation among transects over time in Beaver Pond as computed with a) Bray-Curtis distance (D14), and b) Euclidian distance (D17). Axis X explains 26% and axis Y explains 16% of the variation in species composition for D14 and 32% and 18% for D17. Colors code for years of sampling and symbols refer to transect sampled.

In Beaver Pond, the species composition before and after 2019 was different enough to split the transects in the first branch; all transects in 2019 and 2020 were more similar together, than to the transects before 2019 (Figure 11). Before 2019, transects BP-1, BP-2, BP-4 and BP-6 clustered together, and transects BP-3 and BP-5 grouped together. Species *Matricaria discoidea* (pineapple weed), *Persicaria maculosa* and *Cryptantha torreyana* were indicator of the first group of transects before 2019 while *Chenopodium album* (lambsquaters), *Carex aquatilis* (water sedge) and *Equisetum arvense* were indicator species of transects BP-3 and BP-5 before 2019 (Table 6). Several species were characteristics of the transects in 2019 and 2020. A total of 17 species were indicator species for the transects in 2019 and 2020 (leaf 3), of which only five were unique to those years. Results of the MRT were similar to those of the PCoA (Figure 10 vs Figure 11) for Beaver Pond, suggesting that the trends in species composition observed were strong.

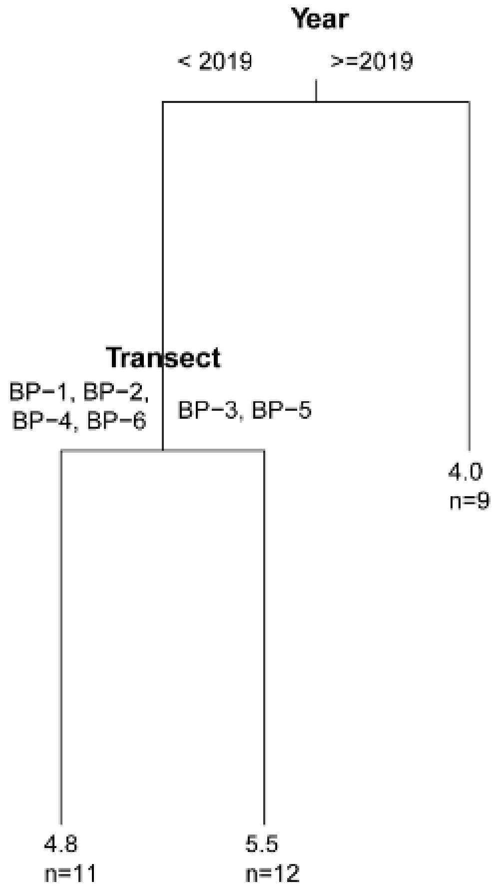

Figure 11. Multivariate regression tree (MRT) showing the partition of transects based on vegetation species compositions from 2012 to 2020 in Beaver Pond. Numbers at each leaf are relative errors and number of transects per leaf. The tree explains 35% of the variance in species composition.

Table 6. Indicator species for each leaf of the MRT in Beaver Pond.

Leaf	Species	Indval	p-values	Characteristics
1	MATRDIS	0.36	0.016	Transects BP-1, BP-2, BP-4, BP-6 before 2019
	PERSMAC	0.67	0.003	
	CRYPTOR	0.665	0.001	
2	CHENALB	0.33	0.028	Transects BP-3 and BP-5 before 2019
	CAREAQU	0.42	0.007	
	EQUIARV	0.72	0.001	
3	RANUPEN	0.36	0.049	All transects in 2019 and 2020
	AGROSCA	0.37	0.032	
	GNAPPAL	0.33	0.018	
	JUNCTEN	0.33	0.018	
	SALIBAR	0.33	0.018	
	CERANUT	0.33	0.015	
	CAREBEB	0.43	0.01	
	RHINMIN	0.42	0.009	
	AGROSTR	0.44	0.005	
	CAREAEN	0.44	0.004	
	CHAMANG	0.44	0.002	
	PLAGHIS	0.56	0.002	
	POA PAL	0.57	0.002	
	ALOPAEQ	0.59	0.001	
	CARELEN	0.76	0.001	
	EPILCIL	0.73	0.001	
	POTENOR	0.7	0.001	

Discussion

The cover of herbaceous vegetation increased slightly on average during construction and immediately after the enhancements at Airport Lagoon (Yeas 2 & 3); however, there was no clear trend in herb cover throughout most of the monitoring program (Year 4 to Year 8), until Years 9 and 10 when cover began to increase. The later sampling dates, particularly in 2020 may have influenced this noticeable change in herbaceous cover. This change was largely due to a measurable increase in one species, *Calamagrostis canadensis* (bluejoint) at two transects (AL-5 and AL-14). *Calamagrostis canadensis* continues to grow and increase its canopy throughout the growing season. In 2020, this species likely also benefitted from the low reservoir year in 2019, which would have improved growing conditions for this, and other grass species.

