The Burns Bog Lagg Zone: An Assessment of Hydrological and Biological Indicators in the Bog

Hannah Avenant
Cyra Canonizado
Robert Jacobson
Kevin Matsuo

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Sara Harris

ABSTRACT

In the Delta Nature Reserve (DNR), there have been observed changes in the hydrology and ecology. The intention of this community project in the DNR was to examine hydrological and biological indicators within the lagg zone in order to begin the establishment of a monitoring and restoration framework for the Burns Bog Conservation Society (BBCS) to pursue with the Corporation of Delta. Groundwater depth, pH, and electrical conductivity were assessed throughout the area to test whether these values fell within regularly observed ranges for a lagg zone. Along with hydrology, percent cover of understorey species was studied to quantify the effects that trampling by humans and dogs may have on the ecosystem. Finally, a literature review was completed to determine potential methods of invasive species removal within the DNR to find viable options for the BBCS. Spatial patterns in groundwater depth and pH suggested heavy mineral water input from flooding by the stream in the northeast, but additional dipwells should be installed near it to make clearer conclusions. Through percent cover measurements near the boardwalk, it was determined that signage should be placed to dissuade patrons of the DNR from stepping off the boardwalk. Mowing or hand-pulling for policeman's helmet and mowing and mulching in combination for reed canary grass are the most feasible management methods. A long-term monitoring plan should be implemented to assess hydrological and ecological parameters, with measurements at least monthly to account for seasonal variation while still maintaining feasible monitoring intervals for the BBCS.

AUTHOR BIOS

Hannah Avenant is a 4th year Environmental Sciences student at UBC, with a concentration of Ecology and Conservation. In the summer of 2016, she worked as a Research Assistant for Agriculture and Agri-food Canada in the Insect Pest Lab. Her interests include plant biology and marine conservation.

Cyra Canonizado is a 4th year Environmental Sciences student at the University of British Columbia, concentrating on Land, Air and Water. She has knowledge in a variety of areas including oceanography, soil science, hydrology, and environmental chemistry. Her technical skills include chemical analysis using analytical chemistry methods and data analysis through Excel and Matlab.

Robert Jacobson is a 4th-year Environmental Sciences student at the University of British Columbia, with a focus on ecology and conservation. An outdoor enthusiast, he plans to pursue further studies and work in the field of ecological restoration after graduating from UBC.

Kevin Matsuo is a 4th year Environmental Sciences student at the University of British Columbia, concentrating on Land, Air and Water. He has experience in chemical and ecological lab and field work including relevant analytical methods from selected UBC courses.

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INTRODUCTION

Burns Bog, due to its hydrological, biological, and topographical features, is classified as a raised peat bog - the largest of its kind in western North America. The features Burns Bog displays include an internal water mound, nutrient-poor and acidic water sourced from precipitation, a two-layered composition, and peat-forming biological communities (Howie *et al.,* 2011). The two layers are the acrotelm, which is the living layer that includes *Sphagnum* mosses, and the catotelm, which is the dense peat that permanently resides underneath (Figure 1). The Burns Bog lagg zone covers most of the Delta Nature Reserve, and can be divided based on two plant communities: the *Spiraea* thicket lagg and Peaty forest lagg (Howie and van Meerveld, 2016). The lagg zone acts as a buffer between the higher nutrient waters surrounding the bog and the nutrient-poor waters within. This buffering system is crucial in maintaining the unique biological communities within the bog, such as *Sphagnum* moss mounds. Along with water chemistry, a high water table is critical to peat communities. Therefore, inflows of water from precipitation must meet water amounts lost to evaporation, transpiration, and runoff to maintain the communities (Howie *et al.,* 2009).

