Impacts of roads and cranberry agriculture on bog wetland hydrology with restoration recommendations for Langley Bog

by

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Abstract

Bog wetlands store a disproportionate amount of carbon for their size, making their conservation an important part of climate change mitigation. The goal of this project is to investigate how roads and agriculture impact the hydrology and vegetation composition of Langley Bog and to provide restoration recommendations. Langley Bog, in Langley Township, BC, is a formerly mined peatland with a fill road running through the center and surrounded to the north and west by cranberry farms. From November 2020 to November 2021, depth to water table and pH were measured monthly at nine wells. Twelve vegetation transects were completed in July 2021. Sites adjacent to the road were correlated with a decrease in summer water level, while sites adjacent to the cranberry farms were correlated with an increase in spring pH levels. A positive relationship was found between an increase in water-table level and percent cover of wetland obligate species. Roads may be lowering the water table through subsidence and drainage. The cranberry farms may be increasing the pH through the deposition of fertilizer. These impacts may have been exacerbated by the unusually dry 2021 summer season.

To raise the water table, tree and road removal is recommended to restore lateral flow and decrease evapotranspiration. Culverts installed under the primary fill road will provide additional hydrologic connectivity. Building a berm at outlet points will also help prevent water loss, keeping a higher water table. To increase carbon sequestration, *Sphagnum* mosses are to be reintroduced to denuded areas in Langley Bog. Tree removal will help in moss establishment by maintaining open bog conditions free from shading. Existing rare ecosystems present in Langley Bog would benefit from the removal of point source pollutants and invasive species on the site. Given the urgency of climate change, restoring the functionality of Langley Bog and protecting the existing stored carbon is a practical and achievable way to move Metro Vancouver a step closer to carbon neutrality.

Keywords: peatlands; ecological restoration; water levels; pH; sphagnum

Dedication

To Dave, who carried me through. I could not have done this without your love and support.

Land Acknowledgement

I respectfully acknowledge that this work was completed on the traditional, ancestral, and unceded territory of the Sto:lo and Tsawwassen First Nations by a visitor and settler of these lands. I hope the results of this project can be useful in supporting indigenous land management.

Acknowledgments

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Thank you to Metro Vancouver Regional Parks East Area Office: Roy Teo for all your field help, Tyler Langeloo for guiding me through the restoration recommendations, and the indomitable Janice Jarvis - I am so grateful for earning your trust. Sarah Howie at the City of Delta, thank you for sharing your incredible knowledge about bog ecosystems – as well as your equipment - I have learned so much from you.

Thank you to my supervisor Doug Ransome, whose eagle eyes catch everything, and to everyone at BCIT including Forrest Bjornson: I will miss our monthly equipment check-ins. To Ruth Joy and Shawn Chartrand, thank you for your help very early on in helping me construct my experiment. Finally I want to thank all of my incredible volunteers: Dorothy Geen, Danae Shephard, Natalie Ross, Elyse Dyck, Will Dias, and of course my parents, for all those hours spent tramping in knee-deep water with me. You are very much appreciated.

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1.1. Introduction

Peatlands are rare ecosystems covering only 3% of the world's landmass (Harenda et al. 2018), yet they provide a disproportionate amount of ecosystem services for their size. Peatlands not only mitigate floods, prevent drought, and improve water quality, they also sequester up to 1,000 Gt of soil carbon (Hanson et al. 2020), more than all of the world's forests combined (Scharlemann et al. 2014). Peatlands store carbon through the gradual accumulation of *Sphagnum* mosses over millennia. Anoxic conditions created by poorly-drained soils, combined with low pH and limited nutrient availability slows the decomposition of organic matter, creating deep layers of carbon-storing peat (Moore et al. 2018). Conserving carbon sequestration function is considered one of the primary ways to mitigate impacts of climate change (Leifeld & Menichetti 2018).

Despite their importance as a global carbon sink, peatlands are exposed to a variety of anthropogenic disturbances. Warm temperatures and summer drought accelerate decomposition of *Sphagnum* mosses, trigger fire, and promote growth of non-peat-forming vascular species (Dise & Phoenix 2011). Roads and other linear disturbances influence both hydrological flows and vegetation changes (Chasmer et al. 2021). Peat extraction and conversion to agriculture reduce peatland carbon storage (Turestsky et al. 2002).

Little research has been done on the impacts of agriculture on adjacent peatlands. Agricultural land use is correlated with an increase in phosphorus and nitrogen in adjacent wetlands (Houlahan & Findlay 2004, Houlahan et al. 2006). However, effects on bog wetlands in the two studies was combined with swamps and marshes. Bogs differ from swamps in having non-vascular plants as their predominant vegetation type. Non-vascular *Sphagnum* mosses act as ecosystem engineers, creating low-nutrient environments that effectively limit competition with vascular species (van Breemen 1995). Cation exchange of *Sphagnum* species creates H^+ ions that are the primary driver of acidity in bog water (Bragazza & Gerdol 2002). This high acidity depresses growth of vascular species, limiting shade and evapotranspiration from trees, creating a positive feedback loop for more *Sphagnum* growth (van Breemen 1995).

Nutrient inputs disrupt this feedback loop by limiting *Sphagnum* mosses and fostering vascular plant growth (Gunnarsson & Rydin 2000). Trees and shrubs neutralize the soil by reducing loss of base cations, creating a positive feedback loop for woody vegetation (Hong et al. 2018). Declines in rare bog-specific species with increasing nutrient inputs is consistent with the theory of centrifugal organization of plant communities. This theory predicts that presence of rare plants will be highest in low biomass, infertile wetlands (Wisheu & Keddy 1992). It is expected that nutrient inputs from agricultural fertilizer will change bog wetlands from ecosystems predominated by bog-specific taxa such as *Rhododendron groenlandicum* (Labrador tea) to ones predominated by more common species such as *Gaultheria shallon* (salal).

This study aims to increase the understanding of how bog wetlands are impacted by agriculture by investigating fertilizer inputs from a cranberry farm adjacent to Langley Bog. Cultivated *Vaccinium macrocarpon* (cranberry) are fertilized with nitrogen and phosphorous in spring (DeMoranville & Ghantous 2018) and are harvested in fall by draining flooded fields through a series of ditches (Strik 2002). Direct application of nitrogen and phosphorous increases bog pH (Chapin et al 2004), however its impact from adjacent land use is not well studied. Two studies have investigated the impacts of cranberry agriculture on adjacent wetlands (Howes & Teal 1995; Garrison & Fitzgerald 2005), finding cranberry farms to be a source of both nitrogen and phosphate. No research has been done on the impacts of cranberry agriculture on adjacent peatlands.

Several studies have investigated the impacts of roads through peatlands (Miller et al. 2015; Bocking et al. 2017; Plach et al. 2017; Strack et al. 2017; Sarswati & Strack 2019; Saraswati et al. 2019; Saraswati et al. 2020; Elmes et al. 2021). However only one bog wetland was included in this research: the remainder investigated impacts of roads on fen wetlands. Bog wetlands differ from fens in their hydrology, chemistry, and vegetation. Where fens have groundwater and surface water inputs, bogs receive only rainwater (Rydin & Jeglum 2013). Bogs are also highly acidic, with a pH usually below 4.2, while fens can range anywhere from 3.8 to 8.5 (Rydin & Jeglum 2013).

In fens, roads placed perpendicular to water flow act as a dam, lowering water levels downstream (Plach et al. 2017). This effect was also seen in a bog wetland since the road cut across a slope (Sarswati et al. 2019; 2020). Where roads run parallel to water flow, fens do not exhibit significant changes in hydrology (Sarswati & Strack 2019). It is unclear whether bog wetlands will respond similarly to road orientation as fens since bogs have both lateral and vertical water movement. In bogs with low-permeability mineral soil, water movement is primarily lateral, focused in the acrotelm, the top 50 cm of peat (Reeve et al. 2000). In bogs with permeable mineral soil, water movement is primarily vertical, moving up and down through both the acrotelm and the deeper catotelm, which has lower hydraulic connectivity (Reeve et al. 2000). This study aims to increase the body of knowledge of road impacts on bog wetlands given the limited research done on these unique ecosystems.

The goals of this study were to investigate the impacts of cranberry agriculture and roads on water levels, water chemistry, and vegetative communities in Langley Bog. I hypothesized that:

1) Since cranberry farmers fertilize their fields, pH levels in Langley Bog would increase with proximity to agricultural fields.

2) There would be lower water levels at sites closer to the road where lateral water flow is restricted, and higher water levels at control sites where water is able to move freely.

3) Presence of bog-specific plants that have adapted to acidic, high-water-table conditions would be positively correlated with wet, low-pH sites.

1.2. Methods

1.2.1. Study Site

The study area is an 80-ha ombrotrophic bog located approximately 50 km east of Vancouver, British Columbia, Canada (49°19’93”N, 122°61’12”W) (Figure 1-1). Thirty-year climate data gathered from the nearest station at Haney East, Maple Ridge, BC (1981-2010) showed an average annual temperature of 10°C, with rainfall highest in November (275.5 mm) and lowest in August (60 mm) (Environment Canada 2021). The bog is predominated by *Pinus contorta* (lodgepole pine) and *Tsuga heterophylla* (western hemlock) trees, *Rhododendron groenlandicum* (Labrador tea) and *Vaccinium corymbosum* (high bush blueberry) shrubs, and graminoid species consisting of *Rhynchospora alba* (white beak sedge) and *Carex utriculata* (beaked sedge). A variety of mosses such as *Sphagnum capillifolium* (red bog moss) and *Sphagnum fuscum* (rusty bog moss) act as the predominant ground cover.

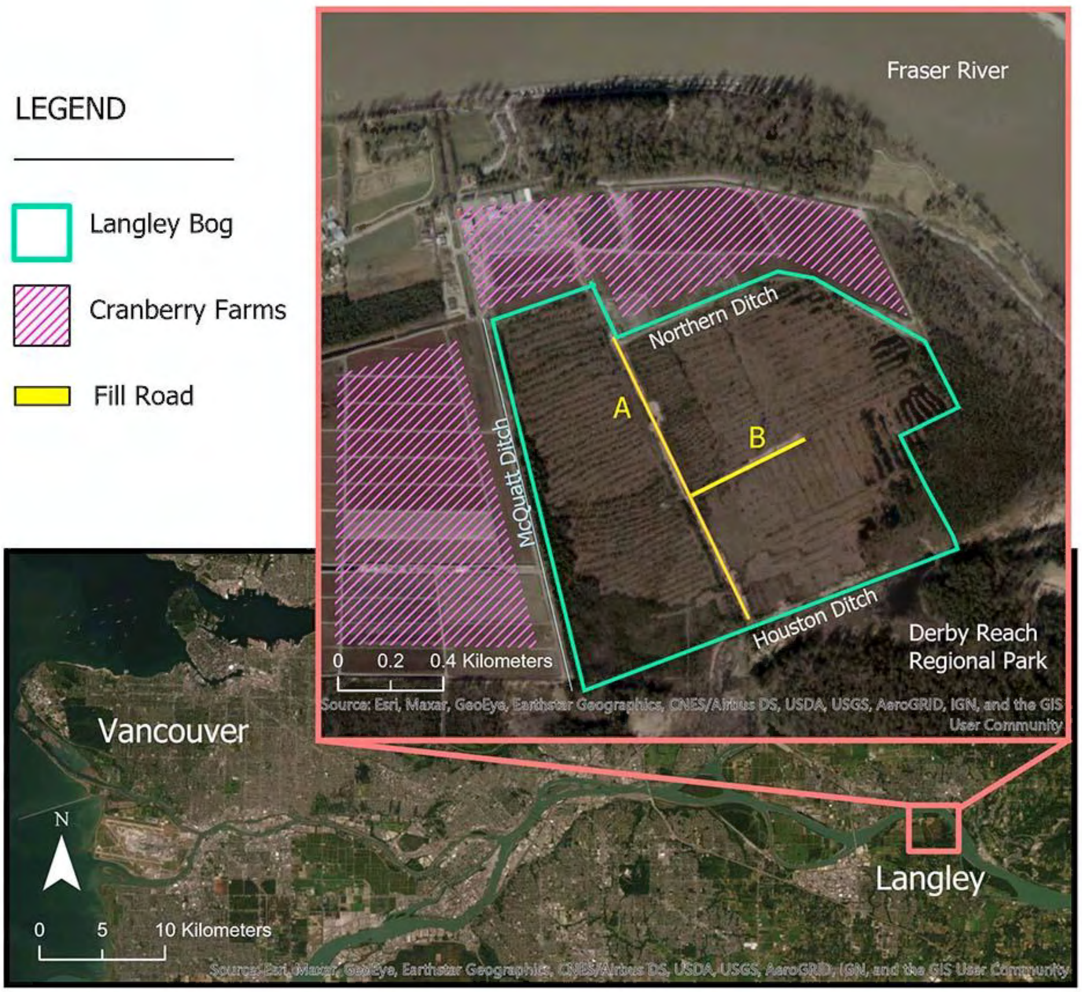

Figure 1-1. Langley Bog (Langley Township, BC, Canada) is outlined in green with adjacent cranberry farms hashed in pink and the central fill road in yellow.

Cranberry farms owned and operated by Coast Cranberries Ltd. are located to the north and west of the site, on land that was historically bog (Douglas & Chapman 1995) (Figure 1-1). The cranberry farms are separated from Langley Bog by two ditches. These ditches are used by Coast Cranberries Ltd to drain their cranberry fields for harvesting in late fall (J. Jarvis, 2021, Metro Vancouver, Langley BC, personal communication). The northern ditch measures approximately 3 m wide and 600 m long and is separated from the bog by an elevated access road. The western ditch, McQuatt ditch, measures approximately 3 m wide and 900 m long, and is directly adjacent to the bog. A third ditch, Houston ditch, is south of the bog and measures approximately 3 m wide and 500 m long. This ditch drains into McQuatt ditch from an inflow located in the south-westernmost corner of the bog.

Between 1958 - 1980, the Langley Peat Limited Company built two primary roads to access the bog for peat removal (Douglas & Chapman 1995). Fill road A is approximately 15 m wide and 800 m long, running NW through the center of the bog (Figure 1-1). Fill road B runs northeast and is approximately 15 m wide and 300 m long (Figure 1-1). The roads were constructed by laying cedar wood-chip hog fuel over the peat column. There is a gradual decrease in slope from the road (average elevation 5 m) to the bog (average elevation 4.3 m) in both directions.

1.2.2. Experimental Design

The bog was divided into three blocks, with three treatments each (Randomized Complete Block Design; Figure 1-2).

Figure 1-2. Water monitoring locations in Langley Bog, Langley Township, BC. The three treatment blocks are delineated with background shading. Each point represents a collection point with a well.

The southwestern region of the bog was excluded due to the existence of a bog forest that remains unmined, leading to differing soil conditions. One treatment unit was adjacent to the road, one to the cranberry field, and a third acted as a control without influence of either. Each treatment unit centered around a pre-existing well made of 3.2 cm diameter PVC piping installed in 2008 (Brown et al. 2010). Starting 30 cm from top of the well, Brown et al. (2010) drilled holes quad-directionally every 15 cm to allow water to flow in. Wells were capped to prevent rainwater input.

1.2.3. Cranberry Agriculture Impacts

To test the hypothesis that proximity to cranberry agriculture is correlated with a rise in pH and a decline in bog-specific plant communities, data were collected from the three wells closest to the cranberry farms and compared to three controls. Well P02 was east of McQuatt ditch, and well P38 was adjacent to the fields on the northern part of the site. I also monitored well P25 in the southern part of the bog, 7 m from Houston ditch. Although cranberry farms do not abut the bog on the southern side, Houston ditch drains into McQuatt ditch. A water level drop in McQuatt ditch, possibly from draining of cranberry fields for harvesting, was assumed to lead to a correlated drop in water level in Houston ditch.

I collected pH levels from eight wells every month from November 2020 to November 2021. First the initial water level of the well was measured by blowing into a 1 cm diameter tube 6 m long and recording the depth at which bubbles were heard. This measurement was subtracted from the height of the well above ground to calculate the depth to water table. I then purged 250 ml of water from the well using a hand-held manual pump to remove any stagnant water and waited until the well refilled to the initial measured depth. Finally another 250 ml of water were pumped from the well and a YSI Pro Plus Multiparameter was used to measure the pH levels. A two-point calibration was completed each morning before going into the field to ensure consistent results.

Percent cover of vegetation was calculated using a set of nested circular plots in July 2021. Starting at a well, a randomly selected heading was followed, then a plot was placed 9.5 m away to avoid impacts of the well. The first plot had a radius of 0.5 m, and percent cover of all herbaceous vegetation was measured. The second plot had a radius of 1 m and included percent cover of all shrubs. The third plot had a radius of 4.5 m and included percent cover of all trees. Six cover categories with midpoints at 2.5%, 10.5%, 20.5%, 38%, 63%, and 87.5% were used. Vegetation was identified to species using dichotomous keys and a hand lens.

Statistical analyses of the randomized complete block design were completed using R Studio (R Core Team 2020). Analysis of variance (ANOVA) with Tukey's post-hoc analysis was used to test for differences in mean pH and water levels between road and control sites. All data were log-transformed and tested for normality using the Shapiro-Wilk test. Bartlett's and Levene's tests from the "rstatix" package (Kassambara 2021) were used to test homoscedasticity. Non-normal and non-homoscedastic data was analyzed with a Kruskal-Wallis test. A beta regression from the betareg package (V3.1-4; Cribari-Neto & Zeileis 2010) was used to investigate relationships of water depth and pH levels to percent cover of obligate wetland (OBL) species. The species were grouped according to their wetland status listed on the USDA National Wetland Plant List (Lichvar et al. 2016). Differences were considered significant if $P \leq 0.05$ for all comparisons.