Despite the cover of herbaceous vegetation increasing in the latter years of the monitoring program, overall cover remained relatively low at around 10-20% (average of 9.8% as predicted by the log model). Most transects were within wet (hydric, subhydric), nutrient rich soils with relatively high organic matter, so a greater herbaceous cover would be expected. However, fluctuating reservoir levels and northern climatic conditions likely affect the growth rates of vegetation. Also, most transect were poorly drained and the prevalence for prolonged wetter conditions also potentially impacted vegetation growth. Despite these conditions, vegetation cover is expected to continue to increase allowing for dominant species at the herb, shrub and tree layers to become established.

At Beaver Pond, the amount of terrestrial vegetation was less than what was recorded at Airport Lagoon; however, some notable changes occurred. The cover of herbaceous vegetation increased significantly during construction and the post-enhancement period. Likewise, species richness was relatively low before the enhancement (e.g., five species) but increased to 15 species in the post-enhancement period. Finally, species composition transitioned over time with distinct changes occurring in the latter years of the program. The vegetation transects at Beaver Pond were in well-drained and typically drier soils, which likely influence the overall less coverage compared to the transects at Airport Lagoon. The establishment of terrestrial vegetation was greater in the more upland sites that were in close proximately to the adjacent forested areas. The areas closer to the impounded water are within the shoreline clay habitat type, where there was typically a higher proportion of mineral soil. Although, despite these tougher substrates for vegetation growth, cover was increasing but it is expected that vegetation establishment at Beaver Pond will take considerably more time than at Airport Lagoon.

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Appendix 9

Analysis of Aquatic Vegetation Data

Introduction

The wetland enhancements at Airport Lagoon and Beaver Pond were designed to create larger areas of permanently flooded habitat and reduce water level changes during reservoir drawdown. Prior to the enhancements, aquatic vegetation was limited at Airport Lagoon and Beaver Pond therefore sampling only commenced later in the monitoring program: Year 4 (2014) at Airport Lagoon and Year 5 (2015) at Beaver Pond.

The stable water level was anticipated to allow for colonization of the wetted areas by aquatic vegetation. As such, aquatic vegetation was identified as an indicator group for determining the effectiveness of the wetland enhancement projects (BC Hydro 2008). Measurements of aquatic vegetation were collected to address the following management question:

> MQ3: Is there a change in the abundance, diversity and extent of vegetation in the enhancement area?

The primary hypothesis to be tested was:

> H_2: The density, diversity, and spatial extent of riparian and aquatic vegetation changes following enhancement.

Data collection for aquatic vegetation started out as visual observations and benthic rake drags to obtain information on species composition and relative abundance. More systematic surveys were completed in the latter years of the monitoring program.

Methods

In 2014, 2015 and 2016, surface sampling of aquatic vegetation at Airport Lagoon included visual observations of aquatic plant cover along the shoreline and shallow water of the flooded areas (where water depth was <2 m). Benthic rake drags (i.e., using a double-headed rake attached to a rope) were also completed at select locations away from the shoreline where water depth limited visual observations of aquatic plant cover (>2 m depth). At each location, the rake was dropped to the bed of the flooded area and dragged along the bed for a distance of approximately 1-3 m to collect samples. This method was repeated a total of 3 times at each location to obtain information on species composition and relative abundance. Results from 2014, 2015 and 2016 were used to describe aquatic vegetation communities. Aquatic plant communities were identified and mapped along the water surface and shoreline of Airport Lagoon based on the dominant species for the community.

Sampling of aquatic plants was not completed at Beaver Pond in 2014 since a reconnaissance of the site revealed no substantial cover of aquatic plants. However, surface sampling of aquatic vegetation was completed here in 2015 and 2016 using visual observations. No data or annual report from Year 7 (2017) were provided to the authors.

Sampling of aquatic vegetation in 2018, 2019 and 2020 was based on a systematic design (Hawkes et al. 2011, Miller and Hawkes 2013) using transects spaced across the wetlands at 100 m to 400 m intervals with sampling points located every 25 m to 50 m along each transect (Figure 1). Transect length and spacing varied depending on the width of the wetland and environmental conditions at the time of the survey. Geographical coordinates corresponding to the sample points were loaded into a hand-held GPS unit to facilitate navigation from point to point in the field.