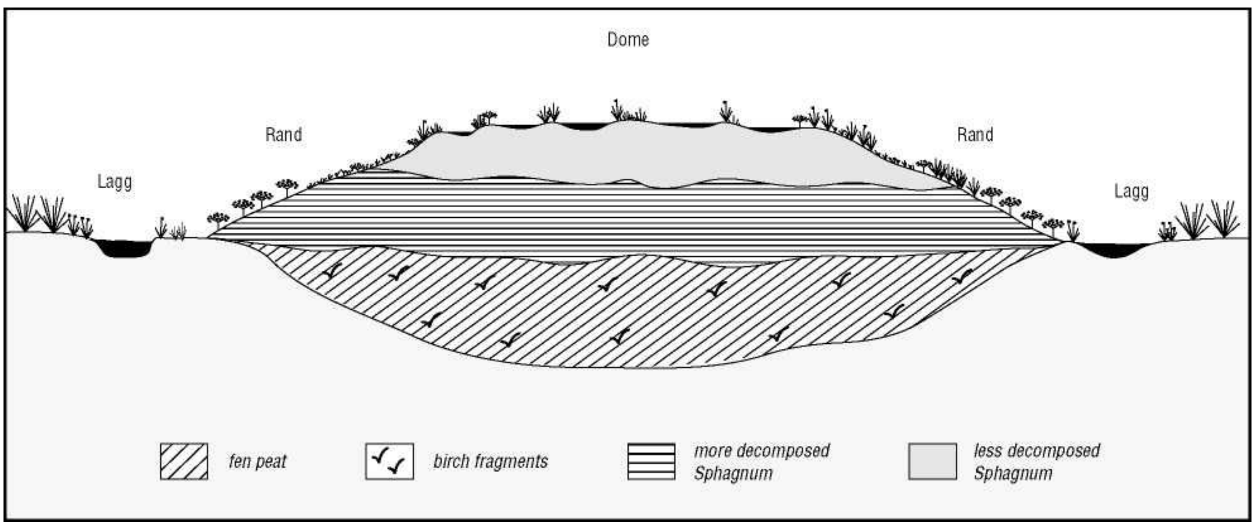


Figure 1. Diagram of a raised peat bog, as is Burns Bog in Delta, BC. Image retrieved from http://www.worldhistory.biz/sundries/43816-bogs-and-drainage.html.

Over the span of the UBC Environmental Sciences community project with the Burns Bog Conservation Society (BBCS), one focus was to begin monitoring the water table height, pH, and electrical conductivity of the groundwater within the Delta Nature Reserve. It had been observed that areas of the Delta Nature Reserve were drying out, and that salal was taking over areas previously inhabited by *Sphagnum* moss, an important bog species. Along with these two issues, high abundances of invasive species reed canary grass and policeman's helmet were observed along the periphery of the reserve. This project was completed to set a framework for the continued monitoring of the hydrology in the lagg zone of Burns Bog, as well as provide methods of invasive species removal for the BBCS. The pH and electrical conductivity are useful indicators for monitoring the ecological succession of the lagg zone in response to recovery efforts (Gorham *et al.,* 2003). There are several restoration strategies that focus on restoring the water table, including blocking ditches, bunds and terracing, and using mulch (Howie *et al.,* 2011). It is our hope that this foundation of data, along with a proposed plan for monitoring in the years to come, can be used to help educate others and preserve the Delta Nature Reserve.

Burns Bog is an ombrotrophic bog, therefore rain is its main source of water. However, years of urban and industrial development adjacent to the bog raise the possibility of contamination by external water sources, such as runoff. These external sources can significantly influence the mineral composition and water chemistry of the lagg zone (Howie *et al.*, 2009). The Burns Bog Conservation Society has raised concerns over changes that they have been noticing over the years, including the concern that some areas have become noticeably drier, *Sphagnum* moss is disappearing, and other species such as salal have begun to outcompete *Sphagnum*, as mentioned above. To address these concerns, we ask the following questions:

- How do the pH and electrical conductivity of the groundwater, as well as the depth to water table vary throughout the Delta Nature Reserve?
- Through spatial analysis of the hydrological factors pH, electrical conductivity, and groundwater level, how do potential outside water sources affect hydrological parameters of the Delta Nature Reserve?
- To what extent does trampling with increasing distance from the boardwalk affect change in species composition and vegetation percent cover in the Delta Nature Reserve?
- What are some feasible invasive species removal methods that can be applied by the Corporation of Delta in the Delta Nature Reserve?