1.2.4. Road Impacts

To test the hypothesis that proximity to roads is correlated with a decline in water table and bog-specific plant communities, data were collected from the three wells closest to the road and was compared to three controls. Water level, pH, and percent cover of vegetation were calculated using methods outlined in Experiment 1.

Statistical analyses were completed using R Studio (R Core Team 2020). Analysis of variance (ANOVA) with Tukey's post-hoc analysis was used to test for differences in pH and water levels between road and control sites. All data were log-transformed and tested for normality using the Shapiro-Wilk test. Bartlett's and Levene's tests from the "rstatix" package (Kassambara 2021) were used to test homoscedasticity. Non-normal and non-homoscedastic data was analyzed with a Kruskal-Wallis test. A beta regression from the betareg package (V3.1-4; Cribari-Neto & Zeileis 2010) was used to investigate the relationship of water depth and pH levels to percent cover of obligate wetland (OBL) species. The species were grouped according to their wetland status listed on the USDA National Wetland Plant List (Lichvar et al. 2016). Differences were considered significant if $P \leq 0.05$ for all comparisons.

1.3. Results

Depth to Water Table

Mean water levels varied throughout the year, coinciding with total precipitation (Figure 1-3). From December to February, water depth was lowest at road sites, and approximately 10 cm lower than control and farm sites (Figure 1-4). Although a difference was detected, it was not statistically significant ($F_{2,4}$ = 2.991, p = 0.13). Differences in mean water depth widened in spring and summer (Figures 1-5, 1-6). There was a statistically significant difference in mean water depth between March and May ($F_{2,4}$ = 5.009, p = 0.05). Water depth at road sites was approximately 20 cm lower than control sites (Figure 1-5). By summer, the difference between road and control sites increased to 30 cm (Figure 1-6). Mean water depth varied significantly between June and August ($F_{2,4}$ = 5.399, p = 0.045). Water levels rose in the fall, with differences between road and control sites decreasing to approximately 15 cm (Figure 1-7). No statistically significant differences were detected between September and November ($F_{2,4}$ = 1.557, p = 0.29).

Figure 1-3. Pink line represents monthly mean water depth of nine wells in Langley Bog, Langley Township, BC. Blue bars represent mean monthly precipitation.

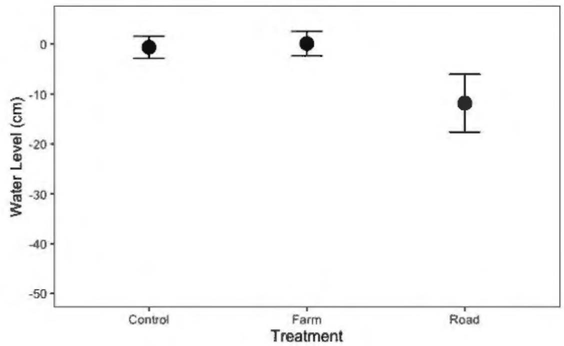

Figure 1-4. Mean (± SE) water depth by treatment at Langley Bog, Langley Township, BC. Data were collected from December 2020 to February 2021.

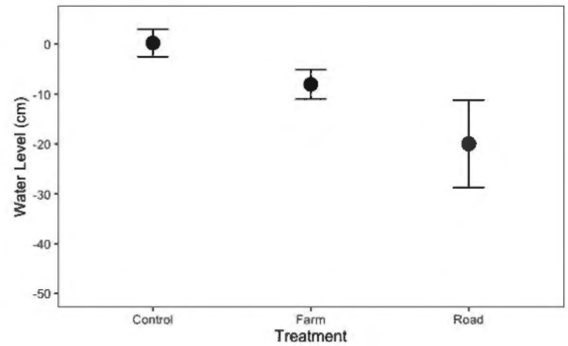

Figure 1-5. Mean (± SE) water depth by treatment at Langley Bog, Langley Township, BC. Data were collected from March to May 2021.

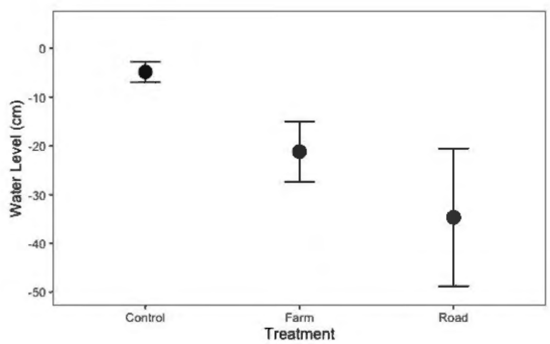

Figure 1-6. Mean (± SE) water depth by treatment at Langley Bog, Langley Township BC. Data were collected from June to August 2021.

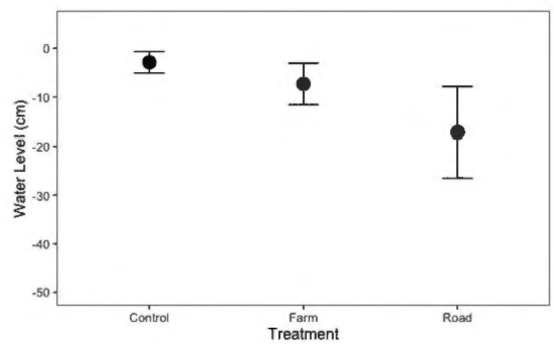

Figure 1-7. Mean (± SE) water depth by treatment in Langley Bog, Langley Township, BC. Data were collected from September to November 2021.

Water pH Levels

For most of the year, pH levels in Langley Bog remained below 4.5 (Figure 1-8). From December to February, mean pH of farm sites was 16% higher than controls (Figure 1-9). Although the difference in pH was not statistically significant, the pH varied strongly and a biological difference was detected ($F_{2,4}$ = 5.42, p = 0.06). By spring, there was a significant difference between sites ($F_{2,4}$ = 4.98, p = 0.05). Mean pH of farm sites was 24% higher than control sites (Figure 1-10). Between June and August, I did not detect a significant difference in mean pH ($F_{2,4}$ = 3.2, p = 0.20). Farm treatment were 17% higher than controls (Figure 1-11). This variance decreased in the fall, with farm sites having 12% higher pH levels than controls (Figure 1-12). I did not detect a significant difference in mean pH between September and November ($F_{2,4}$ = 2.8, p = 0.13).

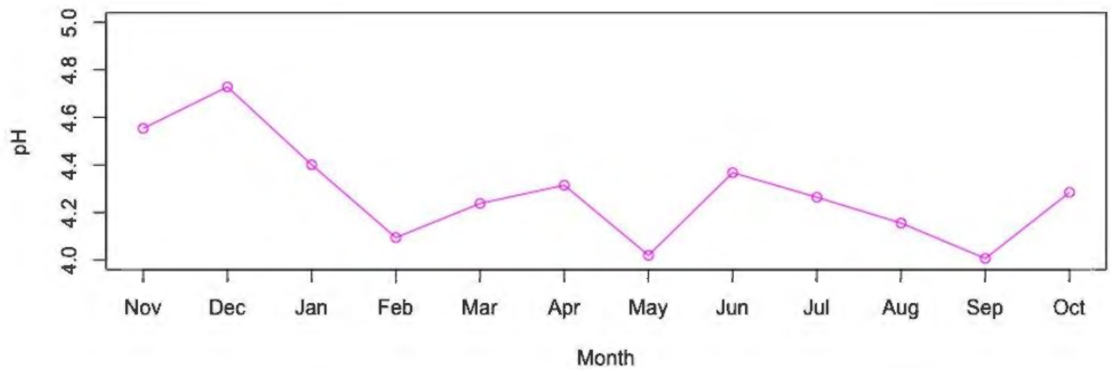

Figure 1-8. Monthly mean pH at Langley Bog, Langley Township, BC, from November 2020 to October 2021.

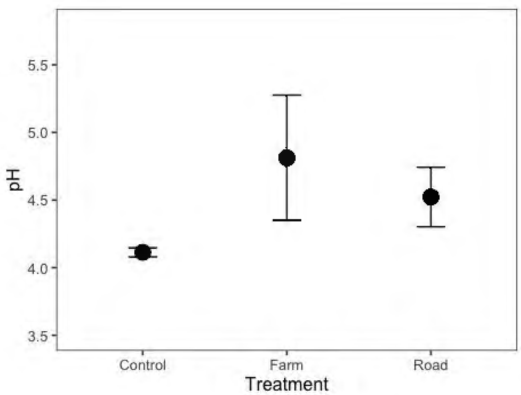

Figure 1-9. Mean (± SE) pH at Langley Bog, Langley Township, BC. Data were collected from December to February 2021.

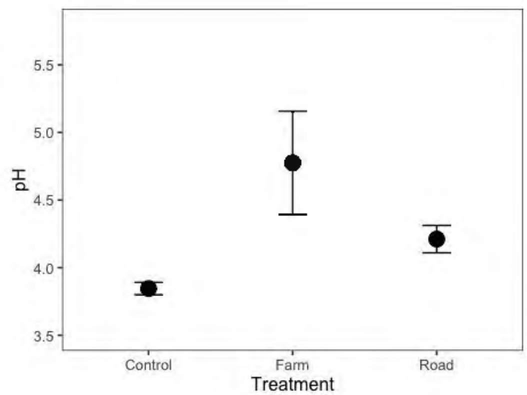

Figure 1-10. Mean (± SE) pH at Langley Bog, Langley Township, BC. Data were collected from March to May 2021.

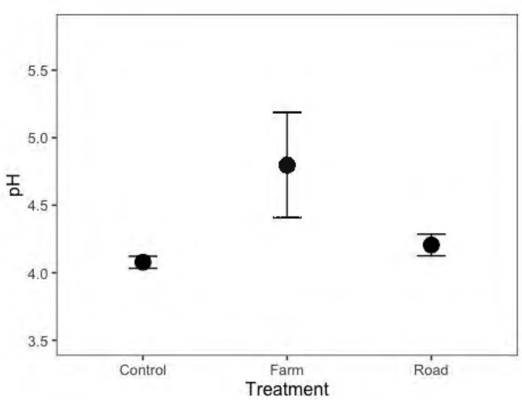

Figure 1-11. Mean (± SE) pH at Langley Bog, Langley Township, BC. Data were collected from June to August 2021.

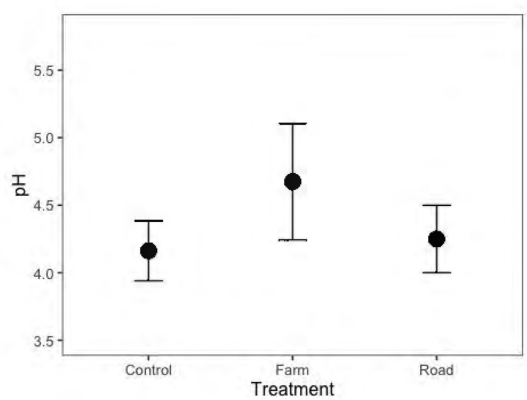

Figure 1-12. Mean (± SE) pH at Langley Bog, Langley Township, BC. Data from September to November 2021.

Vegetation

There are 33 unique species of plants found across 12 sites in Langley Bog: 61% were obligate wetland species (Table 1-1), 31% were upland species, and the remainder were facultative species found in both wetland and upland ecosystems. Presence of obligate wetland species was positively correlated with the mean yearly water depth (Figure 1-13). In beta regression models, the mean yearly water depth explained 52% of the variation in obligate species. The overall regression was statistically significant ($Pseudo\text{-}R^2 = 0.52$, X^2 $(1, N = 7) = 10.80$, $p < 0.01$). I failed to detect a relationship between the presence of obligate wetland species and mean pH ($Pseudo\text{-}R^2 = 0.09$, X^2 $(1, N = 6) = 0.87$, $p = 0.35$; Figure 1-14).

Table 1-1. List of obligate wetland species found in Langley Bog, Langley Township, BC during the summer of 2021. Starred species are non-native.

Scientific name	Common name
Andromeda polifolia	Bog rosemary
Drosera rotundifolia	Round leafed sundew
*Eriophorum virginicum**	Cotton grass
Kalmia microphylla	Bog laurel
Rhododendron groenlandicum	Labrador tea
Rhynchospora alba	White beak sedge
Sphagnum angustifolium	Yellow-green peat moss
Sphagnum capillifolium	Small red peat moss
Sphagnum fimbriatum	Fringed bog moss
Sphagnum fuscum	Rusty bog moss
Sphagnum magellanicum	Magellan’s peat moss
Sphagnum palustre	Blunt-leaf bog moss
Sphagnum papillosum	Fat bog moss
Sphagnum subnitens	Lustrous peat moss
*Vaccinium macrocarpon**	American cranberry

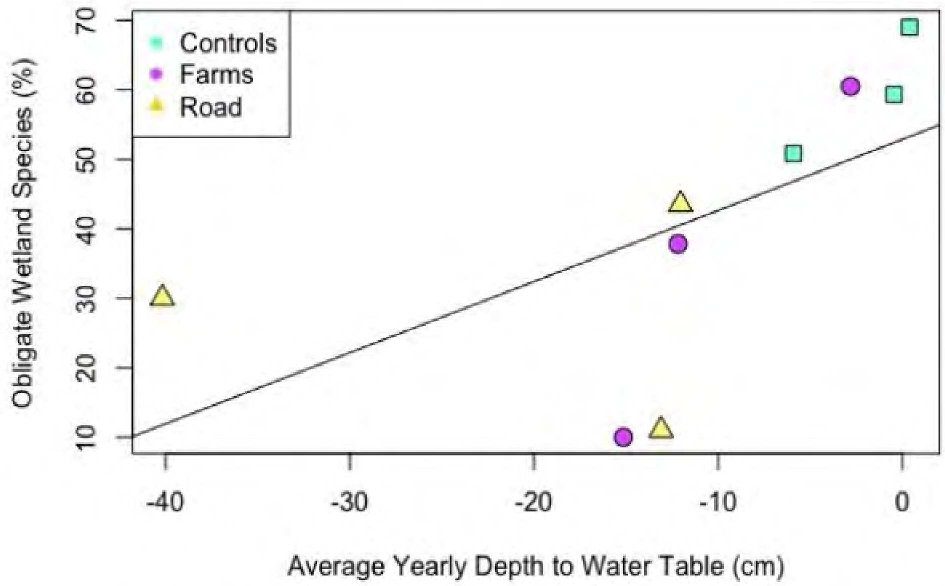

Figure 1-13. Comparing percent cover of wetland obligate plants to yearly water table depth at Langley Bog, Langley Township, BC. Data collected during the summer of 2021.

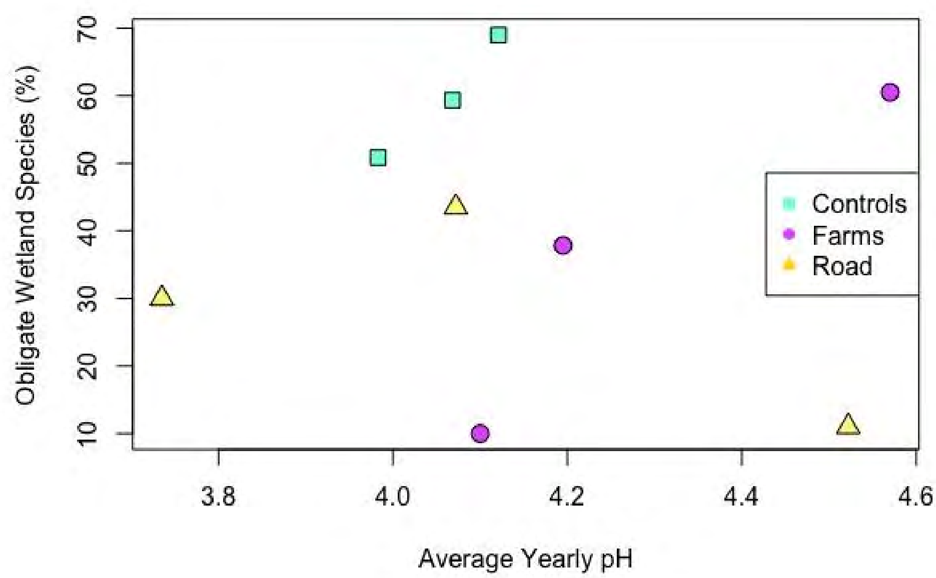

Figure 1-14. Comparing percent cover of wetland obligate species and pH levels in Langley Bog, Langley Township, BC. Data collected during the summer of 2021.

1.4. Discussion

Cranberry Agriculture Impacts

Spring pH levels were significantly higher at sites adjacent to the cranberry farms than at control sites. These results are consistent with earlier findings correlating agriculture with nutrient increases in wetlands (Houlahan & Findlay 2004, Houlahan et al. 2006). The seasonality of the effect also supports the hypothesis by Howes & Teal (1995) that cranberry farms become a net exporter of nutrients shortly after farm fields are fertilized.