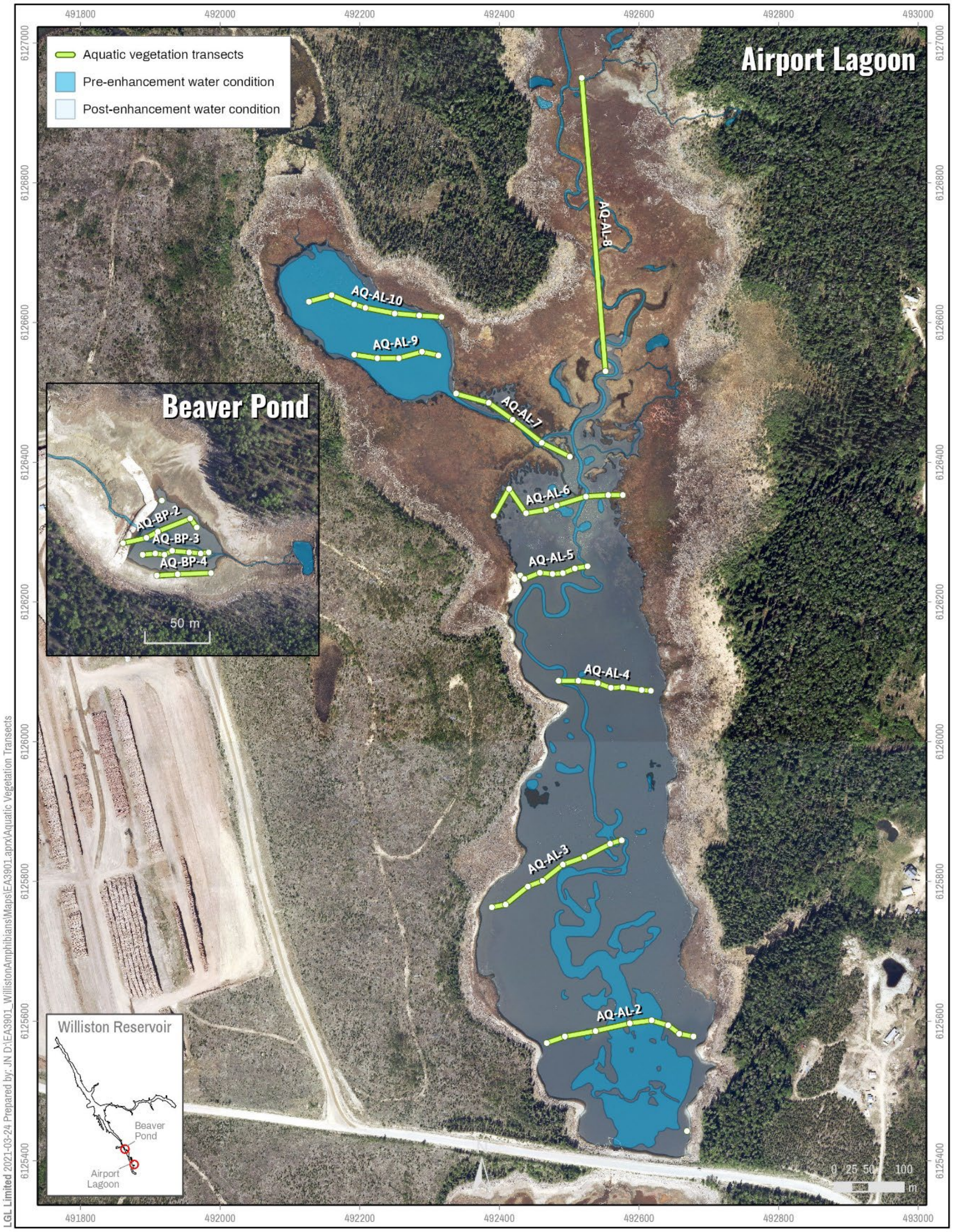

Figure 1. Example of transects and sampling points used in the sampling of aquatic macrophyte species at Airport Lagoon and Beaver Pond in 2018, 2019 and 2020.

Aquatic macrophyte species composition and relative abundance were recorded at each sample point using benthic rake drags. A cluster sampling approach was used in which two samples were taken at each location. The volume of each sample was estimated based on a categorical scale from 1 to 3 (Table 1). Also, each macrophyte species in the sample was assigned a relative cover class (Table 2). Water depths were measured by dropping a weighted tape measure to the bottom at each surface sample point.

Table 1. Volume classes for vegetation samples collected during the sampling of aquatic vegetation in 2018, 2019 and 2020.

Volume Class	Sample Volume	Definition
1	Trace	Sample is restricted to one or very few strands of vegetation
2	Small	Sample fills less than half of the tines of the sampling rake
3	Large	Sample fills half or more of the tines of the sampling rake

Table 2. Cover class for vegetation samples collected during the sampling of aquatic vegetation in 2018, 2019 and 2020.