By pursuing the first two questions, we can observe spatial distributions to determine if any patterns in hydrology could be the reason for the problems at hand. If we observe any deviations from expected patterns found in previous studies, we can explore the possibility of hydrology being altered by outside sources. Knowledge of the spatial distributions can help identify any problem areas that will need to be dealt with. Since hydrology plays a key role in maintaining the stability of the lagg zone's ecosystem (Howie *et al.*, 2009), regular monitoring of hydrology is essential to proper maintenance of the Delta Nature Reserve. Given that hydrology data in the Delta Nature Reserve is very fragmented, this project will mainly serve as baseline research for collecting hydrologic data that can be used in future monitoring and maintenance procedures.

In addition to the hydrology, human activity has the potential to alter the biology of the bog. The Burns Bog Conservation Society has also expressed concern about the disappearance of *Sphagnum* cover adjacent to the boardwalk. *Sphagnum* moss is a highly influential bog species, and is often referred to as the building block of the bog. Trampling, as a result of individuals stepping off of the boardwalk, is a strong possibility for the disappearance of *Sphagnum* moss; this possibility will be explored with the third research question. Sources of trampling damage can be from humans and/ or dogs venturing off the boardwalk into deeper and more sensitive areas of the Delta Nature Reserve. These mechanical disturbances can change the properties of soil components, but more importantly cause a detrimental reduction in plant cover as well as species composition of the plant community, increasing the risk of establishment of invasive species. Low-intensity trampling causes noticeable damage, while high-intensity trampling can reduce the *Sphagnum* cover into a layer of muck with no vegetation. Some studies show that *Sphagnum* cover can recover as quickly as after two years from ceasing the trampling disturbance. (Arnesen, 1999; Robroek *et al*., 2010).

The fourth research question in this report is the potential restoration of the Delta Nature Reserve, as well as the removal of invasive species along the stream banks on the periphery of the Reserve. In order to create the foundation of knowledge necessary to derive a restoration plan for the Delta Nature Reserve, a literature review was completed. The first item of concern within the Delta Nature Reserve is hydrological, as mentioned previously; it has been observed by members of the BBCS that parts of the ecosystem are drier than historically observed. This is problematic for many of the bog species that require an abundance of water to survive, such as *Sphagnum* moss. In the literature review, a goal was to research methods of bog water table restoration that have been previously utilized and pinpoint possible methods that could be successful in the Delta Nature Reserve. Another goal was to discover ways to restore *Sphagnum* community abundance in a bog environment.

The final part of the literature review aimed to address the matter of invasive species removal within the Delta Nature Reserve, specifically on the banks of the stream that flows there. The two main invasive species that have been observed are *Phalaris arundinacae,* or reed canary grass, and *Impatiens glandulifera,* or policeman's helmet. These two plant species display all of the qualities of an invasive species that make them difficult to eradicate - effective dispersal, fast reproduction, and quick growth rate. The process of complete removal of the two invasive species from the Delta Nature Reserve must also aim to minimize damage to the surrounding ecosystem. The literature review aimed to pinpoint both economically and ecologically feasible removal strategies of reed canary grass and policeman's helmet from the Delta Nature Reserve.

METHODS

Hydrology

Data Collection

Depth to water table, pH, and electrical conductivity were collected from eight pre-existing dipwells located throughout the Delta Nature Reserve (Figure 2). Seven were located using coordinates from Owen (2015), and one additional dipwell was found, which we identified as "Unmarked" (DW um). The dipwell marked "4" in Owen's study was inaccessible, and the one she marked as "V" could not be located due to snow. The dipwell marked "I" did not have a lid, so we covered the opening with duct tape.