It is difficult to separate the effects of adjacent land use from other mechanisms due to the necessity of collecting data in edge habitat. In bogs, edge habitat is called a lagg: a unique ecotone with high soil concentrations of total nitrogen and phosphorous (Paradis et al. 2015). Paradis et al. (2015) found the lagg zone had significantly higher pH levels than the open bog, which they attribute to mineral soils. It is unlikely that this is factor at Langley Bog however, since the lagg was historically bog habitat and has similar soils. Given that we see significant differences between open bog and farm-adjacent sites, additional inputs from agriculture may be altering the pH balance. Additional research on bog hydrology as it relates to agricultural land use can help separate these effects.

Road Impacts

Summer water depth was significantly lower at sites adjacent to the road than at the control sites. These results support previous research suggesting roads interrupt water flow in bog wetlands (Saraswati et al. 2020). This impact was measured up to 18 m away from the road, where the furthest monitoring site was located. This supports Saraswati et al. (2020) who found that summer water depth was impacted up to 20 m from the road in both directions.

Saraswati et al. (2020) hypothesized that roads in bogs act as a dam, preventing upstream flow from moving downstream. However Langley Bog does not have a marked elevation gradient from one side of the road to the other, implying that other processes can lower the water table. In contrast to previous studies where the road was built from mineral fill, the road in Langley Bog is constructed of cedar wood chip. Unlike mineral fill, wood chips absorb water reaching moisture levels over 60% (Kumar & Flynn 2006). The wood chip may be lowering the water table directly, or through subsidence.

In undisturbed bogs, capillary action allows for water to move vertically through the peat column, bringing water upward to the surface. If drainage occurs, the peat soil subsides, creating compacted layers with weaker hydraulic conductivity (van der Schaaf 2012). Subsidence can occur immediately after a disturbance, such as the installation of a road, but can also be gradual, slowly compacting a few millimeters over 20 years (Regan et al. 2019). By restricting water movement to the surface, subsidence leads to an eventual lowering of the water table and the drying out of the bog surface (van der Schaaf 2012).

In this study, hydraulic conductivity may have been further impaired by the history of peat mining on the site. Mining removes the porous acrotelm, the top layer of peat in a bog wetland, exposing the denser catotelm below (Price et al. 2003). The decline in pore space limits water exchange, which when paired with the impacts of subsidence and wood chip sorption could exacerbate water loss in bogs. Further study of roads in bog wetlands is needed to differentiate the impacts of these various stressors.

Precipitation and Temperature Impacts

As an ombrotrophic bog that receives water inputs only from rainfall, the water table depth in Langley Bog is directly related to precipitation. While 30-year climate data for the area show July averaging 61 mm of precipitation (Environment Canada 2021a), the last 15 years has seen this average decline by more than half to 30 mm (Environment Canada 2021b). In 2021, the year this study was conducted, no precipitation was recorded in July.

Low summer precipitation was paired with high temperatures: July and August averaged monthly temperatures over 19 °C, two degrees warmer than 30-year averages (Environment Canada 2021a, 2021b). A heat wave in June also brought a maximum temperature of 41.5 °C, the second-hottest temperature ever recorded at the site (Environment Canada 2021b). As temperature rises, evaporation on the bog surface increases (Nichols 1980). Declines in water table depth seen in this study may have been exacerbated by these drought conditions.

Projections for the greater Vancouver area where this study was conducted predict these trends to continue, with increasing average summer temperatures and increasing periods without precipitation (Metro Vancouver 2016). Since this study was completed in a year with lower-than-average summer rainfall and higher summer temperatures, future researchers may find these results useful in investigating how bogs might respond to climate warming.

Differences in Bog Vegetation

An increase in the average yearly water depth was correlated with a higher percent of obligate wetland species found at a site. These results were expected since obligate wetland species are often found in saturated soil conditions with greater than average water depth (Magee & Kentula 2005). The obligate species found in bog wetlands have specific adaptations to help survive flooded conditions and outcompete other species. Sedges such as *R. alba,* and *E. virginicum* have aerenchyma: air-conducting tissues that allow oxygen captured by leaves to be transported into the anoxic root zone (Rydin & Jeglum 2013).

Obligate bog wetland species also have adaptions for low-nutrient environments. Almost all bog species are perennial, using growth over several years to develop a large root mass for higher nutrient uptake (Rydin & Jeglum 2013). Bog sedges tend to reproduce clonally, using energy reserves stored in rhizomes for faster regrowth (Rydin & Jeglum 2013). Other species have developed carnivory to increase their nutrient input: *D. rotundifolia* obtains over 50% of its nitrogen from trapping prey (Rydin & Jeglum 2013).

Because of these adaptations, it was surprising not to find a correlation between pH and percent of obligate wetland species. Acidic sites tend to be nutrient-poor because nitrogen mineralization, the process of making inorganic nitrogen available to plants, is pH-dependent: as pH rises, significantly more nitrogen becomes available (Curtin et al. 1998). The concept of centrifigual organization of plant communities predicts that sites with low fertility will be home to habitat specialists (Wisheu & Keddy 1992). It is hypothesized that as pH rises, sites become habitable for generalists, who can outcompete bog-specific species (Wisheu & Keddy 1992). A lower pH is thus expected to correlate with specialists that have adapted to low-nutrient environments.

It is possible that the impacts of the fill road confounded the results of water pH levels. Cedar wood chip has a low pH of 2.9 (Venner et al. 2009), which may be artificially decreasing the pH in areas adjacent to the road. Since sites near the road are correlated with a decrease in water level, perhaps the hydrological gradient is the limiting factor at these sites, not pH. Experimental research on the impacts of wood chip on soil pH levels are needed to test this hypothesis.

Conclusion

There was a significant decrease in water level at sites adjacent to the fill road in both spring and summer. Given the industrial history of the site, it is hypothesized that the combination of acrotelm removal, peat compression, and presence of absorbent wood chip continue to lower the water table in these areas. The absence of rainfall in July may have also exacerbated the decline in water table seen in summer months. This information may be valuable for future research since this study was completed in a year with lower-than-average summer precipitation, which may help explain how bog wetlands might respond to drier conditions in the future.

Sites adjacent to the cranberry farms were correlated with a significantly increased pH in the spring, supporting the hypothesis that seasonal fertilization of the fields impacts pH in the adjacent bog. Surprisingly, a change in pH was not correlated with a change in vegetation, which was unexpected given the site-specific adaptions of bog species. It is hypothesized that these results were confounded by the presence of the low-pH fill road present on the site, which may be artificially decreasing the pH.

As expected, obligate wetland species were positively correlated with an increase in average yearly water level. Wetland obligates are adapted to flooding and use these mechanisms to outcompete other species. This correlation can help in site management, as vegetation can act as a proxy for water table levels, highlighting areas that require remediation.

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Chapter 2. The Restoration Plan

2.1. Site Assessment

Langley Bog is in Langley Township, British Columbia, approximately 50 km east of Vancouver, Canada (Figure 1-1). While Langley Township is in the densely populated Lower Fraser mainland, the township is primarily suburban, bordered by agricultural land. Langley Bog is 0.8 km^2 and is part of Derby Reach Regional Park, a rural park surrounded to the north and west by cranberry farms. Maple Ridge is located 3 km to the north and is separated from Langley Bog by the Fraser River. Due to the sensitivity of its habitat, Langley Bog is off-limits to the public.

2.1.1. Historical Conditions

Langley Bog is part of the ancestral land of the Sto':lo First Nations (Greater Vancouver Regional Parks Department 1996). It was primarily used for harvesting wild berries and no settlements were constructed in the bog either by the First Nations or later Europeans (GVRD 1996). In 1827, Fort Langley was built approximately 500 m south of the bog. Since it was one of the primary contact points between Europeans and the Sto':lo, the area was designated a heritage site by the province of British Columbia (GVRD 1996). When Langley Bog was acquired by Metro Vancouver in 1995, it was folded into the existing heritage designation, heavily restricting alterations to the site (Government of British Columbia 2021a).

Historical aerial photographs from 1938 to 1949 show that Langley Bog was largely undisturbed until the twentieth century. The photographs show Langley Bog extending continuously from the banks of the Fraser River westward for 3 km^2 (Figure 2-1). The photographs reveal that Langley Bog was predominately low-growing herbaceous vegetation, absent of large trees. Dendrochronological studies done of over 300 trees in Langley Bog showed that the median age of tree establishment was 1965, and that prior to this the bog was an open environment devoid of large trees (Brown et al. 2010). Sub-fossil wood samples reveal that *Pinus contorta* (lodgepole pine) were present in the bog; however they were quite small, some having over 200 growth rings in a 6 cm diameter trunk (Brown et al 2010). Farmers who lived near Langley Bog between 1912 and 1970 recount finding native *Oxycoccus oxycoccos* (cranberry), *Vaccinium uliginosum* (bog blueberry), *Rubus ursinus* (blackberry), and *Vaccinium* spp. (huckleberry) growing in the bog (GVRD 1996). In the remaining 5 hectares of unmined bog, I also confirmed the presence of *Sphagnum* mosses, species we expect to find in an undisturbed bog ecosystem (Antonella et al. 1999).

Langley Bog was a raised or domed bog, where the ecosystem becomes elevated over the surrounding landscape through the gradual accumulation of peat made from decomposing *Sphagnum* moss (Clague et al. 1991). From peat cores taken at the site, Brown et al (2010) estimated the peat in the center of the dome was approximately 8 to 10 m in depth. Bogs have low hydraulic conductivity: they drain slowly, allowing incoming precipitation to remain in the system, keeping the soils moist (Howie & Tromp-van Meerveld 2011). Rainfall in Langley Bog is seasonal, with highs averaging 300 mm in November and lows of 60 mm in July (Environment Canada 2021).

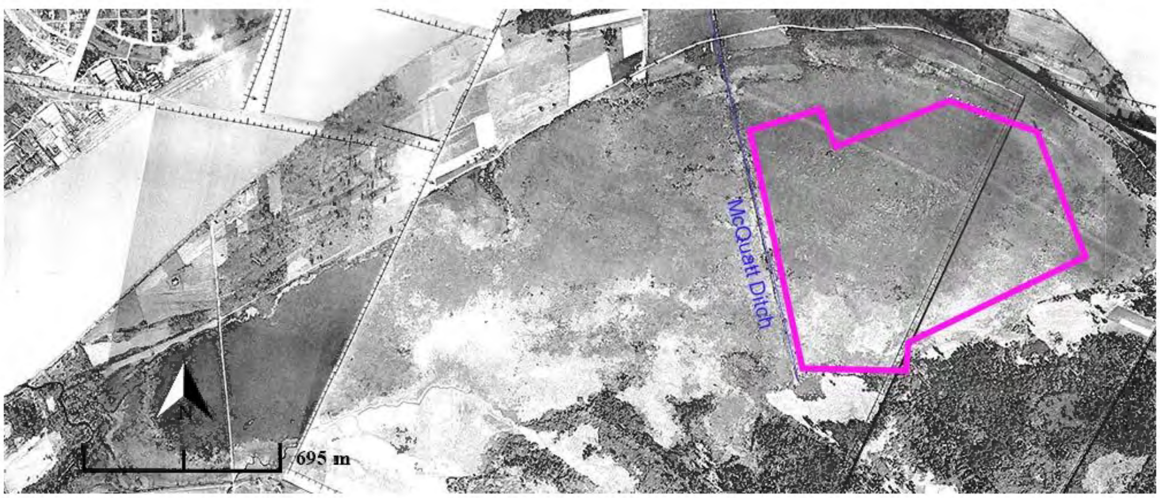

Figure 2-1. The earliest aerial photograph of Langley Bog, Langley Township, B.C., Canada, in 1938. The pink outlines the current extent of Langley Bog.

2.1.2. Impacts and Stressors

Drainage

The first known disturbance to Langley Bog was the creation of McQuatt ditch, which is seen running north south parallel to the western edge of the current bog in the earliest aerial photograph available (Figure 2-1). McQuatt ditch was therefore installed prior to 1936 and continues to drain the Langley Bog watershed into the Fraser River.

In the southwestern corner of the bog, surface water flows directly into McQuatt ditch (Figure 2-2). Depending on depth, ditches can drain 40 m of soil in either direction (Phillips et al. 2009). In the case of Langley Bog, McQuatt ditch is bordered by an upland forest ecosystem, suggesting a long history of drainage.

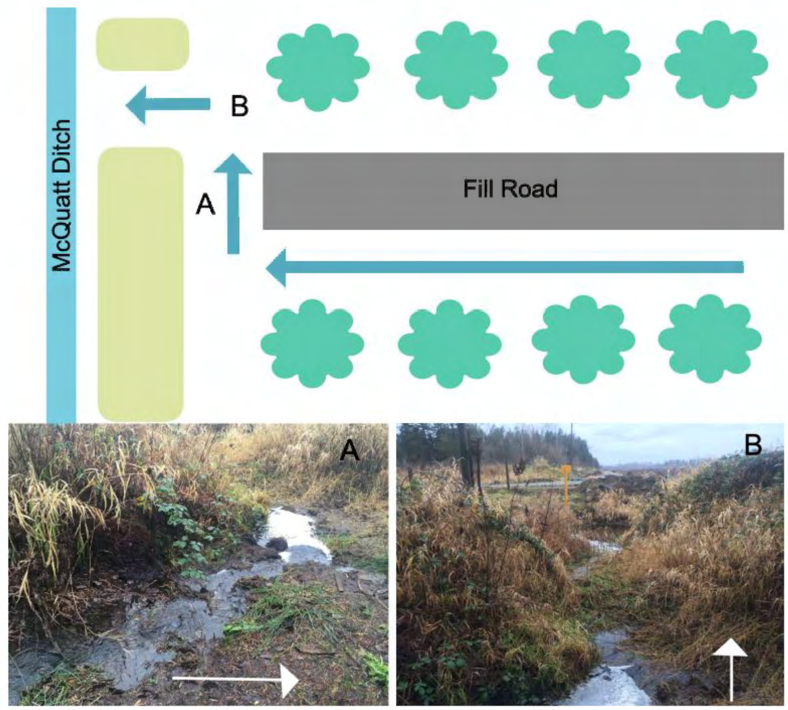

Figure 2-2. Surface water flowing into McQuatt ditch, in the southwestern corner of Langley Bog, Langley Township, BC. Arrows represent direction of water flow. A: Water running northward along edge of berm. B: Water running west through break in berm.

Peat Mining

From 1958 to 1980, the Langley Peat Limited Company harvested peat from the bog to sell as a fuel source (Douglas & Chapman 1995). The wet peat was dug out in channels and dried out in a processing plant built on site (Chartbrand 1995). This process altered the vegetation, topography, and hydrology of the site.

To access the peat, the Langley Peat Limited Company removed the top layer of vegetation from the bog surface. Peat is formed through the gradual accumulation of slowly-decomposing organic matter (Moore et al. 2018). Without the presence of *Sphagnum* mosses, the creation of new peat stopped. The Langley Peat Limited Company removed the peat in linear channels that left behind higher-elevation ridges on either side (Figure 2-3). Having a pattern of low channels and high ridges altered the hydrology of the site, creating an elevation gradient where water moves down the ridges, keeping them dry, and collects in the channels, keeping them wet.

Figure 2-3. The topography of Langley Bog in 1974, after mining began. The white outlines the current extent of the bog. Note the channel and ridge pattern in the mined areas of the bog.

Dry bog conditions are correlated with an increase in tree establishment (Frelechoux et al. 2000; Edvardsson et al. 2015). Trees interrupt *Sphagnum* establishment in two ways: they neutralize the soil and increase shade cover. *Sphagnum* mosses rely on low-nutrient, acidic conditions to outcompete vascular species (van Breemen 1995). As ecosystem engineers, *Sphagnum* create H+ ions through cation exchange, depressing tree growth and creating conditions for further moss establishment (Bragazza & Gerdol 2002). Trees neutralize the soil by reducing the loss of base cations, creating a positive feedback loop for woody vegetation (Hong et al. 2018). Once trees are established, they further inhibit *Sphagnum* growth by shading out light both through canopy and litter cover (Lamers et al. 2000; Berendse et al. 2001). As canopy density increases, *Sphagnum* biomass decreases (Pouliot et al. 2011).

Sphagnum is not the only bog specialist that declines with afforestation. Bog laurel, cloudberry, and blueberry are all associated with open bogs (Lachance et al. 2005). As the forest expands, areas formerly vegetated with bog specialists are replaced with common forest-floor species, reducing local and regional biodiversity (Woziwoda & Kopec 2014).

Roads

The Langley Peat Company built two main roads that are still present on the site. Fill road A runs northwest through the bog, and fill road B extends northeast through the center of the site (Figure 1-1). Both are made of cedar wood chip sourced from the MacDonald cedar mill and extend approximately 7 m below the surface (J Smith, 2020, pers. comm., November 29).

Roads in peatlands lower the water table both by acting as dams inhibiting lateral movement, and by compressing the peat so that vertical water movement slows (Plach et al. 2017). As water levels decrease, bog soils dry out. When bog soils dry out, organic material begins to decompose with increased oxygen availability, releasing carbon and making bogs carbon emitters (Hanson et al. 2020). Water levels in peatlands are therefore correlated to the amount of greenhouse gases released in this ecosystem (Couwenberg et al. 2011). By raising the water level, carbon dioxide emissions in the bog decrease - in some cases lowering the global warming potential by 85% (Couwenberg et al. 2011).

Debris

Industrial debris left behind from peat production has been found in Langley Bog (Figure 2-4). Plastic bags used for packaging mined peat was unearthed adjacent to the former peat processing plant (Figure 2-4a). The plastic bags are in a pile at least 1 meter deep, covered by a layer of cedar wood chip. Plastic bags do not readily decompose and are known to leach heavy metals such as cadmium and lead into the environment (Ohidul et al. 2018).