Cover Class	Definition
T	Species is present but contributes negligibly (< 1 per cent) to the sample volume
1	Species contributes less than 10 per cent of the sample volume
2	Species contributes 11–20 per cent of the sample volume
3	Species contributes 21–50 per cent of the sample volume
4	Species contributes 51–75 per cent of the sample volume
5	Species contributes 76–100 per cent of the sample volume

Dataset

Aquatic vegetation spatial data (i.e., aquatic plant communities) and electronic data from the benthic rake drags from 2015 to 2016 was not provided to LGL Limited; therefore, data on aquatic vegetation from these years was compiled from the annual reports.

Quantitative data on aquatic plant communities at Airport Lagoon, in terms of area (ha) and percent coverage, was provided for 2014 – 2016. During these years, species composition and relative abundance of aquatic vegetation was based on the presence/not-detected of aquatic plant species at dredge points. However, dredge locations were presented on maps, but coordinates and water depth data were not provided, so the analysis was limited to a qualitative description of species occurrence and distribution at Airport Lagoon. No cover of aquatic plants was documented at Beaver Pond in 2015 and 2016; therefore, analysis is limited to the data collected from 2018 to 2020.

Table 3. Aquatic plant communities documented at Airport Lagoon between 2014 and 2016.

Aquatic Plant Community	2014		2015		2016	
	ha	%	ha	%	ha	%
Closed-leaved Potamogeton / Fennel-leaved Pondweed	9.29	33.12	12.24	43.63	12.24	43.63
Lady's Thumb / Water Smartweed	5.41	19.29	4.43	15.81	4.43	15.81
Water Smartweed	0.06	0.21	0.94	3.35	0.94	3.35
Common Hornwort	2.86	10.12	2.86	10.2	2.86	10.2
Non-aquatic	10.43	37.19	7.58	27.02	7.58	27.02

From 2014 to 2020, aquatic macrophyte frequency (defined as the proportion of sample plots in which a species or group of species was detected) was compared across each year at Airport Lagoon. Macrophyte frequency (a proxy for overall cover) was calculated as the number of sample points in which a species was detected divided by the total number of sample points.

Table 4. Frequency (%) of aquatic macrophyte species detected in random samples (rake grabs) at Airport Lagoon from 2014 to 2020.

Scientific Name	Common Name	2014	2015	2016	2018	2019	2020
Callitriche palustris	spring water-starwort	-	-	27.3%	3.2%	-	-
Ceratophyllum demersum	common hornwort	36.4%	-	54.5%	45.2%	28.3%	-
Chara sp.	stonewort		18.2%	36.4%	4.8%	13.3%	91.7%
Drepanocladus aduncus	common hook moss	45.5%	81.8%	72.7%	56.5%	36.7%	-
Hippuris vulgaris	common mare's tail	-	-	9.1%	1.6%	1.7%	-
Myriophyllum sibiricum	verticillate water-milfoil	-	9.1%	36.4%	64.5%	80.0%	-
Najas flexilis	wavy water nymph	-	9.1%	-	-	-	-
Persicaria maculosa	lady's thumb	-	-	-	3.2%	-	-
Potamogeton foliosus	closed-leaved potamogeton	-	36.4%	90.9%	45.2%	25.0%	53.3%

Potamogeton praelongus	long-stalked potamogeton	9.1%	-	18.2%	17.4%	11.7%	23.3%
Ranunculus aquatilis	white water-buttercup	-	-	-	1.6%	10.0%	-
Sparganium sp.	bur-reed	-	-	-	1.6%	-	-
Stuckenia pectinata	fennel-leaved pondweed	27.3%	27.3%	-	-	36.7%	-
Utricularia macrorhiza	common bladderwort	-	-	18.2%	21.0%	-	-
Utricularia spp.	bladderwort	9.1%	-	-	3.2%	-	-

From 2018 to 2020, macrophyte density was estimated for each species and sample point as volume multiplied by relative cover (Miller and Hawkes 2013). Volume classes ranged from 1 through 3, and relative abundance classes ranged from 0.1 (for trace) to 1 through 5 (Table 1, Table 2). For each sample point, the values were averaged across two rake grabs. Thus, the minimum possible volume value was 0.5 and the minimum possible relative cover value was 0.05. The minimum possible (non-zero) value for the volume x cover metric was then 0.5 x 0.05 = 0.025, and the maximum possible value for the volume x cover metric was 3 x 5 = 15.

A total of 14 species and 2 taxa, identified only to genus, were included in the dataset for the last three years of the monitoring program. For this dataset, changes in density of aquatic species (volume x abundance) per species and changes in richness were examined. The relationship between total density, water depths and years for both sites and all species were analyzed with principal component ordination and multivariate regression trees.