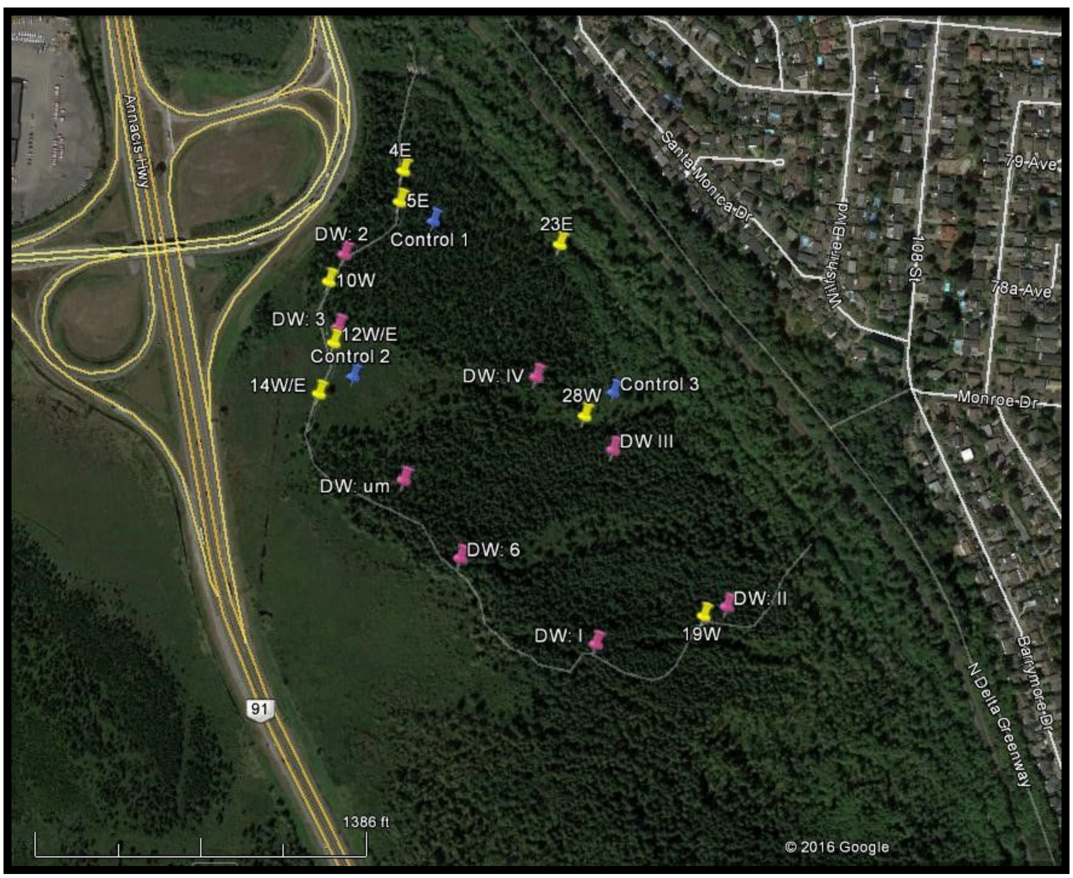


Figure 2. Sampling locations of transects (yellow), control transects (blue), and dipwells (pink) in the Delta Nature Reserve.

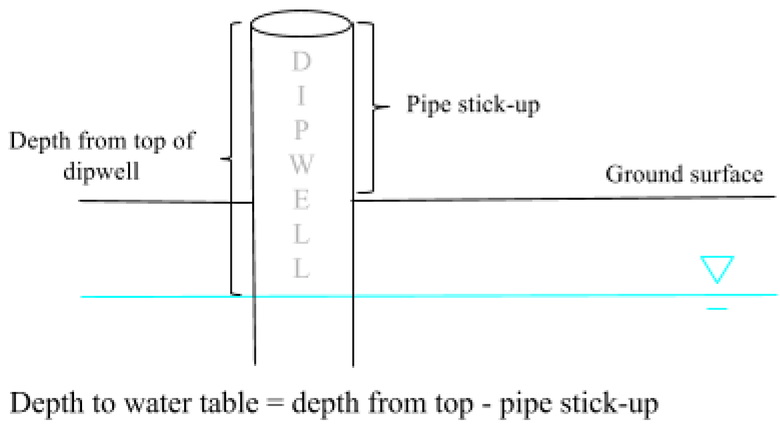


Figure 3. Diagram detailing calculation of depth to water table. Labels are shown for depth from top of dipwell (to the water table) and pipe-stickup. The blue line indicates the water table