Wood waste is also present on the site (Figure 2-4b), which was likely treated with chromated copper arsenate (CCA) as it was produced prior to 2004 (Government of Canada 2019). CCA-treated wood retains arsenic even after 20 years (Environmental Working Group 2002) and leaches arsenic as well as copper, chromium, and zinc into the surrounding soil (Lebow et al. 2002).

The center of the bog appears to have been used as a dumping ground for construction and demolition waste. The Langley Peat Company dumped concrete and metal frames, then covered them with fill material (Figure 2-4c). Metro Vancouver now bans the disposal of concrete and metal construction materials that can be recycled (Metro Vancouver 2020). It is possible that additional, unknown types of waste are below the surface in other areas of the bog.

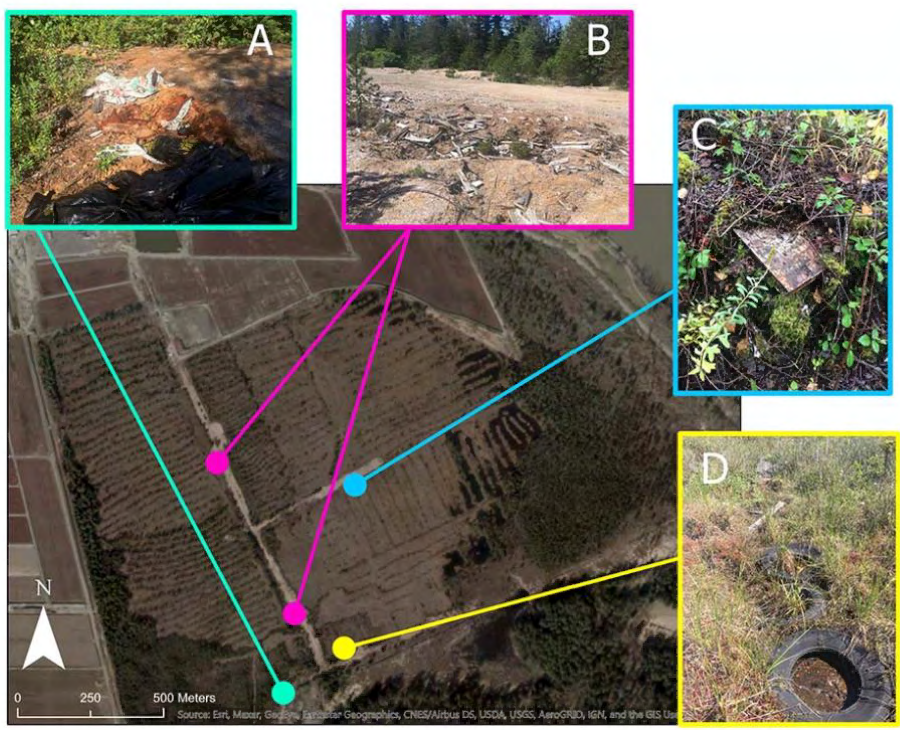

Figure 2-4. Locations of debris in Langley Bog, Langley Township, BC, Canada. A: plastic bags used in peat packaging. B: wood waste. C: construction waste D: rubber tires.

In the open bog, 16 rubber tires were found, with traces of additional tires covered by peat (Figure 2-4d). In acidic conditions such as the bog, where pH is between 3 and 5, rubber tires leach barium, cadmium, chromium, lead, selenium, and zinc into the surrounding environment (Evans 1997). Rubber tires are also a fire hazard as their high carbon content allows them to absorb heat, making them difficult to extinguish once ignited (US Fire Administration 1998).

2.2. Current Conditions

2.2.1. Vegetation

Succession

There are two primary ecosystem types in Langley Bog: open bog and bog forest (Figure 2-5). Open bog has a sedge overstory consisting of *Rhynchospora alba* (white beak rush), non-native *Eriophorum virginicum* (tawny cottongrass), and *Carex utriculata* (beaked sedge). It has an understory of *Drosera rotundifolia* (round-leaved sundew) and *Sphagnum* mosses, with *S. magellanicum* forming scattered hummocks. Hummocks are sparsely vegetated with ericaceous shrubs such as *R. groenlandicum* and *Vaccinium oxyccocus* (bog cranberry).

Figure 2-5. Sphagnum moss ecosystems in Langley Bog, Langley Township, BC. On the left, open bog. On the right, bog forest.

Bog forest has an open tree canopy consisting primarily of *P. contorta* (Figure 2-5). It has a shrub understory of *R. groenlandicum, V. uliginosum* (bog blueberry), and *K. microphylla* (bog laurel). *Sphagnum palustre* is the predominant moss. Open bog is the historical ecosystem (Figure 2-1). It is currently found in channels where peat was removed and the elevation was lowered, supporting a high water table. Several forms of open bog exist on the site. The earliest successional stage in Langley Bog consists of open water vegetated with aquatic species such *Brasenia schreberi* (water shield) (Figure 2-6). Over time, sedges and mosses infill the water, covering the surface (Klinger 1996). Open bogs are currently hypothesized to be a climax community, preceded by, rather than replaced by, upland forest (Klinger 1996). It is only through a disturbance event – such as peat mining lowering the water table – that the community transitions into forest (Jagodzinski et al. 2018).

Figure 2-6. Successional stages in Langley Bog, Langley Township, BC. Top row: early open bog with open water, mid open bog with scattered mosses, late open bog with surface covered in moss. Bottom row: early bog forest with scattered pines, mid bog forest with shrub understory, late bog forest with open canopy and shrub understory.

Bog forest is found at higher elevations, where the water table is low. In Langley Bog this occurs both in the western and eastern forests and in linear strips adjacent to the mined channels. This pattern of low channel and high ridge can be seen clearly from above (Figure 2-8). In early stages of bog forest, a single *P. contorta* may exist with a *R. groenlandicum* understory (Figure 2-6). Once established, *R. groenlandicum* aggressively expands, forming vast colonies (Hebert & Thiffault 2011). *R. groenlandicum* outcompetes other species by taking up organic N and sequestering it in forms not available to species such as conifers (Hebert & Thiffault 2011). *R. groenlandicum* is thus negatively associated with tree establishment, maintaining a bog forest with few trees and an open canopy (Figure 2-6). Because of the tree-limiting effects of *R. groenlandicum*, *Sphagnum* mosses persist in the understory of bog forest ecosystems.

Peat-forming, carbon-sequestering *Sphagnum* can be found in both the open bog and bog forest. However *Sphagnum* is not found in areas where bog forest has transitioned into birch forest or pine-salal forest (Figure 2-7). *Betula pubescens* (downy birch) and *B. papyrifera* (paper birch) are early successional species that shade out *Sphagnum* and create ideal conditions for late-successional forest species (Jagodzinski et al. 2018). In bogs, *Betula* species are known to occur near drainage ditches where the water table has been lowered through human disturbance (Jagodzinski et al. 2018).

In Langley Bog, birch forest is found in areas adjacent to the road, where the water table has been further lowered (Figure 2-8). Similarly, pine-salal forest is found in drier areas, where the low water table limits *Sphagnum* establishment (Howie et al. 2009a). In Langley Bog, pine-salal forest occupies edge habitat adjacent to drainage ditches surrounding the bog (Figure 2-8).

Figure 2-7. Non-Sphagnum moss ecosystems in Langley Bog, Langley Township, BC. On the left, birch forest. On the right, pine-salal forest.

Different vegetation is expected in edge habitat. Natural bogs are surrounded by a lagg, a transitional zone between the bog and its surrounding habitat (Howie et al. 2009b). Where bogs border swamps, minerotrophic plant communities that do not support *Sphagnum* mosses are found (Howie et al. 2009b). In Langley Bog, shrub thickets predominated by *Spirea douglasii* (hardhack) can be found on the southern border where the bog transitions into swamp wetland (Figure 2-8).

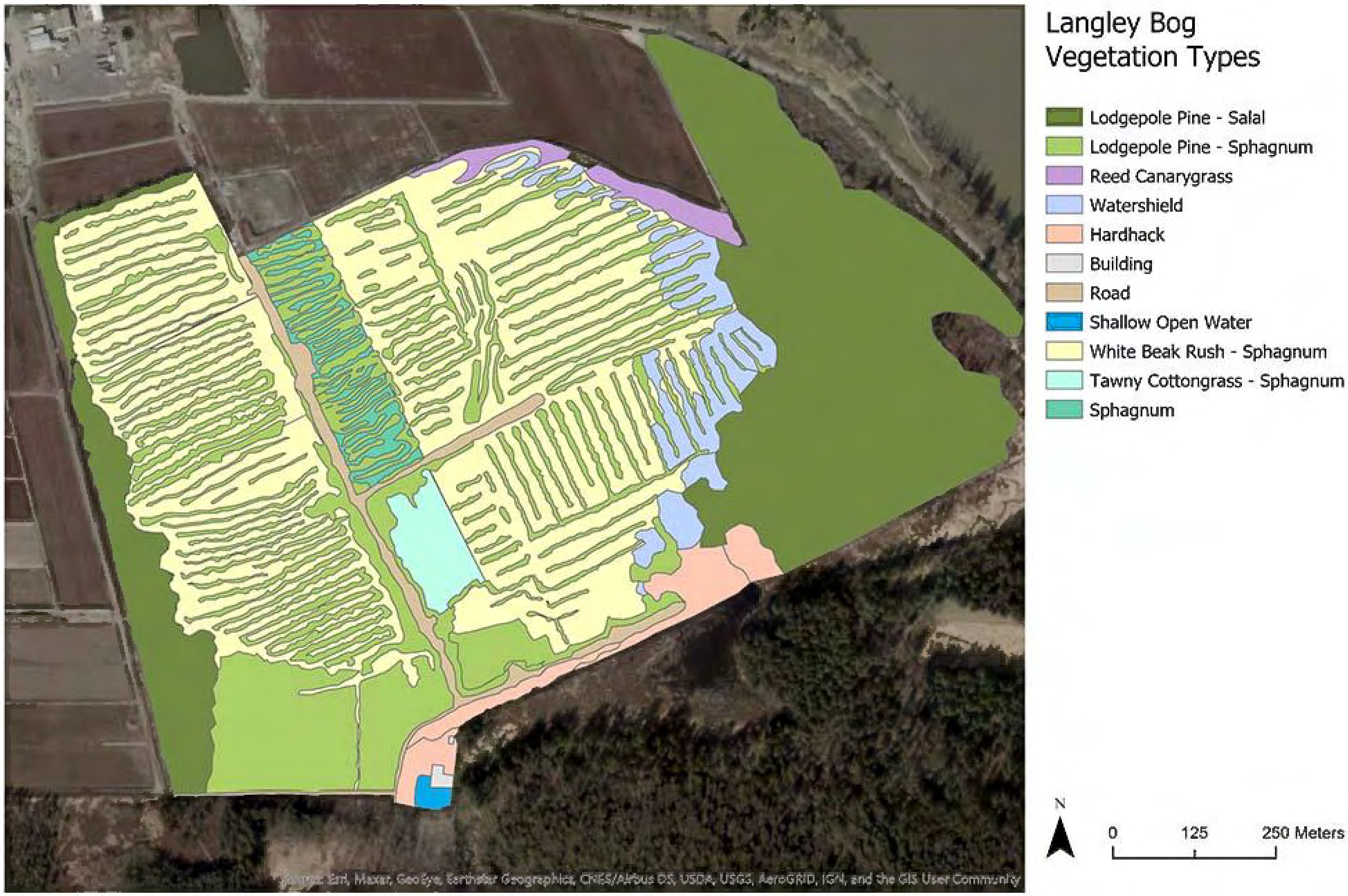

Figure 2-8. Vegetation types of Langley Bog, Langley Township, BC.

Invasive Species

Invasive flora is restricted to bog edges, since only a few specialist species are adapted to the low pH, conductivity, and nutrient content of bog habitat (Dube et al. 2011). There are six invasive plants in Langley Bog that are prioritized by BC (Government of British Columbia 2021b). *Cytisus scoparius* (Scotch broom) and *Rubus armeniacus* (Himalayan blackberry) occur on all fill roads. *R. armeniacus* also occurs as a dense thicket bordering the western cranberry farm. *Iris pseudocarus* (yellow flag iris) and *Lythrum salicaria* (purple loosestrife) occur in the northern ditch bordering the cranberry farm. *Fallopia japonica* (Japanese knotweed) is growing in the southwestern corner of the bog (Figure 2-9).

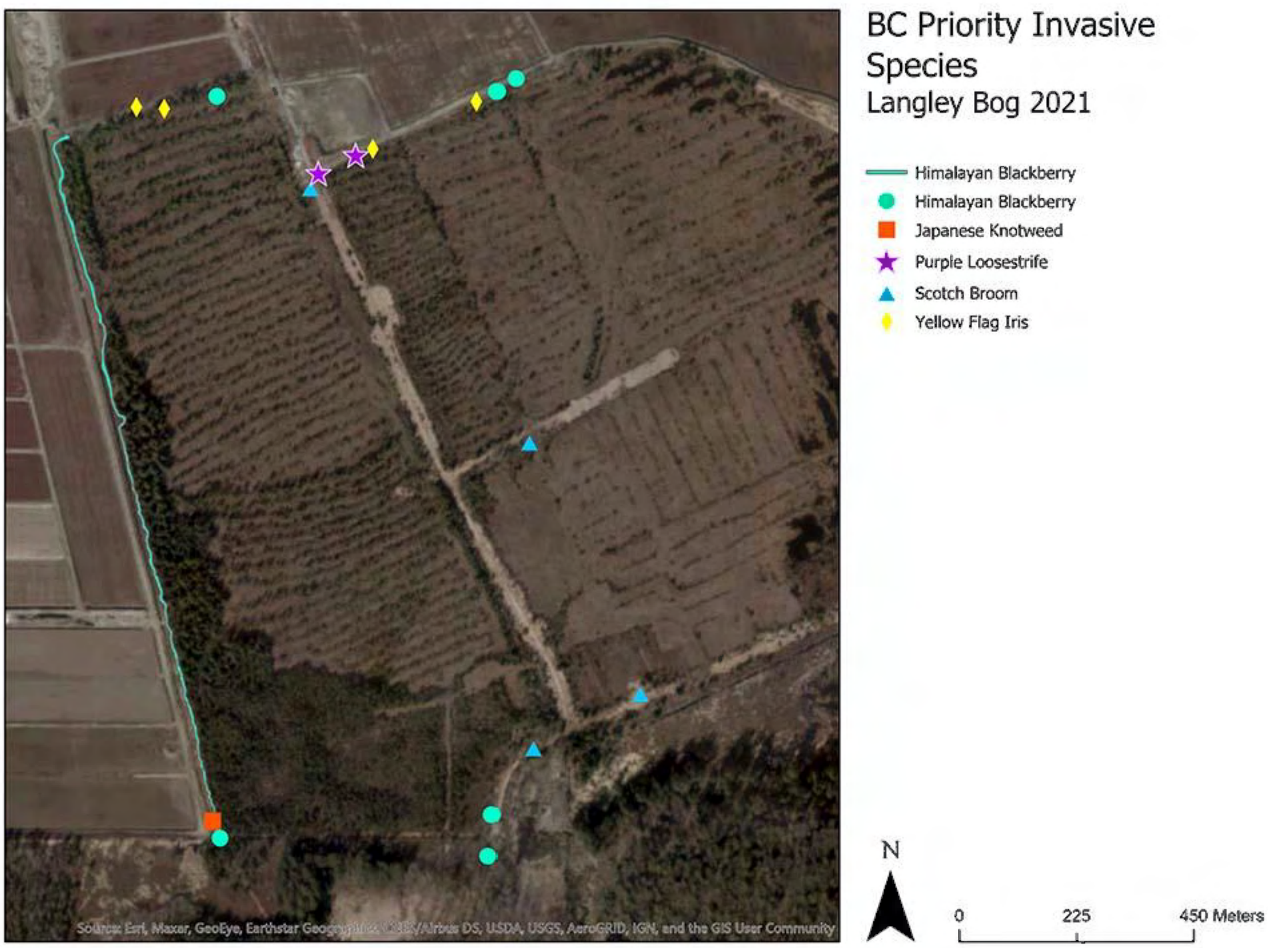

Figure 2-9. Location of invasive species from the BC Priority Invasive Species List in Langley Bog, Langley Township, BC.

Rare Species

There are three blue-listed ecosystems present in Langley Bog: the *R. groenlandicum* / *K. microphylla* / *Sphagnum* ecosystem, the *R. groenlandicum* / *Sphagnum* ecosystem, and the *Scheuchzeria palustris* / *Sphagnum* ecosystem (BC Conservation Data Center 2021). All three ecosystems are of special concern provincially, with a vulnerability to extirpation or extinction. The two *R. groenlandicum* ecosystems are found throughout Langley Bog, at all stages of bog forest succession (Figure 2-6). The *S. palustris* ecosystem is in one mined channel at 49° 12' 2.34" N, 122° 36' 40.122" W (Figure 2-10).