Analysis

2014 – 2016

At Airport Lagoon, between 2014 and 2016, the most widely distributed and common aquatic plant species in very shallow water (<1 m; shoreline) were *Persicaria maculosa* (lady's thumb) and *Callitriche palustris* (spring water-starwort). *Stuckenia pectinata* (fennel-leaved pondweed) was typically observed in the in the central area of the site at water depths of 1-2 m, as was *Potamogeton foliosus* (closed-leaved pondweed) and Callitriche palustris later in the monitoring program (i.e., Year 6 [2016]).

Ceratophyllum demersum (common hornwort) and *Potamogeton praelongus* (long-stalked pondweed) were typically recorded in deeper water (>2m depth), primarily on the west side of the lagoon. *Ceratophyllum demersum* and *Myriophyllum sibiricum* (verticillate watermilfoil) were also recorded in deeper water (>2 m depth) in the northwest arm of the lagoon. These species were less prevalent in 2014 and began to be recorded in 2015 and 2016.

Table 5. Per cent frequency and average volume:abundance metric of aquatic macrophyte species detected in random samples (rake grabs) at Airport Lagoon in 2019.

		2018		2019		2020	
Scientific Name	**Common Name**	**Frequency (%)**	**Average volume x Abundance**	**Frequency (%)**	**Average volume x Abundance**	**Frequency (%)**	**Average volume x Abundance**
Bidens cernua	nodding beggarticks	1.61	0.20				
Callitriche palustris	spring water-starwort	3.23	0.15				
Ceratophyllum demersum	common hornwort	45.16	4.52	28.3	2.01		
Chara sp.	stonewort	4.84	0.10	13.3	0.46	91.67	10.9
Drepanocladus aduncus	common hook moss	56.45	11.56	36.7	2.37		
Hippuris vulgaris	mare's tail	1.61	0.10	1.7	0.08		
Myriophyllum sibiricum	verticillate water-milfoil	64.52	6.13	80.0	6.58		
Persicaria maculosa	lady's thumb	3.23	0.20				
Potamogeton foliosus	closed-leaved pondweed	45.16	3.49	25.0	1.54		
Potamogeton praelongus	long-stalked pondweed	17.74	7.77	11.7	1.16	23.33	20.9
Ranunculus aquatilis	whitewater buttercup	1.61	0.10	10.0	0.21	53.33	5.7
Sparganium sp.	bur-reed	1.61	0.10				
Stuckenia pectinata	fennel pondweed	36.7	0.86	36.7	0.86		
Utricularia intermedia	flat-leaved bladderwort	3.23	3.05				
Utricularia macrorhiza	greater bladderwort	20.97	3.45				

2018 – 2020

Between 2018 and 2020 a total of 14 species and 2 taxa identified only to genus were recorded at Airport Lagoon and Beaver Pond combined. There was a sharp decline in species richness over time at Airport Lagoon, with species richness going from a total of 15 in 2018, to 9 in 2019, to only three in 2020. Species richness was more stable but much lower in Beaver Pond, varying between two species in 2018 and 2020 and four species in 2019. Only *Potamogeton natans* (floating pondweed) was recorded at Beaver Pond (and only once in 2019) but not in Airport Lagoon.

Table 6. Aquatic species sampled in Airport Lagoon and Beaver Pond from 2018 to 2020.

Species	2018	2019	2020
POTAFOL[1,2,3]	1	1	1
POTAPRA[2,3]	1	1	1
CHARA.SP	1	1	1
CERADEM	1	1	--
DREPADU	1	1	--
MYRISIB	1	1	--
RANUAQU[1,2]	1	1	--
STUCPEC	1	1	--
HIPPVUL	1	1	--
UTRIMAC	1	--	--
UTRIINT	1	--	--
CALLPAL	1	--	--
PERSMAC	1	--	--
BIDECER	1	--	--
SPARG.SP	1	--	--
POTANAT[2]	--	1	--
No. unique species	6	1	0

[1] Seen in Beaver Pond in 2018

[2] Seen in Beaver Pond in 2019

[3] Seen in Beaver Pond in 2020

Four species were sampled only once from all collection points over the three years (*Bidens cernua*, *Persicaria maculosa*, *Potamogeton natans*, and *Sparganium* sp.); however, *Persicaria maculosa* was recorded in 2014, 2015 and 2016. Three species were sampled only twice (*Callitriche palustris*, *Hippuris vulgaris*, and *Utricularia intermedia*) between 2018 and 2020, but again, *Callitriche palustris* was recorded earlier in the monitoring program. All other species were sampled from more than 12 collection points over time, with *Potamogeton foliosus* and *Myriophyllum sibiricum* being the two most frequent species (83 and 84 samples, respectively).