As suggested by Howie (2012), one week prior to collecting the first samples, a peristaltic pump (Pegasus® Athena) was used for 30 minutes at 300mL/min to remove stagnant water in each dipwell, allowing them to be refreshed with groundwater. We took measurements a total of four times (January 14th, January 29th, February 11th, and March 5th, 2017), visiting the dipwells in the same order each time. To calculate the depth to water table from the surface, the pipe stick-up (height of each dipwell opening above the ground) was subtracted from the depth to the water table from the rim of the dipwell (Figure 3), as measured by an electric water level probe (Solinst® Model 101 Water Level Meter). pH and electrical conductivity were measured by directly inserting the probes into the dipwells (Oakton® pH 11/110 Handheld Meter; Oakton® Con 6 Handheld Meter). Coordinates for each dipwell were recorded from the compass app on an iPhone 6. After measurements were collected, each dipwell was pumped out for 20 minutes at 300mL/min..

Data Analysis

The mean values for each of the three parameters at each of the dipwells were mapped using ArcGIS 10.5. The data were loaded as XY data, converted to a point shapefile, and then a raster for each was interpolated using bilinear interpolation. To determine if the measurements taken at each dipwell formed a statistically significant spatial pattern, R (version 3.3.2) was used to conduct a Welch's ANOVA was for each of the three parameters, as the minimum and maximum variance among the groups for each parameter differed by more than a factor of four.

Trampling

Data Collection

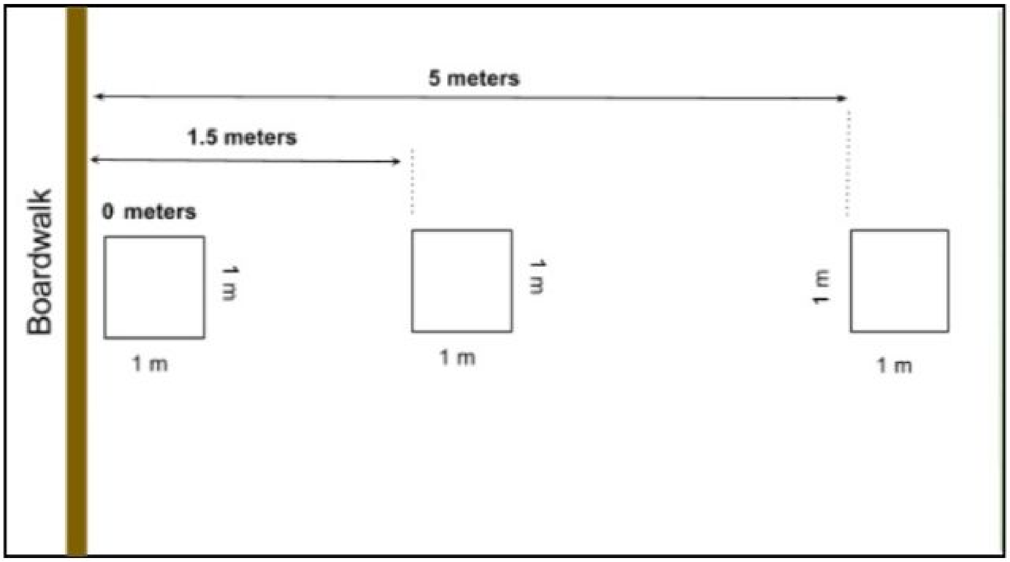


Figure 4. Diagram of $1m^2$ quadrats placed at different distances from the boardwalk.