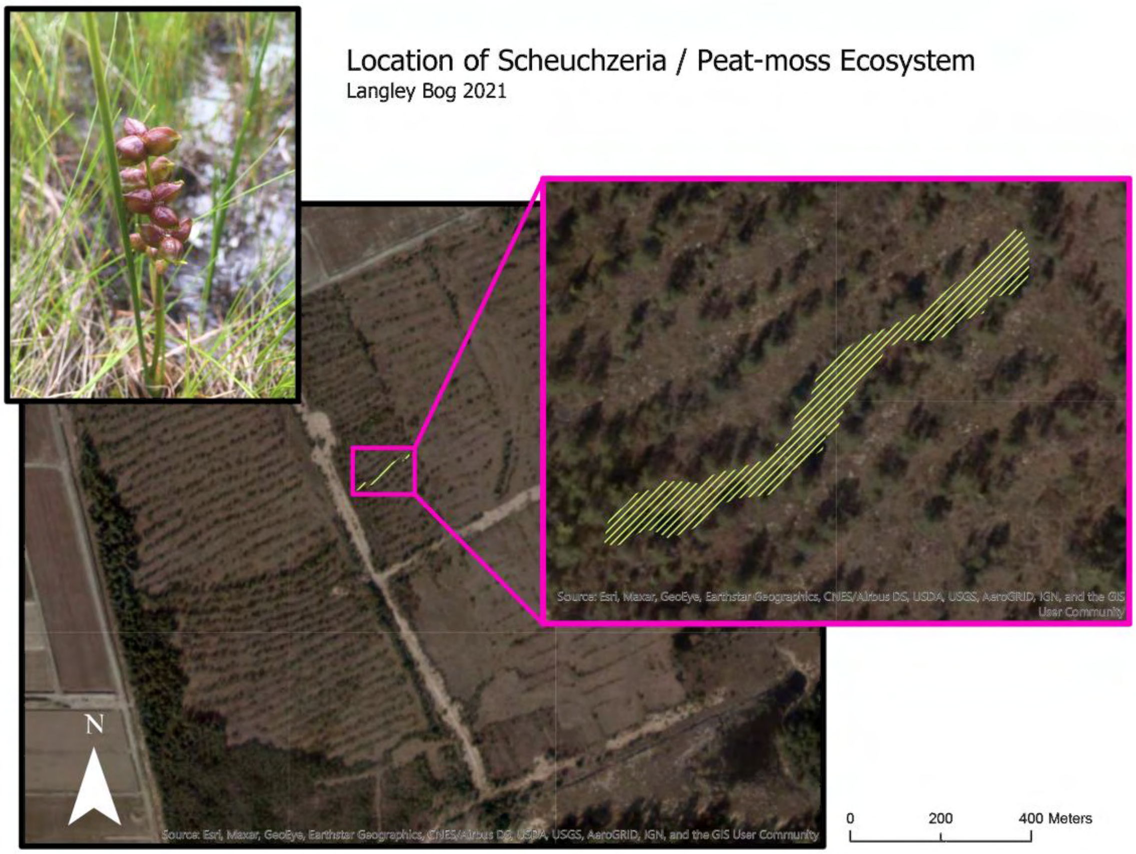

Figure 2-10. Location of blue-listed *S.palustris / Sphagnum* ecosystem in Langley Bog, Langley Township, BC.

2.2.2. Hydrology

On average, monthly water depths in Langley Bog remained within 30 cm of the surface throughout the year (Figure 1-7). However the water depth was not uniform across the bog, and when broken down by individual locations, high priority sites come visible (Figure 2-11).

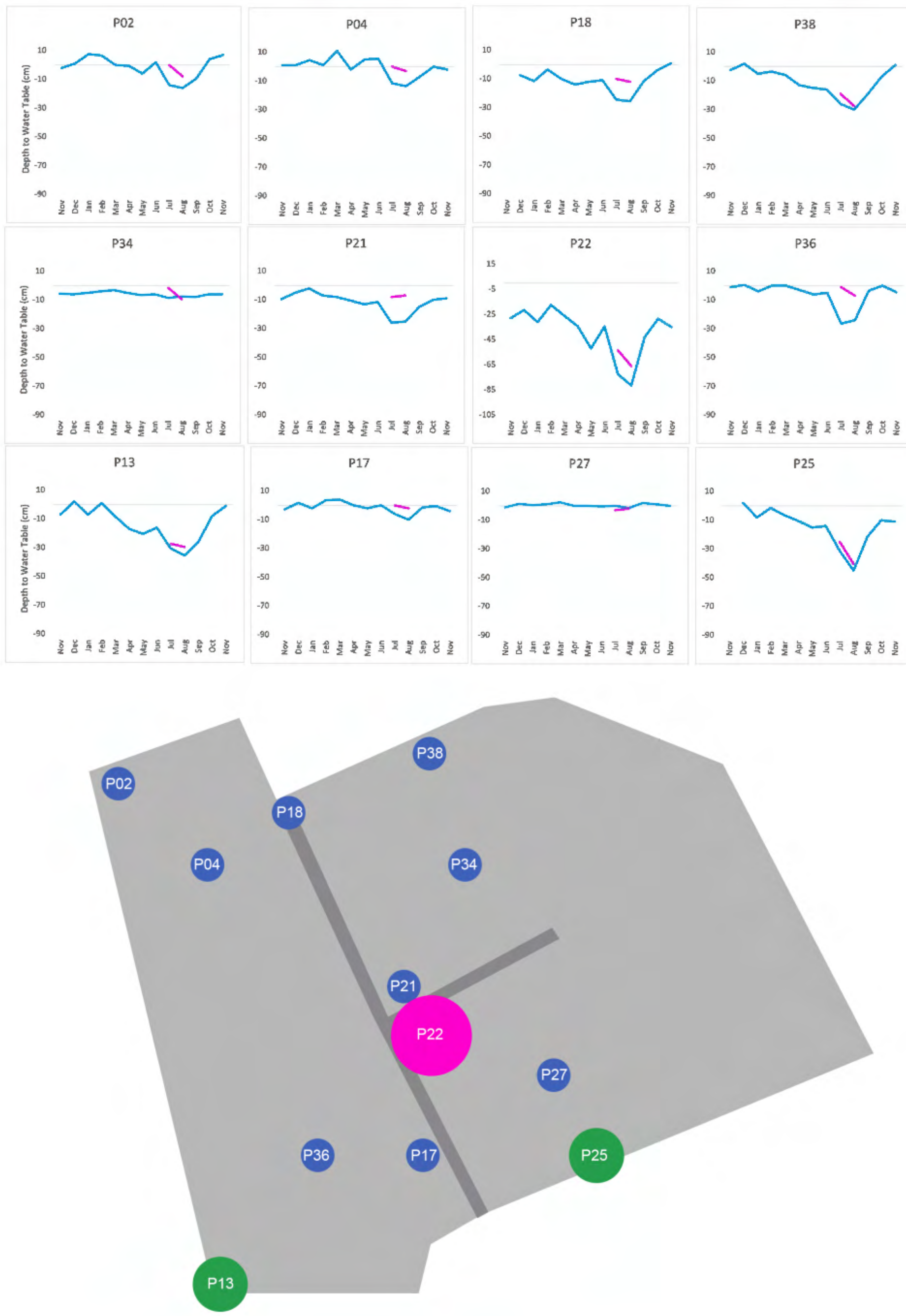

Figure 2-11. Yearly water depth for 2021 (blue line) and 2008 (pink line) across Langley Bog, Langley Township. The map shows the driest site with a large, pink circle, followed by the smaller green circles, with the wettest sites in blue.

Water depth measured from locations furthest from the road and cranberry farms remained within 30 cm of the surface throughout the year. Water depth measured adjacent to the road reached lows of up to 72.5 cm below the surface. The highest priority site is P22, which had the lowest water depths of the 12 wells monitored in 2008 and 2021 (Brown et al. 2010; Figure 2-11).

Bogs typically have pH levels between 4.0 and 4.8 (National Wetlands Working Group 1997). On average, monthly pH levels in Langley Bog remained below 5.0 throughout the year (Figure 1-12). However just as with water depth, when grouped by location, pH levels at sites bordering the cranberry farm reached highs of 5.99. Sites furthest from the cranberry farm and road did not exceed 4.75.

2.3. Desired Future Conditions

It is well established that to maintain *Sphagnum* moss cover and associated carbon sequestration, water depth must average less than 25-30 cm below the surface throughout the year (Schouweanaars 1993; Weltzin et al. 2000; Taminskas et al. 2018). Langley Bog averages a yearly water depth of 9.8 cm below the surface, and a summer average of 19.4 cm below the surface, keeping the site within the range of bog conditions. Given the seasonal summer droughts experienced in British Columbia (Figure 1-7), average water levels in June, July, and August should also remain above 25 cm to prevent moss die off. Where water depth drops below 30 cm at individual locations, such as at well P22 with average water levels of 39 cm below the surface, levels should be raised by at least 14 cm.

Bog floristic composition is significantly correlated to pH levels below 4.0 (Kleinebecker et al. 2008). As pH rises, carbon sequestration diminishes: Ye et al. (2012) found CO_2 production increased by up to 600% when bog pH rose from 3.5 to 6.5. The average yearly pH level across Langley Bog is 4.3 and will need to remain below 5.0 to protect bog carbon-storage functionality.

Sphagnum grows slowly, not readily recolonizing sites (Lavoie et al. 2005). Manually reintroducing *Sphagnum* would restart peat accumulation more quickly by increasing percent cover. The higher percent cover of *Sphagnum*, the higher carbon uptake by the system: a bog with 88% *Sphagnum* cover can act as a carbon sink during the growing period (Samaritani et al. 2010), while a bog with 20-50% *Sphagnum* cover may not store enough carbon to offset methane and carbon dioxide losses (Malmer & Wallen 1999). While bogs in British Columbia may differ from these studies because of their coastal climate, their carbon sequestration rates are comparable because the higher *Sphagnum* productivity is offset by higher decomposition rates (Asada & Warner 2005). As such it is desirable to increase *Sphagnum* moss cover to as close to 100% as possible.

In forests, the heavy canopy of birches shade out mosses, where they cover less than 10% of the understory (Foster & King 1986). Similarly, closed-canopy pine forest limits light availability to mosses and increases dryness through evapotranspiration (González et al. 2014). To protect existing moss cover and promote establishment, it is desirable to have an open canopy forest in Langley Bog where light penetrates to the forest floor.

Eradication of invasive species in Langley Bog is feasible because they are not well-established, allowing for an offensive rather than a defensive strategy (Rejmanek 2001). It is desirable to remove all *C. scoparius, R. armeniacus, F. japonica, I. pseudocarus* and *L. salicaria* from edge and fill road areas. Native lagg vegetation such as *S. douglasii* can be introduced where conditions allow to prevent invasives from re-establishing in these areas.

2.4. Restoration Goals & Objectives

Goal 1: Protect the estimated 270,000 tons of carbon currently stored in Langley Bog from oxidizing by raising water table.

Objective 1.1: Remove top 1 m of cedar wood chip from first 170 m of fill road B to raise average yearly water table at the nearest well by 10 cm after 3 years.

Objective 1.2: Build 500 m^3 berm in southwestern corner of bog to raise average yearly water table at nearest well by 10 cm after 1 year in southwestern quadrant.

Objective 1.3: Reduce width of all fill roads to 3.5 m by removing cedar wood chip from either side to decompress peat and raise yearly water table at nearest well by 10 cm after 3 years.

Objective 1.4: Install 25 evenly-spaced culverts along fill road A to improve water movement through acrotelm and raise yearly water table by 10 cm after 1 year.

Goal 2: Restart peat accumulation and carbon sequestration by increasing *Sphagnum* moss cover.

Objective 2.1: Reintroduce *Sphagnum* into three 3,000 m^2 mined channel to achieve 60% cover of moss in 10 years.

Objective 2.2: Remove all standing trees from southern 2,000 m^2 area directly adjacent to fill road B to increase peat-forming moss cover by 10% in 3 years.

Objective 2.3: Remove all standing trees from western 10,000 m^2 area directly adjacent to fill road A to increase peat-forming moss cover by 10% in 3 years.

Goal 3: Protect extant blue-listed ecosystems by reducing disturbances from non-bog species and debris.

Objective 3.1: Remove 100% of BC priority invasive species along edge and fill habitat in 1 year.

Objective 3.2: Remove 100% of plastic bag, rubber tire, and wood waste in 1 year to prevent input of nutrients and contaminants as they break down.

2.5. Restoration Treatments

2.5.1. Remove Debris

A group of ten volunteers from Derby Reach / Brae Island Park Association will remove wood waste, rubber tires, and plastic debris by hand into a 30-yard Trash King bin installed on the fill road. Collection will occur in October, to coincide with invasive species removal. One bin will be placed at the former peat plant and the second bin will be placed at the northern end of the fill road. After three days, Trash King will collect the bins for disposal. Volunteers will wear work gloves for protection against contaminants present on wood waste.

Construction debris in the center of the bog is too heavy to be removed by hand and contains materials such as glass that pose a danger to volunteers. An operator will place the debris into a Trash King bin using a small excavator that will remain on the fill road to avoid compressing the peat.

2.5.2. Remove Invasive Species

Himalayan Blackberry

Rubus armeniacus growing on the fill road is not yet well-established so it can be managed by hand (Figure 2-9). If roots are removed completely, mechanical removal is effective at eliminating *R. armeniacus* (Gaire et al. 2015). Five volunteers from the Derby Reach / Brae Island Park Association (DRBIPA) will cut back stems of *R. armeniacus* with loppers then flag the root crown. One additional volunteer will follow with a shovel to dig out the root crown, ensuring rootstocks are fully removed. Metro Vancouver will provide tools. Removal will take place in November when the soil is moist and removal is easier, and when nesting birds are absent.

All *R. armeniacus* growing along the western edge of the bog is too large and well-established for manual removal. This population is also within 1 meter of McQuattt ditch which connects to the Fraser River, so pesticides cannot be applied (BC Ministry of Environment 2009). In this case, the most effective means of control is bimonthly mowing starting in July, when in bloom, until the roots are exhausted (Bennett 2006, Gaire et al. 2015). A Metro Vancouver mower can access the site from the adjacent Coast Cranberries farm.

In November, the cleared area will be replanted with *P. contorta. P. contorta* is already present on the site and is a fast-growing, facultative wetland plant that grows in full sun under a wide range of soil types (US Department of Agriculture n.d.). As *P. contorta* grows, the closed canopy will shade out *R. armeniacus* (Gaire 2015). Metro Vancouver staff, with the assistance of DRBIPA volunteers, will plant 588 container trees 6 m apart to achieve the maximum recommended density of 700 trees per acre (US Department of Agriculture n.d.). *R. armeniacus* can continue to be managed under the *P. contorta* canopy, and once the roots are exhausted, the understory can be replanted with *G. shallon*.

Japanese Knotweed

Fallopia japonica grows from an extensive rhizome system, so herbicide is the recommended treatment method (Metro Vancouver 2019). Because it is growing along McQuatt ditch, a contractor will inject glyphosate herbicide into the stem in May while *F. japonica* is actively growing.

Purple Loosestrife

Lythrum salicaria is only present in two locations on the northern edge of Langley Bog so can be removed manually (Figure 2-9). Two volunteers from DRBIPA will hand pull the plants, ensuring that all plant parts are removed, then bag them (Invasive Species Council of BC 2017). Removal will take place in September when flowers make the plants easy to identify but have not yet gone to seed.

Yellow Flag Iris

Although *I. pseudocarus* is only present in four locations in Langley Bog (Figure 2-9), the populations should not be removed by hand as it stimulates rhizomatous growth (Invasive Species Council of BC 2017b). Instead, benthic barriers will be installed to passively kill off plants by anoxia. This method has been successfully used experimentally, where 100% of the treated area did not regrow even 200 days after the barriers were removed (Tarasoff et al. 2016). In September, *I. pseudocarus* will be cut to 0 cm using shears, then covered with 3 mm-thick rubber sheets. Each sheet will be stapled to four wooden stakes affixed at each end. The benthic barrier will remain in place until March.

Scotch Broom

In Langley Bog, *C. scoparius* grows exclusively on the fill road, so it can be removed manually without disturbing other vegetation (Figure 2-9). Two volunteers from DRBIPA will dig up plants using either a weed puller or pickaxe provided by Metro Vancouver to remove the roots (Invasive Species Council of BC 2019). Unlike the other invasive species, *C. scoparius* cannot be removed in fall because it has already gone to seed and attempts at removal will increase dispersal. Instead volunteers will remove *C. scoparius* in May, before it goes to seed. Road removal (Section 2.6.5) will assist in *C. scoparius* management, since any seeds currently banked in the cedar wood chip will also be removed from the site.

2.5.3. Plant Moss

To restart peat accumulation, it is desirable to reintroduce *Sphagnum* mosses as they recolonize sites very slowly (Lavoie et al. 2005). In Quebec, Price and Whitehead (2001) found that even after 30 years *Sphagnum* had only recolonized less than 10% of a formerly mined peatland. In British Columbia, Howie et al (2009a) found new *Sphagnum* colonies in a mined bog after three years, suggesting *Sphagnum* may recolonize coastal bogs more quickly than those in eastern Canada. When *Sphagnum* is reintroduced in eastern Canada, percent cover can reach 60% in a decade (González & Rochefort 2014). No studies of *Sphagnum* reintroductions have been published for British Columbia, however since mean annual temperature is strongly correlated with productivity, we expect the warmer climate in British Columbia to result in higher rates of establishment (Gunnarsson 2005).