Total density (volume x abundance) of aquatic vegetation generally declined over time at Airport Lagoon but remained fairly constant at Beaver Pond (Figure 2).

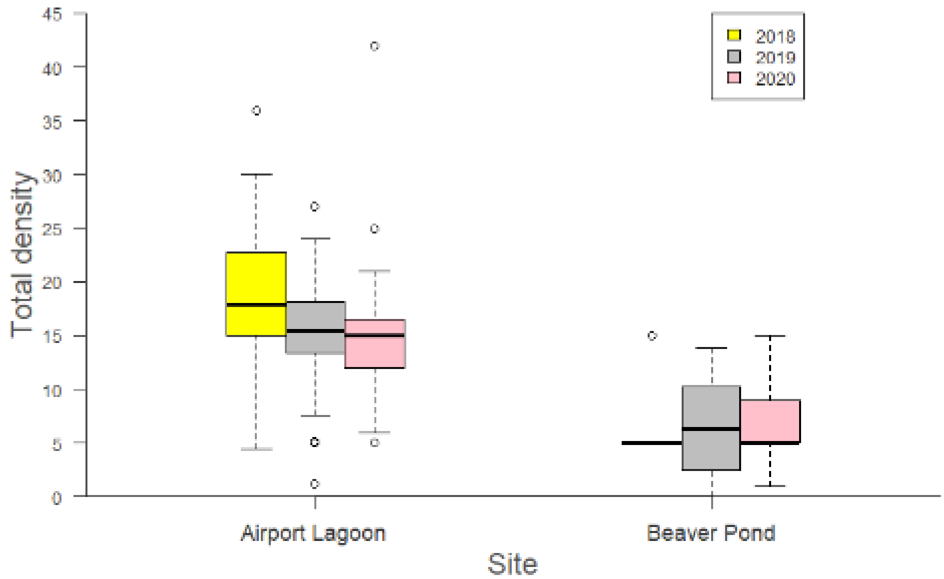

Figure 2. Variation in total density (volume x abundance) of aquatic vegetation in Airport Lagoon and Beaver Pond from 2018 to 2020.

Total density also clearly varied in relation to water depth and years, with density generally declining with increasing water depth at Airport Lagoon in 2018 and 2019 but increasing along with water depth in 2020 (Figure 3). No clear relationships between density and water depth are obvious for Beaver Pond.

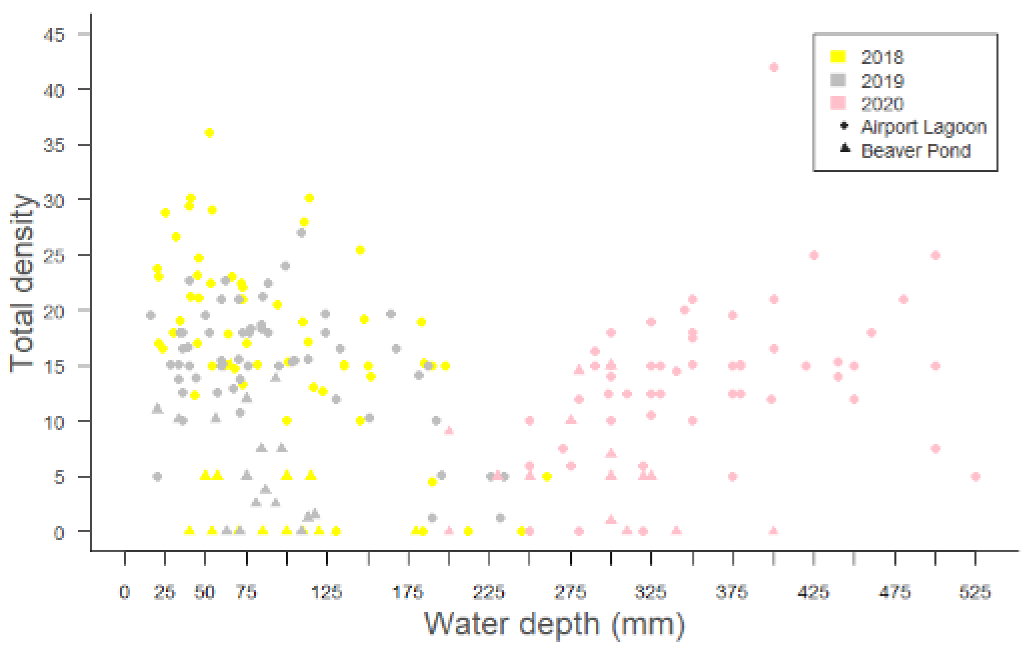

Figure 3.Variation in total density of aquatic vegetation in relation to water depth (mm) over time in Airport Lagoon and Beaver Pond.