To examine the possibility of the decrease in *Sphagnum* cover from trampling, 10 transects perpendicular to the trail 5-20 m apart were randomly allocated using MS Excel (Figure 2). 1 m x 1 m quadrats were used to create three plots along each transect. To enable sampling of 10 transects in the 3 distinctly different ecosystems of salal-rich, “bog”, and peat forest, transects were randomized to be placed in any ecosystem. The quadrats were placed along the transect at 0, 1.5, and 5 m away from the boardwalk (Figure 4). Three Control plots were each randomly placed 8 m away from the boardwalk in each ecosystem, with the assumption of no history of trampling. 8 m was selected for the control because accessibility at this distance is very low. Control 1 represents the salal-rich region, Control 2 is “bog” and Control 3 is peat forest. This led to a total of 30 plots, and three control plots. The distances between each plot were chosen to be used as a proxy for three trampling intensities (low, medium and high), with the assumption that trampling intensity will be higher adjacent to the boardwalk and lower at farther distances. The dominant species in each control (largest relative cover) were chosen as a representative species for trampling, this allowed a more consistent comparison between each ecosystem. species Percentage cover of different species were recorded and the species composition at the different quadrats were graphed. In addition, the relative cover of species were also calculated by:

$$\frac{\text{Sum of \% Species Cover on Trampled Plots}}{\text{Sum of \% Species Cover at Control}}$$

To determine the impact of trampling on species diversity, the Simpson's diversity index (D) was estimated using the following equation:

$$D = \sum_{i=1}^{S} \frac{n_i(n_i - 1)}{N(N-1)}$$

where *n* is the percent cover for species *i. S* is the number of species and *N* is total number of plants in the population. For this calculation, the distances at different transects in each ecosystem were grouped. This resulted to 4 diversity indices of each distance (including the control) for the 3 ecosystems.

Data Analysis

The standard error of the mean was calculated to estimate variability of the average percentage cover with increasing distance from boardwalk. Standard error bars that overlap between distances show no significant difference.

Invasive Species Removal Literature Review

To complete this literature review, peer-reviewed papers were compiled and read through in order to locate scientific research projects that assessed removal methods. Along with peer-reviewed papers, articles from cities that faced similar issues with the invasive species were read, as these articles often had valuable information about the use of different methods in a non-scientific context. Once these methods had been compiled, they were evaluated in the context of the Delta Nature Reserve to conclude if each method was a viable one for the area (Table 1). Findings were compiled into a literature review format; twenty sources in total were utilized to form practical removal methods for the two invasive species. Success of removal of invasive species is particular to size of stand and location.

Table 1. Literature review synopsis of methodology for removal of reed canary grass and policeman's helmet in the DNR.

Reed Canary Grass	
Removal Method	**Viable for DNR**
Hand-pulling	✓
Shading/Mulching	✓
Mowing	✓
Plowing	✗
Fire	✗
Herbicides	✗
Policeman's Helmet	
Removal Method	**Viable for DNR**
Hand-pulling	✓
Mowing	✓
Herbicides	✗

RESULTS

Hydrology

Spatial analyses revealed three different patterns for the measured water parameters. The water table was closest to the surface on the northeast side of the Delta Nature Reserve (Figure 5). The electrical conductivity was highest in the southern area of the Delta Nature Reserve (Figure 6), while pH showed an opposite pattern to that of the water table depth (Figure 7), being lowest in the south-east corner.

A Welch's ANOVA (Table 2) revealed that depth to water table, pH, and electrical conductivity all varied significantly between dipwells ($P=0.0072$, 0.034, 0.00024 respectively). For depth to water table, the dipwells in the north-west did not differ from any of the other dipwells, but several of the other dipwells differed from one another, though spatial groupings cannot be made (Figure 8). Dipwell I differed from dipwells in the north-west corner and some of the other western dipwells, having a much higher electrical conductivity (Figure 9). Dipwell I also had a lower pH on average than most of the other dipwells, which usually did not differ from one another (Figure 10).