In Langley Bog, *Sphagnum* is heterogeneously distributed throughout the mined channels. In the southeast region of the bog *Sphagnum* is absent and channels are primarily vegetated with *Rhynchospora alba* (white-beaked rush) (Figure 2-12, yellow). Conditions in the southeast of Langley Bog are well-suited for moss re-establishment. The most significant factor in *Sphagnum* reestablishment is a water table at or just below the surface (Ferland & Rochefort 1997). Water levels have been monitored for a year in this area and did not drop below 20 cm during the monitoring period. The area also has an existing cover of *Eriophorum virginicum* (tawny cottongrass). *Eriophorum* spp. act as a nurse plant for *Sphagnum,* holding moisture in the surrounding soil, providing shade (Rochefort et al. 2003), limiting soil decomposition, and sequestering carbon (Kastovska et al. 2018). It creates such favorable conditions for *Sphagnum* that *Eriophorum* spp. have been described as a keystone species (Buttler et al. 1998). Although *E. virginicum* is not native to western Canada, it has been shown to support the establishment of *Sphagnum* (Groeneveld & Rochefort 2002).

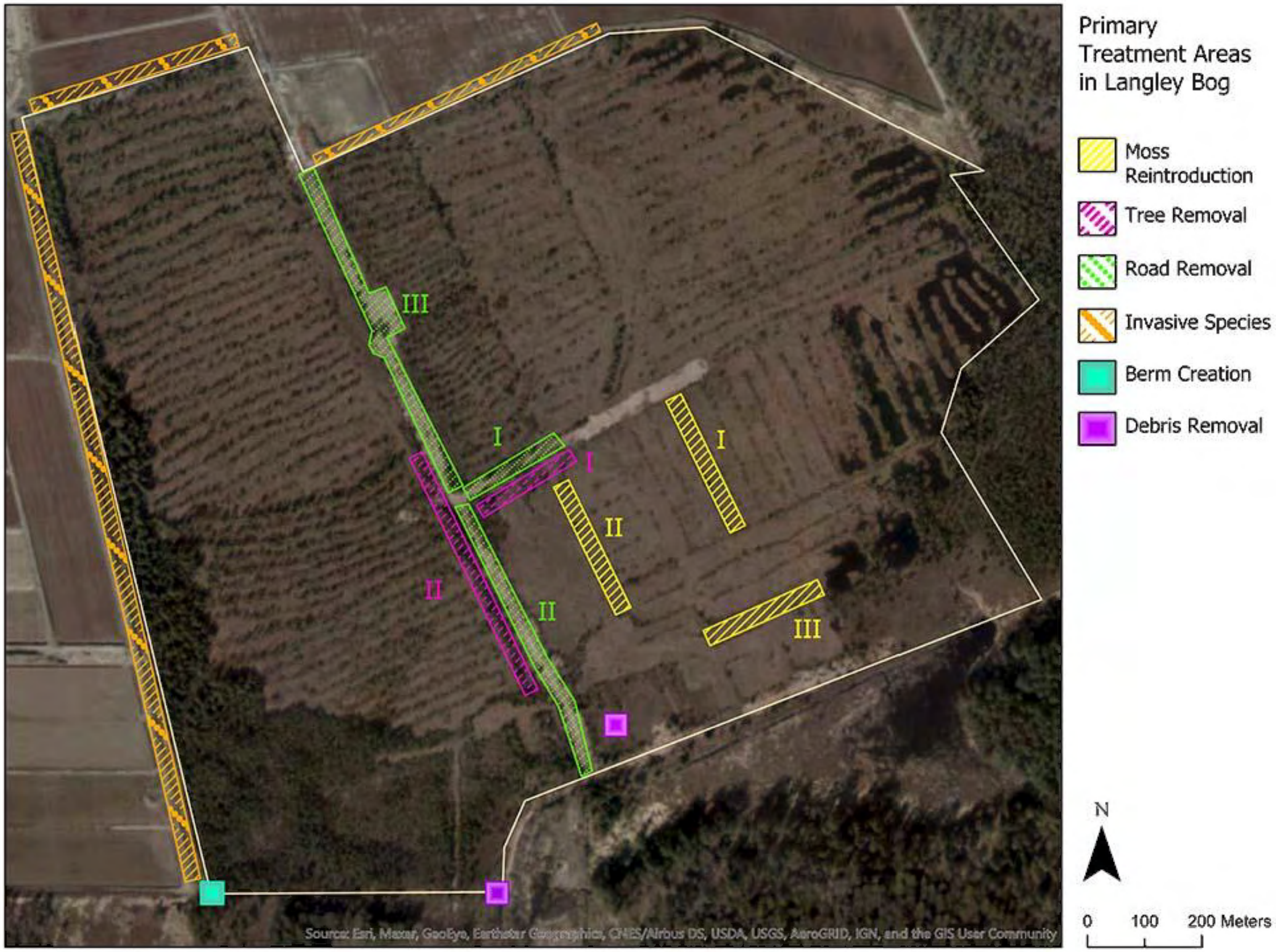

Figure 2-12. Areas of restoration in Langley Bog (Langley Township, BC). Areas where treatments overlap have been excluded. Numbers correspond to the phase in which work will be completed.

Sphagnum capillifolium (red peat moss), and *S. magellanicum* (Magellan's peat moss) will be used for revegetation since they are already present in Langley Bog and have been shown to successfully establish in already-vegetated mined channels (Boudreau & Rochefort 1999). Collections will be made using the Moss Layer Transfer Technique (MLTT) outlined in Ferland and Rochefort (1997). The top 10 cm of a moss hummock will be removed from an area in Langley Bog where it is abundant. It will be broken apart by hand. Every 1 m^2 of collected peat moss will be spread evenly over 10 m^2 ensuring there is peat soil contact with the diaspores. Where needed, white-beak rush and cotton grass leaves will be cut back to ensure spore-soil contact. As water is the limiting factor for *Sphagnum* establishment, planting will occur in November so spores remain wet (Chirino et al. 2006).

It is important that areas where moss is sourced are not negatively impacted. Guêné-Nanchen et al. (2018) demonstrated that harvesting *Sphagnum* does not impede recovery of donor sites. Even when the top layer of *Sphagnum* was removed with a bulldozer – which is more disruptive than the hand-collecting method recommended here – all donor sites recovered to reference conditions after 10 years, some as quickly as 2-5 years (Guêné-Nanchen et al. 2018). Given the large quantities of *Sphagnum* needed for revegetation, it is recommended that revegetation be done in a phased approach, allowing enough time for harvested areas to regenerate. Revegetation will occur in five-year intervals using a patch-dynamic approach, where the introduced *Sphagnum* acts as a source for spores and spreads outwards, populating the adjacent areas. This "island" approach has been used successfully in the regeneration of peatlands in Australia and New Zealand, where financial considerations restricted the large-scale revegetation of mined areas (Clarkson et al. 2017).

2.5.4. Remove Trees

Sphagnum mosses rely on acidic soil and sunny conditions to flourish. Trees and shrubs, however, neutralize the soil and shade out *Sphagnum* mosses, creating a positive feedback loop for further establishment of woody vegetation (Hong et al. 2018). Removing trees and shrubs therefore promotes the re-establishment of peat-forming mosses (Czerepko et al. 2018). In one experiment, when birch and saplings were removed, the moss layer increased in cover by 6% in two years (Czerepko et al. 2018). An added benefit is that by reducing evapotranspiration, water levels also rise, in one study by up to 7 cm (Paivanen & Sarkkola 2000). A similar treatment occurred at nearby Burns Bog, Delta, BC, where high water levels and positive bog-plant growth occurred after woody vegetation was removed (Danyluk 2012).

Since trees have never been removed in Langley Bog, this restoration should be done in phases to evaluate the impact on water level and *Sphagnum* moss cover before large-scale tree removal. The first phase will occur on the 2,100 m^2 area located at the southern intersection of the two fill roads (Figure 2-12, pink, I). This site was chosen because of the low water table and the pre-existing *Sphagnum* cover that would benefit from the restoration. A 1 m^2 visual cover survey done every 10 meters along a 180 m transect through the center of the site found 30% *Sphagnum* moss cover.

Contractors will hand-fell all trees with chainsaws in September 2022 when fire risk is low, and leave trees on site. *Betula* stumps will be painted with herbicide to prevent regrowth. Contractors will return in June of the following year to remove the downed trees once the road becomes passable in the dry season. The second, larger phase will occur in September 2023 by removing trees in the 8,000 m^2 area to the west of the primary fill road (Figure 2-12, pink, II).

2.5.5. Remove Road

Documenting impacts of road removal in peatlands is a relatively new area of research. In one study, road removal in a peatland resulted in a 10-cm increase in water level three years after removal (Elmes et al. 2021). Earlier restoration work done in Langley Bog supports these outcomes. In 2008 over 1 m of cedar wood chip was removed from a 150-m stretch of fill road B. Although data were not collected prior to removal, water levels measured in November 2020 were more than 10 cm higher at wells adjacent to the restored portion of the road as compared to the non-restored portion.

The top 1 m of wood chip from fill road B (Figure 2-13, I) will be removed in the same manner as was done in 2008: with a Coast Cranberries Ltd. earth mover accessing the site through the adjoining access road to the north. Coast Cranberries Ltd. will use the removed cedar wood chip in their cranberry agriculture operations. Removal will be done in May when the soil is stable for heavy-machinery access but moist enough to prevent fire. To prevent spontaneous combustion, the removed wood chip should not be placed in piles over 60 feet high, and a Metro Vancouver Park employee with access to a fire extinguisher and a fire truck will monitor the operation for fire hazards (National Fire Protection Association 2021).

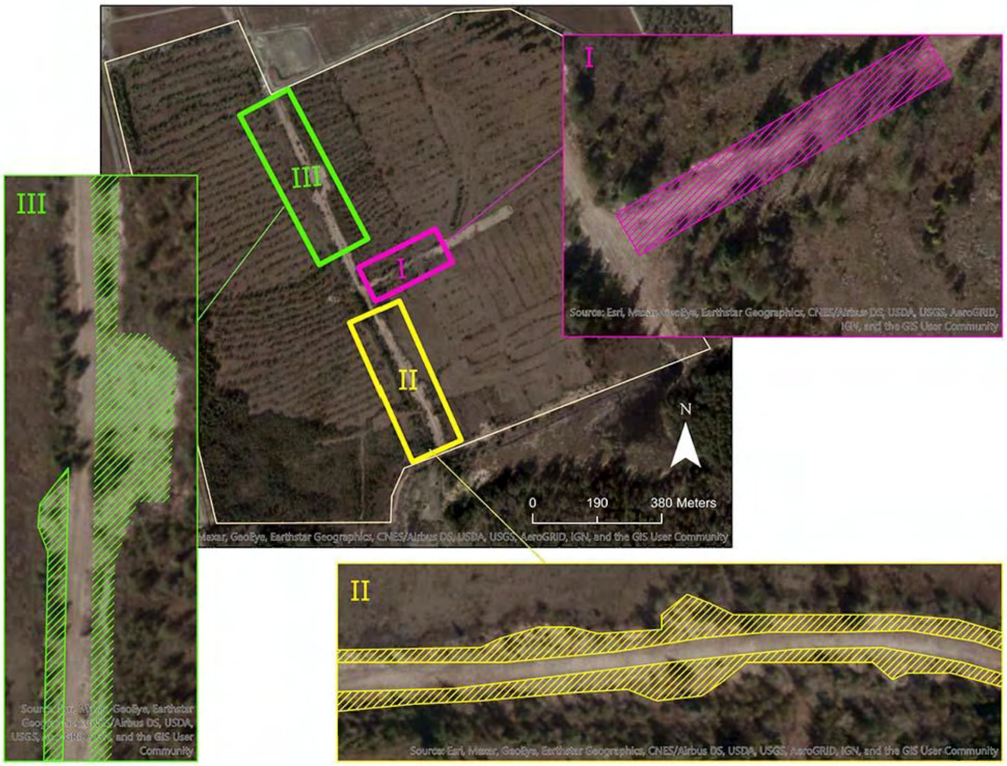

Figure 2-13. Proposed removal areas of fill road in Langley Bog, Langley Township, BC. The top 1 m of cedar wood chip will be removed from area I (pink). The road in areas II (yellow) and III (green) will be reduced in width by the removal of wood chip from both sides of the road.

Due to safety concerns the road cannot be completely removed. Peat soils are very soft, with a low weight-bearing capacity of between 5-20 kPa (Kalantari & Huat 2009). An agricultural tractor exerts a mean ground pressure of 28-33 kPa (Schäffer et al. 2007) exceeding the ability of the peat soil to support machinery. As the road is removed, the weight-bearing capacity is reduced, putting the excavator operator at risk of sinking into the peat. Also, Metro Vancouver requires some road access to remain for fire safety. As the climate warms, bogs may become more xeric, increasing fire risk (Camill et al. 2009). Park managers would like to maintain a road capable of sustaining the weight of a fire truck.

To maintain access for fire safety, fill road A will remain, but will be minimized by removing cedar wood chip from either side (Figure 2-13, II; III). Currently fill road A measures on average 14 m wide. The Government of BC requires a resource road to be only 7 m wide if it is two-way, and even less for one-way (Government of British Columbia 2019). The cedar wood chip on either side of the road will be removed with a Coast Cranberries Ltd. excavator as outlined above. Because the excavator will remain on the stable surface of the road, all fill will be removed until bare peat is reached.

2.5.6. Build Berm

In the southwestern corner of Langley Bog, surface water flows directly into McQuatt ditch, and then into the Fraser River (Figure 2-2). To reduce water loss from the southwestern breach in the ditch, a berm 3 m tall x 13 m long x 13 m will be built using 500 m^3 of compressed peat soil to block water from entering the ditch. Ditch blocking is a common, well-established restoration technique to restore wetlands and stabilize bog water fluctuations (Howie et al. 2009a, Jarasius et al. 2015). After blocking a ditch and measuring water levels, Howie et al. (2009a) saw the average yearly depth to water table increase by 17 cm in the closest well.

To prevent erosion and the establishment of invasives, the berm will be planted with a mix of bog shrubs that are tolerant of drier conditions such as *Vaccinium parvifolium* (red huckleberry), *Vaccinium ovalifolium* (oval-leaf blueberry), and *Vaccinium myrtilloides* (velvetleaf huckleberry). Access to the site will be through the cranberry farm road. Metro Vancouver has gained access to this road in the past by working in cooperation with owners of the cranberry farm to restore Langley Bog (Brown et al. 2010).

2.5.7. Install Culverts

Installing culverts on resource access roads intersecting peatlands increases surface and sub-surface flow between fragmented areas (Bocking et al. 2017; Saraswati et al. 2019; 2020). In experiments measuring water levels in peatlands, the water table was significantly higher at sites adjacent to a culvert, with some wells showing an increase in average yearly water depth of 15 cm (Saraswati et al. 2020).

A contractor will install 25 evenly-spaced culverts along fill road A (Figure 2-14). Saraswati et al (2020) recommends culverts to be spaced approximately 30 m apart, as each culvert can connect water up to approximately 15 m. Contractors will install the culvert below the peat surface to encourage lateral water movement. Culverts will be at least 250 mm in diameter (Saraswati et al. 2020).

Installation will occur in July over three consecutive years (Figure 2-14). A phased installation will make the project cost-effective, requiring less funds upfront, and will provide data on the impacts of installation. Any lessons learned from the first phase can then be applied to subsequent phases.

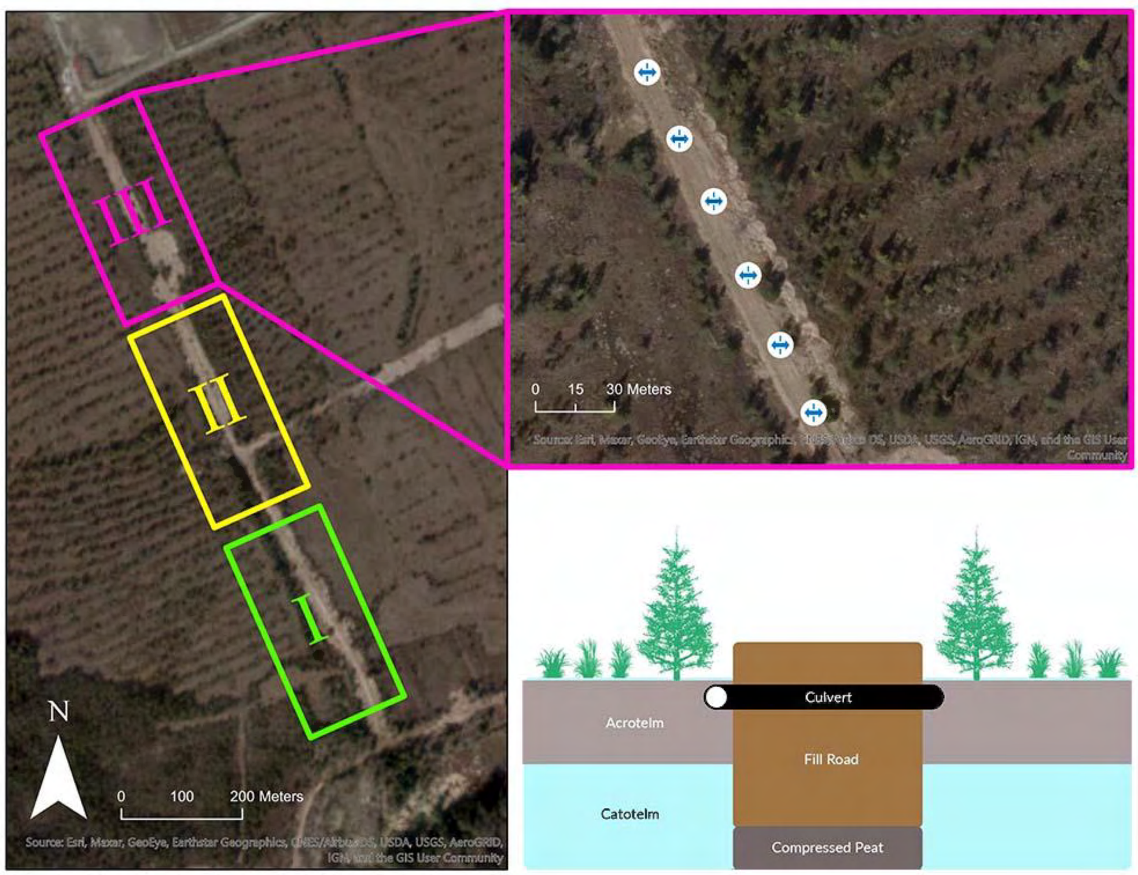

Figure 2-14. Map of culvert locations in Langley Bog, Langley Township, BC. The culverts are placed 30 m apart.