The density of species varied over time both in Airport Lagoon and Beaver Pond, with years clearly segregating on the two PCA diagrams. In Airport Lagoon, the density of *Drepanocladus aduncus* (common hook moss) was highest in 2018 while the density of *Myriophyllum sibiricum* was highest in 2019 (Figure 4).

Water depth appeared to mostly influence density of aquatic species in 2020. High water depth was also correlated with 2020 in Beaver Pond, whereas *Potamogeton foliosus* (closed-leaved pondweed) was associated closely with 2018 and *Potamogeton praelongus* (long-stalked pondweed) was associated with 2019 (Figure 5).

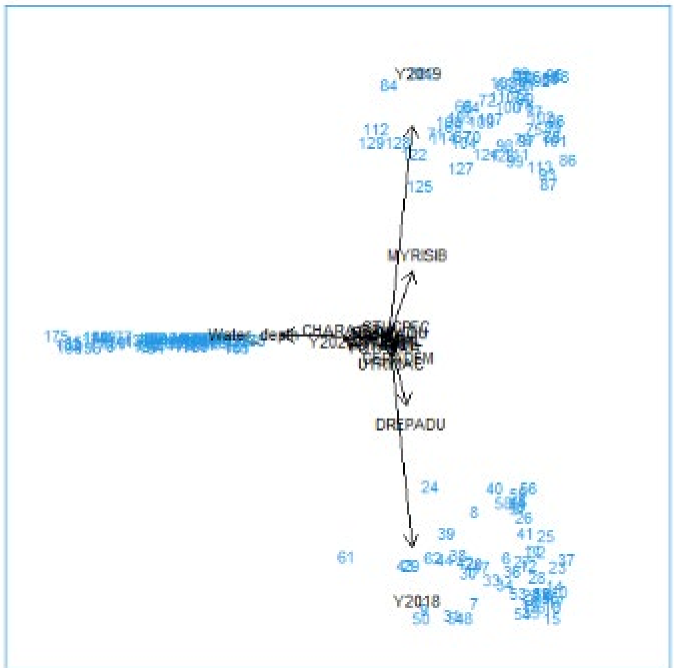

Figure 4. Principle component analysis (PCA) ordination showing the correlation among aquatic species, water depth, and years in Airport Lagoon. Species density, water depth and years are represented with black arrows and samples are in blue. Axis X explain 65% of variation, and axis Y, 14%.

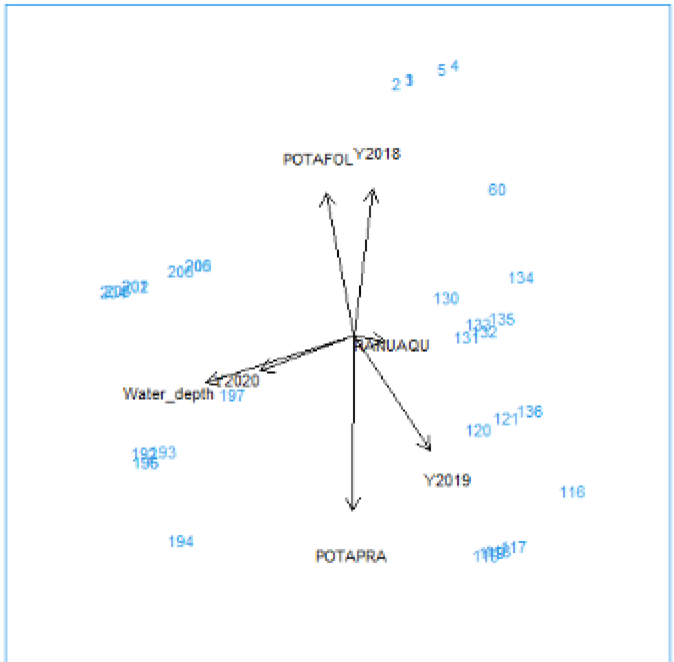

Figure 5. Principle component analysis (PCA) ordination showing the correlation among aquatic species, water depth, and years in Beaver Pond. Species density, water depth and years are represented with black arrows and samples are in blue. Axis X explain 60% of variation, and axis Y, 22%.