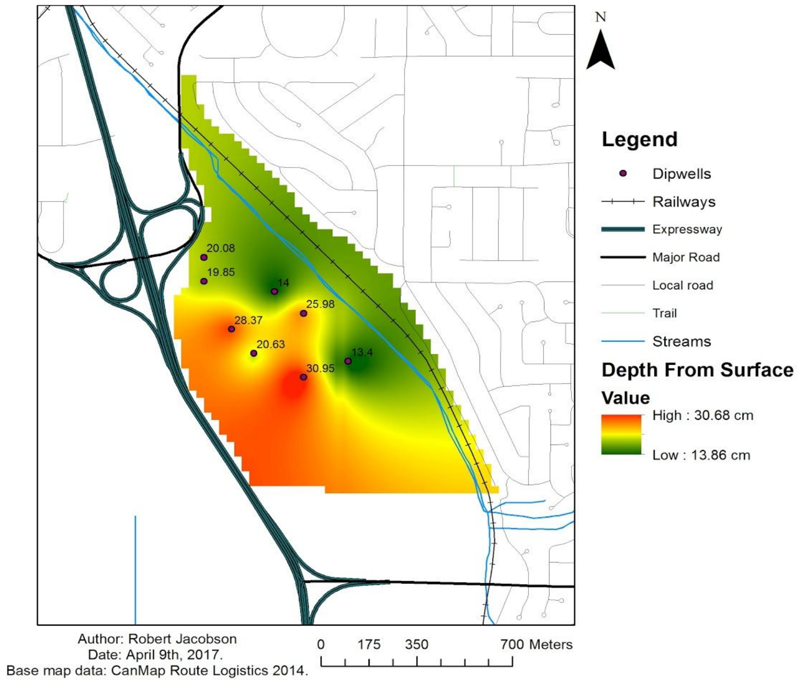


Figure 5. Average depth to water table from the surface of the ground. Lower depths (in green) are considered better values for the persistence of a bog. Measurements were taken in the Delta Nature Reserve biweekly from January to March 2017.

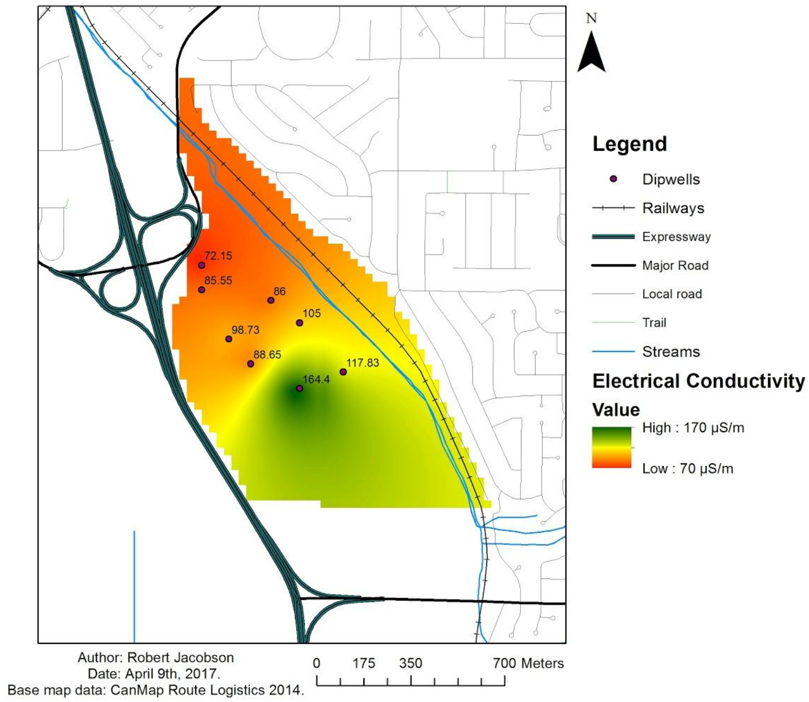


Figure 6. Average electrical conductivity of groundwater in Delta Nature Reserve. Higher EC values (in green) are usually better for a bog, as pH values further from 7 lead to more dissolved ions and thus higher electrical conductivity. Measurements were taken biweekly from January to March 2017.