2.6. Monitoring Plan

Invasive Species

All invasive species found in Langley Bog are either on the fill road, or in edge habitat adjacent to a Coast Cranberries Ltd. access road (Figure 2-9). These locations make for ideal long-term monitoring: two staff members from Metro Vancouver Regional Parks can circumnavigate the bog annually each July during the height of growing season. They will visually monitor potential regrowth of previously managed species and flag any new invasions using GPS that may require management.

Moss Reintroduction

Sphagnum grows slowly: its establishment is measured in years rather than months (González & Rochefort 2014). Following González & Rochefort (2014), newly revegetated channels will be monitored starting after the third year of restoration. This lag in monitoring is recommended due to the small size of developing *Sphagnum* moss which makes it difficult to identify. After the third year, the channel will be monitored annually in October to assess percent cover of moss regrowth. As percent cover is a subjective measure, the same staff member will measure regrowth each year. Prior to moss reintroduction, the mined channel will be split into 15 blocks measuring 10 m wide and 12 m long, flagged with epoxy-coated rebar at the corners. Percent cover of moss will be visually estimated in each block and compared to percent cover prior to restoration. This block design will make data collection easier and will allow for a greater understanding of how channel micro-topography may affect moss reestablishment.

Tree Removal

As the objective of tree removal in Langley Bog is to increase percent cover of *Sphagnum*, monitoring will follow the timeline outlined in Moss Reintroduction, above. Prior to tree removal, a baseline assessment will be completed by running a transect across the length of the site and measuring percent cover of moss in 1-m^2 quadrants every 10 m. Once three years have elapsed, this assessment will be completed annually each October to compare percent growth. The same staff member collecting data for moss reintroduction could also collect data for tree removal to maintain consistency across Langley Bog.

Road Removal and Culvert Installation

Currently there are four wells located directly east of fill road A: P18, P21, P22, and P24 (Figure 2-15), which should be used to monitor the effect road removal has on the adjacent water table. However only one well is to the west of the fill road: P17 (Figure 2-15). To best capture the impact of road removal and culvert installation on Langley Bog hydrology, three additional wells should be installed at evenly spaced intervals immediately to the west of the main road. A Metro Vancouver Regional Park staff can visit the eight wells monthly to measure the water level by blowing into a tube to measure the water level in the well and subtracting it from the well height. If resources are limited, automated water levels can be downloaded from P18, P21, P22, and P17 in August of each year. The level loggers collect water depth measurements every 30 minutes and have been doing so since May 2021, so data can be compared to the baseline prior to restoration. Data can be processed using desktop HOBOware.

Berm Installation

As the objective of the berm construction is to raise the water table, methods will follow those outlined in Road Removal, above. The well adjacent to the berm installation site, P13 (Figure 2-15, southwest corner) can be monitored monthly. If resources are limited, the data from the HOBO U20 level logger can be downloaded yearly and compared to pre-restoration levels.

2.7. Maintenance Plan

Invasive Species

Invasive species grow faster and are more resilient than non-invasive species due to their ability to use resources more efficiently and photosynthesize at faster rates (Gaire et al. 2015). These characteristics mean that ongoing maintenance is required to manage their populations.

Since *R. armeniacus* can re-sprout from broken roots or stems, hand-pulling must be done for at least two consecutive years to capture areas that may have been missed (Gaire et. 2015). Similarly, mowing must occur multiple times in a year, over consecutive years. Bennett (2006) found substantial reductions in *R. armeniacus* cover after mowing five to nine times a year.

Location of Langley Bog Wells, August 2021

P01 - 528028 5450118	P14 - 528316 5449236	P26 - 528695 5449481	P37 - 528304 5449981	P48 - 528630 5449506
P02 - 527855 5450072	P16 - 528280 5449365	P27 - 528625 5449585	P38 - 528369 5450119	P49 - 528615 5449475
P03 - 527884 5449900	P17 - 528433 5449444	P28 - 528800 5449677	P39 - 528930 5450014	P50 - 528277 5449323
P04 - 528025 5449921	P18 - 528158 5450047	P29 - 528680 5449723	P40 - 528315 5449225	P51 - 528333 5449246
P07 - 527987 5449696	P19 - 528325 5449969	P30 - 528715 5449857	P41 - 528029 5449452	P52 - 528320 5449315
P08 - 528206 5449792	P20 - 528293 5449852	P31 - 528608 5449838	P42 - 528216 5449276	P53 - 528346 5449313
P09 - 528283 5449614	P21 - 528343 5449705	P32 - 528638 5450037	P43 - 528361 5449384	P54 - 528319 5449394
P10 - 528056 5449514	P22 - 528353 5449672	P33 - 528529 5450064	P44 - 528370 5449387	P55 - 528113 5449310
P11 - 528122 5449360	P23 - 528480 5449626	P34 - 528464 5449950	P45 - 528302 5449372	
P12 - 528042 5449244	P24 - 528473 5449442	P35 - 528530 5449770	P46 - 528454 5449538	
P13 - 528041 5449229	P25 - 528595 5449395	P36 - 528211 5449474	P47 - 528030 5449287	

Figure 2-15. Location of all wells in Langley Bog, Langley Township, BC. Numbers to the right of the well number represent easting and northing.

Because of its extensive rhizome network, a follow-up glyphosate stem injection for *F. japonica* is recommended one year following initial treatment (Metro Vancouver 2019). Ongoing monitoring is critical to actively manage new growth as *F. japonica* can re-sprout three years after the last herbicide treatment, and can lay dormant for up to twenty years (Metro Vancouver 2019).

Like other invasive species listed here, *L. salicaria* can re-sprout from root fragments: 80% of cut shoots survived a greenhouse experiment, from fragments as small as 5 cm (Brown & Wickstrom 1997). Mechanical removal must be done for at least two consecutive years to capture areas that may have been missed.

The benthic barriers installed over *I. pseudocarus* populations will need to be removed six months after installation. If during monitoring the rubber sheeting is found to be damaged or has shifted so as no longer to be covering the plants, then it will need to be re-stapled to the wooden stakes or replaced with a new benthic barrier.

C. scoparius has a large seed bank: 4-year-old plants can accumulate an average of 200 seeds/m^2 (Allen et al. 1995). Mechanical removal of *C. scoparius* should be repeated every 3 to 5 years to capture new growth from seed (Invasive Species Council of BC 2019).

2.8. Adaptive Management

Debris

Given the industrial nature of peat mining and the more than twenty years it was performed at Langley Bog, it is likely that more debris may be uncovered over time. As an example, an initial survey uncovered five rubber tires buried in the peat, but subsequent visits uncovered additional tires, eventually totaling 16. Additional tires may be buried in the peat and will be accessible only by excavator. Ongoing surveys may also uncover unknown or hazardous materials that would be best managed by specialized contractors.

Moss Re-establishment

Experiments using the Moss Layer Transfer Technique (MLTT) as outlined by Ferland and Rochefort (1997) have not been published for any sites in British Columbia. The

MLTT was designed for the Quebec climate (Ferland & Rochefort 1997) and has been used successfully across eastern Canada (González & Rochefort 2014) and Europe (Purre et al. 2020). It is unknown how successful the MLTT will be in Langley Bog. Because of this lack of information, it is recommended that initial moss reintroduction be done as an experiment, using different types of *Sphagnum* and spreading the moss at two different ratios. Information gained from these initial treatments can then be used to adapt processes for further reintroductions.

Tree Removal

Since fill road A will remain as an access route for Metro Vancouver Regional Parks, it will continue to negatively impact the water table. Tree removal, culvert installation, and road narrowing may not raise the water table enough to prevent regrowth of trees. If trees continue to grow on either side of the fill road, ongoing removal in five-year intervals is recommended to avoid the shading out of *Sphagnum* mosses and evapotranspiration. Metro Vancouver may also consider grading the areas adjacent to the road, lowering the elevation to allow for pooling of water. Since this will require the removal of existing bog species, this action should be used with caution.

Climate Change

Climate change projections for Metro Vancouver predict the average summer temperature highs will increase by 3.7 °C by 2050, and 6.0 °C by 2080 (Metro Vancouver 2016). Generally *Sphagnum* mosses are resilient to temperature increases: Weltzin et al (2000) found bog bryophytes were unaffected by temperature increases of up to 4.1 °C. Similarly Gerdol and Vicentini (2011) found *Sphagnum* was able to recover after being grown at temperatures of 43 °C.

However these results were predicated on the *Sphagnum* species having a high water table. When high temperatures are paired with drought, such as in the 2003 European heat wave, *Sphagnum* resiliency to heat stress decreases (Bragazza 2008). In 2003, bogs in the Italian Alps experienced an average summer temperature increase of 2.0 °C that was paired with a 30 mm average decrease of summer precipitation (Bragazza 2008). This heat wave resulted in a mass die-off of hummock-forming peat mosses in the Italian Alps (Bragazza 2008).

Climate change projections for Metro Vancouver predict a 38 mm average decrease in summer precipitation by 2050, and a 59 mm decrease by 2080 (Metro Vancouver 2016). Paired with the 3 - 6 °C increase in temperature, Langley Bog may suffer similar mass die-offs of *Sphagnum* as was seen in the 2003 European heat wave.

If mass die-offs of *Sphagnum* were to occur, it does not immediately follow that Langley Bog will move away from a bog ecosystem. Bog ecosystems are resilient to periods of drought, and climate change projections predict that average fall precipitation will increase by 62 mm by 2050 and 113 mm by 2080 (Metro Vancouver 2016). Heijmans et al (2013) found that drought events did not shift moss-predominated sites to tree-predominated ones because of the lack of positive feedback required to maintain a new ecosystem.

Because average yearly precipitation rates are predicted to increase in all seasons except for summer (Metro Vancouver 2016), future management of Langley Bog may need to prioritize sealing outlets so water remains on the site through seasonal droughts. Purchasing the agricultural land currently owned by Coast Cranberries Ltd to the west of Langley Bog would facilitate this by decommissioning McQuatt ditch and removing the elevation gradient between the sites.

Ongoing monitoring of Langley Bog water levels will help in detecting trends and allowing for adaptive management. Prior to 2021, water levels were collected only in July 2008 and 2009. From 2008 to 2021, average July water levels decreased from 12 to 23 cm below the surface (Figure 2-16). Because of the limited data, it is difficult to ascertain whether this is a trend or a reflection of environmental conditions since it was both cooler and wetter in 2008-09 than in 2021. Yearly analysis of Langley Bog water levels is recommended.

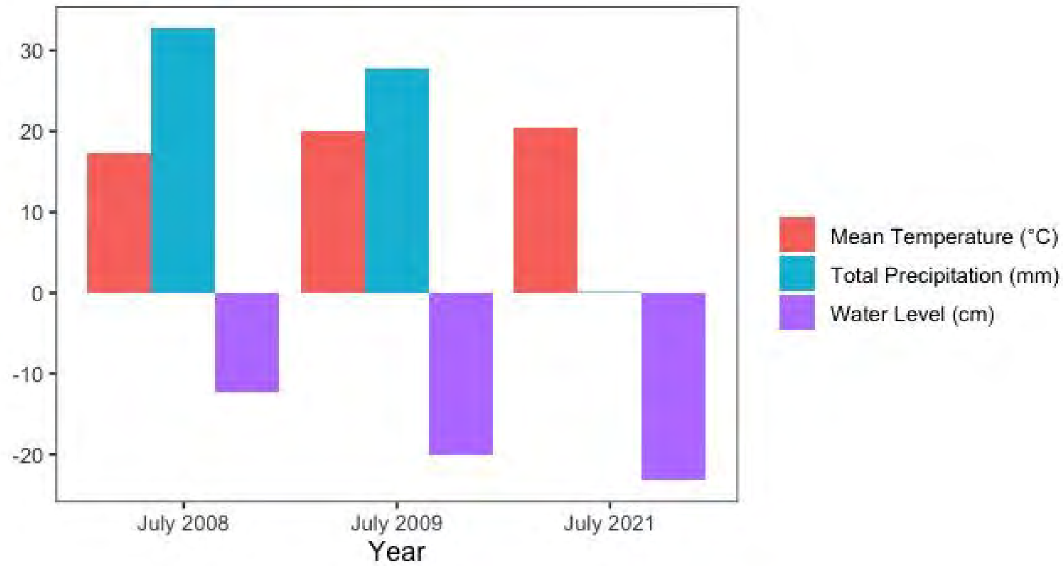

Figure 2-16. Total precipitation, mean temperature, and mean water level for 12 wells in Langley Bog, Langley Township, BC. Data were collected in July 2008, 2009, and 2021.

2.9. Project Budget

Table 1. Project budget for restoration plan of Langley Bog, Langley Township, BC. Prices in CAD.

Item(s)	Vendor	Units	Cost/Unit	Cost
Debris Removal				
30 yard bin, 2 ton capacity	Trash King	2	$695	$1,390
Tire removal	Trash King	16	$25	$400
Excavator and operator	Bobcat Rental	4 hrs	$75	$300
Total				$2190
Invasive Species				
1/4" Rubber sheet, 36" x 10 ft	Grainger Canada	1	$616	$616
Wooden stakes 1x48", Box of 25	Home Depot	1	$41	$41
P. contorta, #25 container	NATS Nursery	588	$12.60	$7,408
Japanese knotweed stem injection 1st year	Summit Earthworks	1	$7,070	$7,070
Japanese knotweed stem injection 2nd year	Summit Earthworks	1	$3535	$3,535
Removal of plants	Summit Earthworks	$137m^2$	$16	$2,192
Total				$20,862
Moss Reintroduction				
Botanist		360 hrs	$25	$9000

Total				$9000
Tree Removal				
Tree removal phase I	Diamondhead Tree Care	5	$2,040	$10,200
Wood processing	Diamondhead Tree Care	7	$3,400	$23,800
Bobcat rental	Diamondhead Tree Care	7	$550	$3,850
Delivery	Diamondhead Tree Care	1	$600	$600
Haul debris	Diamondhead Tree Care	1	$400	$400
Tree removal phase II	Assertive Demolition Ltd.	1	$17,000	$17,000
Total				$55,850
Berm Installation				
Mobilization/Demobilization	Summit Earthworks	1	$4,000	$4,000
Temp culvert crossing	Summit Earthworks	1	$4,245	$4,245
Berm, peat fill, pit run, 3-8" rip rap armor	Summit Earthworks	$300m^2$	$56	$16,800
Growing medium, 24" depth	Summit Earthworks	$240yrd^3$	$41.30	$9,912
Planting, #1 containers	Summit Earthworks	$300m^2$	$15.15	$4,545
Total				$39,502
Culvert installation				
Culvert purchase and installation	Valleyside Contracting	25	$500	$12,500
Total				$12,500
Project Subtotal				$139,904
GST (5%)				$6,995
PST (7%)				$9,793
Contingency (15%)				$20,985
Project Total				$177,678

2.10. References

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Appendix A. Fauna List for Langley Bog

Table A-1. Fauna list for Langley Bog, Langley Township BC. Data collected between November 2020 to 2021.

Species	Common Name
Birds	
Aix sponsa	Wood duck
Antigone canadensis	Sandhill crane
Ardea herodias	Great blue heron
Bombycilla cedrorum	Cedar waxwing
Branta canadensis	Canada goose
Calypte anna	Anna's hummingbird
Cathartes aura	Turkey vulture
Charadrius vociferus	Killdeer
Chordeiles minor	Common nighthawk
Colaptes auratus	Northern flicker
Corvus brachyrhynchos	American crow
Corvus corax	American raven
Cyanocitta stelleri	Steller's jay
Dryobates pubescens	Downy woodpecker
Dryocopus pileatus	Pileated woodpecker
Empidonax difficilis	Pacific-slope flycatcher
Empidonax traillii	Willow flycatcher
Geothlypis trichas	Common yellowthroat
Junco hyemalis	Dark-eyed junco
Larus glaucescens	Glaucous-winged gull
Leiothlypis celata	Orange-crowned warbler
Melospiza melodia	Song sparrow
Melospiza lincolnii	Lincoln's sparrow
Myadestes townsendi	Townsend's solitaire
Pheucticus melanocephalus	Black-headed grosbeak
Pipilo maculatus	Spotted towhee
Poecile atricapillus	Black-capped chickadee
Psaltriparus minimus	Bushtit
Regulus satrapa	Golden crowned kinglet
Sitta canadensis	Red-breasted nuthatch
Spinus tristis	American goldfinch
Sturnus vulgaris	European starling
Tachycineta bicolor	Tree swallow
Troglodytes pacificus	Pacific wren

Turdus migratorius	American robin
Vireo gilvus	Warbling vireo
Zonotrichia leucophrys	White-crowned sparrow
Mammals	
Canis latrans	Coyote
Castor canadensis	American beaver
Odocoileus hemionus	Black tailed deer
Peromyscus maniculatus	Deer mouse
Procyon lotor	Raccoon
Ursus americanus	American black bear
Amphibians/Reptiles	
Lithobates clamitans	Green frog
Thamnophis sirtalis	Common garter snake

Appendix B. Flora List for Langley Bog

Table B-1. Flora list for Langley Bog, Langley Township BC. Data collected between November 2020 - 2021.