The trends over time observed at Airport Lagoon and association with water depth observed in Beaver Pond were reproduced in the multivariate regression trees (MRTs), with species density showing a relation to years before and after 2020 in Airport Lagoon (Figure 6), but to water depth in Beaver Pond (Figure 7). *Chara* sp. was the indicator species for samples from 2020 at Airport Lagoon, while *Myriophyllum sibiricum* (verticillate water-milfoil), *Ceratophyllum demersum* (common hornwort), *Drepanocladus aduncus* (common hook moss), *Stuckenia pectinate* (fennel-leaved pondweed) and *Utricularia macrorhiza* (common bladderwort) were indicators for samples taken in 2018 and 2019 (Table 2). At Beaver Pond, *Potamogeton foliosus* (closed-leaved pondweed) was indicator of depth equal or above 98.5 cm while *Ranunculus aquatilis* (white water-buttercup) was indicator of samples below 98.5 cm.

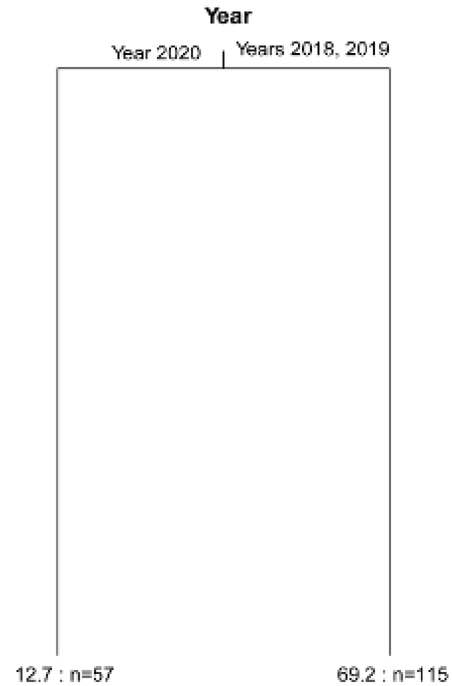

Figure 6. Multivariate regression tree (MRT) showing the partition of samples based on aquatic species density from 2018 to 2020 in Airport Lagoon. Numbers at each leaf are relative errors and number of samples per leaf. The tree explains 33% of the variance in species density.

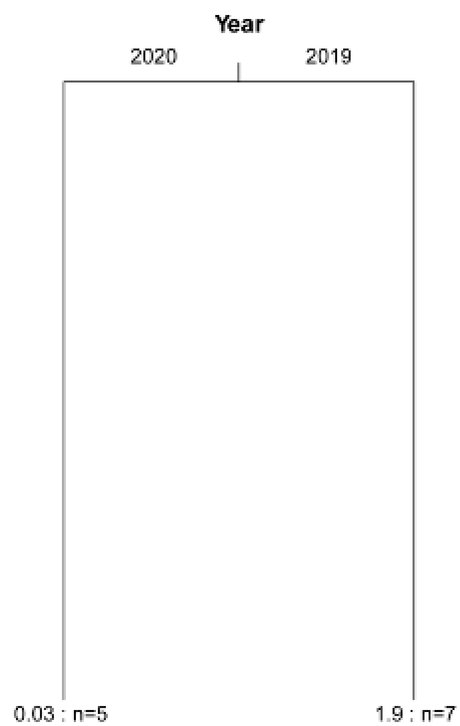

Figure 7. Multivariate regression tree (MRT) showing the partition of samples based on aquatic species density from 2018 to 2020 in Beaver Pond. Numbers at each leaf are relative errors and number of transects per leaf. The tree explains 43% of the variance in species density.

Discussion

Aquatic plant sampling was initiated in 2014 (Year 4) to monitor the development of aquatic plant communities at Airport Lagoon and Beaver Pond following completion of the wetland enhancement projects. The overall macrophyte community at Beaver Pond remains poorly developed. The analysis of aquatic vegetation data from Beaver Pond was limited to the final three years of the monitoring program (2018-2020). The density of species varied over this period and there were no clear trends. Water depth appeared to influence species densities in 2020; however, the water levels of the Williston Reservoir were highest in this year of GMSMON-15 and Beaver Pond was actually connected to the main reservoir into the summer.

Aquatic macrophytes were relatively well developed in the shallower sections of Airport Lagoon, including areas that are directly influenced by the enhancements. The frequency of species detections were quite variable over the years; however, there was a trending decrease in detections for *Drepanocladus aduncus* (common hook moss) and a trending increase for *Myriophyllum sibiricum* (verticillate water-milfoil), which is likely attributed to the more consistent water levels resulting from the enhancements. *Myriophyllum sibiricum* was typically recorded in deeper water and became more prevalent in the later years of the monitoring program. The density of aquatic vegetation typically declined with increasing water depth, but the inverse was noted in the final year of the program. As mentioned above, water levels were high this year, which likely affected the results of the analysis. Regardless, different aquatic vegetation communities are becoming established in shallower and in deeper section of the wetland. Overall, it is clear that the density, diversity, and spatial extent of aquatic vegetation has changed following the construction of the enhancements.

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