Scientific Name	Common Name	Family	Status
Trees			
Acer rubrum	Scarlet maple	Aceraceae	Introduced
Alnus rubra	Red alder	Betulaceae	Native
Betula pendula	Silver birch	Betulaceae	Introduced
Betula papyrifera	Paper birch	Betulaceae	Native
Corylus cornuta	Beaked hazelnut	Betulaceae	Native
Thuja plicata	Western red cedar	Cupressaceae	Native
Picea sitchensis	Sitka spruce	Pinaceae	Native
Pinus contorta var. contorta	Lodgepole pine	Pinaceae	Native
Tsuga heterophylla	Western hemlock	Pinaceae	Native
Rhamnus purshiana	Cascara	Rhamnaceae	Native
Malus fusca	Pacific crab apple	Rosaceae	Native
Crataegus suksdorfii	Black hawthorn	Rosaceae	Native
Crataegus monogyna	Common hawthorn	Rosaceae	Introduced
Sorbus aucuparia	Rowan ash	Rosaceae	Introduced
Populus balsamifera ssp.trichocarpa	Black cottonwood	Salicaceae	Native
Populus tremuloides	Trembling aspen	Salicaceae	Native
Salix hookeriana	Hooker's willow	Salicaceae	Native
Salix scouleriana	Scouler's willow	Salicaceae	Native
Salix sitchensis	Sitka willow	Salicaceae	Native
Shrubs			
Ilex aquifolium	Holly	Aquifoliaceae	Introduced
Sambucus racemosa	Red elderberry	Caprifoliaceae	Native
Andromeda polifolia var. polifolia	Bog rosemary	Ericaceae	Native
Calluna vulgaris	Heather	Ericaceae	Introduced
Gaultheria shallon	Salal	Ericaceae	Native
Kalmia angustifolia	Eastern bog laurel	Ericaceae	Introduced
Kalmia microphylla ssp. Occidentalis	Western bog laurel	Ericaceae	Native
Vaccinium macrocarpon	Eastern cranberry	Ericaceae	Introduced
Rhododendron ferruginea	False huckleberry	Ericaceae	Native
Rhododendron groenlandicum	Labrador Tea	Ericaceae	Native
Vaccinium corymbosum	High bush blueberry	Ericaceae	Introduced

Vaccinium myrtilloides	Velvet-leaved blueberry	Ericaceae	Native
Vaccinium ovalifolium	Oval-leaved blueberry	Ericaceae	Native
Vaccinium oxycoccos	Bog cranberry	Ericaceae	Native
Vaccinium parvifolium	Red huckleberry	Ericaceae	Native
Vaccinium uliginosum ssp. Occidentale	Bog blueberry	Ericaceae	Native
Cystisus scoparius	Scotch broom	Fabaceae	Invasive
Myrica gale	Sweet gale	Myricaceae	Native
Rubus allegheniensis var. allegheniensis	Allegheny blueberry	Rosaceae	Introduced
Rubus laciniatus	Evergreen blackberry	Rosaceae	Introduced
Spiraea douglasii	Hardhack	Rosaceae	Native
Rubus spectabilis	Salmonberry	Rosaceae	Native
Rosa nutkana	Nootka rose	Rosaceae	Native
Rubus armeniacus	Himalayan blackberry	Rosaceae	Invasive

Forbs

Alisma lanceolatum	Lance leaved water plantain	Alismataceae	Introduced
Lysichiton americanus	Western skunk cabbage	Araceae	Native
Bidens cernua	Nodding beggarticks	Asteraceae	Native
Bidens connata	Purplestem beggarticks	Asteraceae	Introduced
Bidens frondosa	Common beggarticks	Asteraceae	Introduced
Bidens tripartita	Three parted beggarticks	Asteraceae	Introduced
Brasenia schreberi	Water shield	Cabombaceae	Native
Cornus canadensis	Bunchberry	Cornaceae	Native
Drosera anglica	Great sundew	Droseraceae	Native
Drosera intermedia	Spoonleaf sundew	Droseraceae	Introduced
Drosera rotundifolia	Round leaved sundew	Droseraceae	Native
Epilobium angustifolium	Fireweed	Onagraceae	Native
Epilobium ciliatum	Willowherb	Onagraceae	Native
Fallopia japonica	Japanese knotweed	Polygonaceae	Invasive
Galeopsis tetrahit	Hemp nettle	Lamiaceae	Introduced
Galium trifidum ssp. Columbianum	Small bedstraw	Rubiaceae	Native
Hypericum boreale	Northern St Johns Wort	Clusiaceae	Introduced
Hypericum perforatum	Common St Johns Wort	Clusiaceae	Introduced
Iris pseudacorus	Yellow flag iris	Iridaceae	Invasive
Ludwigia palustris	Water purslane	Onagraceae	Native
Lycopus uniflorus	Northern water hound	Lamiaceae	Native
Lysimachia terrestris	Bog loosestrife	Primulaceae	Introduced
Lysimachia thyrsiflora	Tufted loosestrife	Primulaceae	Native
Lythrum salicaria	Purple loosestrife	Lythraceae	Invasive
Maianthemum dilatatum	False lily of the valley	Liliaceae	Native

Myosotis laxa	Small flowered forget me not	Boraginaceae	Native
Myosotis scorpioides	European forget me not	Boraginaceae	Introduced
Nuphar polysepala	Yellow pond lily	Nymphaceae	Native
Polygonum convolvulus	Blind bindweed	Polygonaceae	Introduced
Polygonum hydropiperoides	Water pepper	Polygonaceae	Native
Polygonum lapathifolium	Willow weed	Polygonaceae	Introduced
Rubus chamaemorus	Cloudberry	Rosaceae	Native
Scheuchzeria palustris	Scheuchzeria	Scheuchzeriaceae	Native
Scutellaria lateriflora	Blue skullcap	Lamiaceae	Native
Solanum dulcamara	European bittersweet	Solanaceae	Introduced
Sparganium emersum	Emersed bur reed	Sparganiaceae	Native
Spiranthes romanzoffiana	Hooded ladies tresses	Orchidaceae	Native
Taraxacum officinale	Common dandelion	Asteraceae	Introduced
Triadenum fraseri	Eastern bog St Johns Wort	Clusiaceae	Introduced
Trientalis europaea ssp. Arctica	Northern star flower	Primulaceae	Native
Utricularia gibba	Humped bladderwort	Lentibulariaceae	Native
Veronica beccabunga var. americana	American speedwell	Scrophulariaceae	Native
Veronica scutellata	Marsh speedwell	Scrophulariaceae	Native
Viola lanceolata ssp. Lanceolata	Lance leaved violet	Violaceae	Introduced

Graminoids

Carex amplifolia	Bigleaf sedge	Cyperaceae	Native
Carex aquatilis var. aquatilis	Water sedge	Cyperaceae	Native
Carex arcta	Northern clustered sedge	Cyperaceae	Native
Carex canescens	Grey sedge	Cyperaceae	Native
Carex deweyana	Dewey's sedge	Cyperaceae	Native
Carex exsiccata	Inflated sedge	Cyperaceae	Native
Carex interior	Inland sedge	Cyperaceae	Native
Carex lenticularis var. lipocarpa	Kellogg's sedge	Cyperaceae	Native
Carex magellanica ssp. irrigua	Poor sedge	Cyperaceae	Native
Carex obnupta	Slough sedge	Cyperaceae	Native
Carex pachystachya	Thick-headed sedge	Cyperaceae	Native
Carex pauciflora	Few-flowered sedge	Cyperaceae	Native
Carex rossii	Ross' sedge	Cyperaceae	Native
Carex scoparia	Pointed broom sedge	Cyperaceae	Native
Carex siccata	Bronze sedge	Cyperaceae	Native
Carex sitchensis	Sitka sedge	Cyperaceae	Native
Carex stipata var. stipata	Awl-fruited sedge	Cyperaceae	Native

Carex utriculata	Beaked sedge	Cyperaceae	Native
Cyperus esculentus var. leptostachyus		Cyperaceae	Introduced
Dulichium arundinaceum	Three-way sedge	Cyperaceae	Native
Eleocharis acicularis	Needle spike rush	Cyperaceae	Native
Eleocharis obtusa	Blunt spike rush	Cyperaceae	Native
Eriophorum chamissonis var. chamissonis	Chamissos cotton grass	Cyperaceae	Native
Eriophorum virginicum	Tawny cotton grass	Cyperaceae	Introduced
Rhynchospora alba	White beak sedge	Cyperaceae	Native
Scirpus atrocinctus	Wool grass	Cyperaceae	Native
Scirpus microcarpus	Small flowered bulrush	Cyperaceae	Native
Juncus acuminatus	Tapered rush	Juncaceae	Native
Juncus articulatus	Jointed rush	Juncaceae	Native
Juncus bulbosus	Bulbous rush	Juncaceae	Introduced
Juncus canadensis	Canadian rush	Juncaceae	Introduced
Juncus conglomeratus	Compact rush	Juncaceae	Introduced
Juncus effusus	Common rush	Juncaceae	Native
Juncus ensifolius var. ensifolius	Dagger leaf rush	Juncaceae	Native
Juncus pelocarpus	Brown fruit rush	Juncaceae	Introduced
Juncus tenuis	Slender rush	Juncaceae	Native
Agrostis oregonensis	Oregon bent grass	Poaceae	Native
Echinochloa crusgalli	Large barnyard grass	Poaceae	Introduced
Glyceria maxima	Giant mannagrass	Poaceae	Introduced
Leersia oryzoides	Rice grass	Poaceae	Native
Panicum capillare	Common witch grass	Poaceae	Native
Panicum dichotomiflorum	Smooth witch grass	Poaceae	Introduced
Phalaris arundinacea	Reed canary grass	Poaceae	Native
Typha latifolia	Cattail	Typhaceae	Native

Ferns & Horsetails

Blechnum spicant	Deer fern	Blechnaceae	Native
Pteridium aquilinum	Bracken fern	Dennstaedtiaceae	Native
Athyrium felix-femina var. cyclosorum	Lady fern	Dryopteridaceae	Native
Dryopteris carthusiana	Toothed wood fern	Dryopteridaceae	Native
Dryopteris expansa	Wood fern	Dryopteridaceae	Native
Polystichum munitum	Sword fern	Dryopteridaceae	Native
Equisetum arvense	Common horsetail	Equisetaceae	Native
Equisetum fluviatile	Swamp horsetail	Equisetaceae	Native

True Mosses

Aulacomnium palustre	Glow moss	Aulacomniaceae	Native

Climacium dendroides	Tree moss	Climaciaceae	Native
Dicranum scoparium	Broom moss	Dicranaceae	Native
Dicranum undulatum	Waved fork moss	Dicranaceae	Native
Hylocomium splendens	Stair step moss	Hylocomiaceae	Native
Pleurozium schreberi	Red-stemmed feathermoss	Hylocomiaceae	Native
Rhytidiadelphus loreus	Lanky moss	Hylocomiaceae	Native
Rhytidiadelphus triquetrus	Goose necked moss	Hylocomiaceae	Native
Calliergonella cuspidata	Spear moss	Hypnaceae	Native
Campylopus introflexus	Heath star moss	Leucobryaceae	Introduced
Plagiothecium undulatum	Wavy leaved cotton moss	Plagiotheciaceae	Native
Polytrichum commune	Common haircap moss	Polytrichaceae	Native
Polytrichum longisetum	Slender haircap moss	Polytrichaceae	Native
Polytrichum piliferum	Awned haircap moss	Polytrichaceae	Native
Polytrichum strictum	Bog haircap moss	Polytrichaceae	Native

Peat Mosses

Sphagnum andersonianum		Acutifolia	Native
Sphagnum capillifolium	Small red peat moss	Acutifolia	Native
Sphagnum fimbriatum	Fringed bogmoss	Acutifolia	Native
Sphagnum fuscum	Rusty bog moss	Acutifolia	Native
Sphagnum rubiginosum		Acutifolia	Native
Sphagnum subnitens		Acutifolia	Native
Sphagnum angustifolium	Yellow-green peat moss	Cuspidata	Native
Sphagnum cuspidatum	Feathery bog moss	Cuspidata	Introduced
Sphagnum majus	Olive bog moss	Cuspidata	Introduced
Sphagnum mendocinum	Mendocino sphagnum	Cuspidata	Native
Sphagnum pacificum	Pacific sphagnum	Cuspidata	Native
Sphagnum tenellum	Soft bog moss	Cuspidata	Native
Sphagnum compactum	Cushion peat moss	Rigida	Native
Sphagnum austinii	Austin's sphagnum	Sphagnum	Native
Sphagnum henryense	Henry's sphagnum	Sphagnum	Native
Sphagnum inexspectatum		Subsecunda	Native
Sphagnum magellanicum	Magellan's bog moss	Sphagnum	Native
Sphagnum palustre	Blunt-leaf bog moss	Sphagnum	Native
Sphagnum papillosum	Fat bog moss	Sphagnum	Native
Sphagnum squarrosum	Spread-leaved peat moss	Squarrosa	Native

Appendix C: Permits and Approvals

Langley Bog is managed by Metro Vancouver, and in-park activities are regulated by the Greater Vancouver Regional District Bylaw No. 1177. Individuals cannot excavate soil, remove vegetation, or add living vegetation without approval from Metro Vancouver (Metro Vancouver 2012). Before issuing a permit, Metro Vancouver would perform a desktop-based archaeological review using internal databases that map sensitive sites in the park (L Mynott, 2021, pers. comm.).

While Langley Bog is physically separated from Coast Cranberries Ltd. by roads and ditches, these barriers do not align with official property boundaries. Legally the invasive species found on the western boundary of Langley Bog are on Coast Cranberries Ltd. property, and the access road used by the cranberry farmers is on Metro Vancouver property (Figure C-1). Building of the berm to prevent water loss and the removal of invasive species along the property line therefore requires approval from Coast Cranberries Ltd.

Figure C-1. Property boundaries surrounding Langley Bog, Langley Township BC. Pink lines represent boundary line.

Confirmation has been made of greater sandhill cranes (*Antigone canadensis*) nesting in Langley Bog (Greater Vancouver Regional Parks Department 1996). Because they are a migratory species in the family Gruidae, crane nests are protected under the Migratory Birds Convention Act and it is prohibited for any restoration activity to impact nests either by removing them or “depositing a substance that is harmful to migratory birds” (Government of Canada 1994).

Under the BC Water Sustainability Act (WSA), the construction of the berm will require a Notification of Authorized Changes in and About a Stream. The WSA requires approval for any activity that “may or may not have an impact on a stream or stream channel” (Government of British Columbia 2021d) McQuatt ditch is considered a “stream” as it is a natural source of ground water supply.

Langley Bog is protected by the Heritage Conservation Act, which does not allow for any alteration of a site that “contains artifacts, features, materials or other physical evidence of human habitation or use before 1846” (Government of British Columbia 2021a). Derby Reach Regional Park is a provincially-designated heritage area for its location as an initial contact site between Euro-Americans and Sto’:lo culture (Greater Vancouver Regional Parks Department 1996). If Metro Vancouver deems the proposed restoration work to be a high risk to the heritage area, an archaeologist will be hired to submit a Heritage Inspection Permit Section 14, which may, depending on the archaeologist’s findings, require archeological monitoring of restoration work. After restoration work is complete, the archeologist will submit a report to the BC Archaeology Branch with any findings. If Metro Vancouver deems the proposed restoration work to be a low risk to the heritage area, all contractors will take Chance Find training to ensure any uncovered artifacts are protected (Government of British Columbia, n.d.). Given that Langley Bog was a former industrial site and has already been mined, the risk is expected to be low (L Mynott, 2021, pers. comm.).

The Integrated Pest Management Act prohibits the use of pesticides within 10 m of a body of water and dry stream (BC Ministry of Environment 2009). If glyphosate is being used for the purposes of noxious weed removal, this buffer can be reduced to 1 m if the application method is selective. Japanese knotweed, purple loosestrife, and yellow flag iris are all classified as noxious in BC (BC Ministry of Environment 2021).

As outlined in the Weed Control Act, Metro Vancouver Regional Parks is required to manage noxious weeds found on their land (BC Ministry of Environment 2021). Private landowners are also required to manage noxious weeds, so where Japanese knotweed, purple loosestrife, and yellow flag iris are found on Coast Cranberries Ltd property, they must either control for it or the government can do so and tax the owner (BC Ministry of Environment 2021).

According to the BC Wildlife Act (Section 34), it is a crime to injure, molest, or destroy a bird, egg, or occupied nest (Government of British Columbia 2021e). If tree removal takes places in Langley Bog during spring nesting season, all efforts must be made to identify active bird nests to avoid damage. Work must commence 24-48 hours after a nest survey has been completed.

Appendix D: Proposed Schedule

Table D-1. Schedule of restoration treatments for Langley Bog, Langley Township, BC.