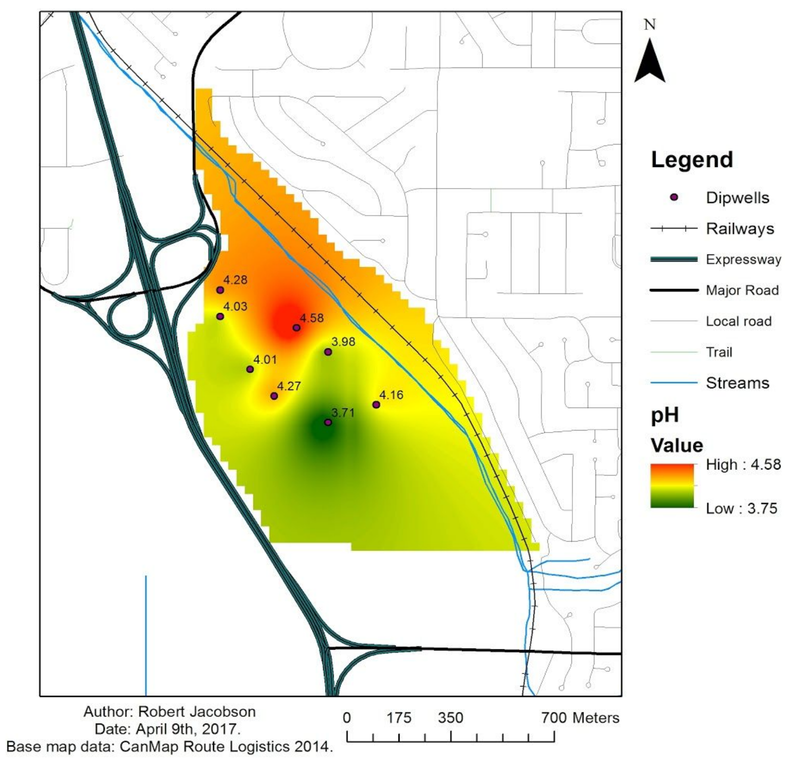


Figure 7. Average pH taken at dipwells throughout the Delta Nature Reserve biweekly from January to March 2017. Lower pH values (in green) are closer to standard bog values.

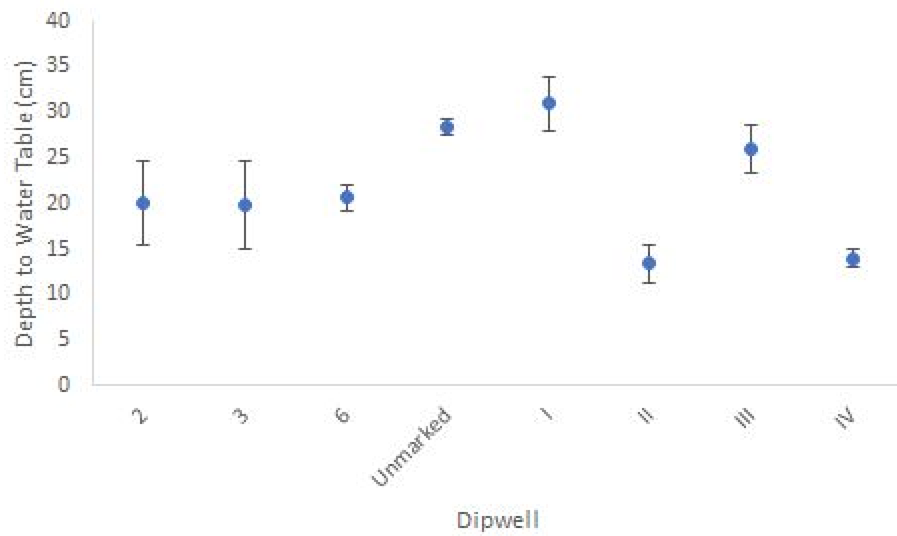


Figure 8. Mean depth to water table at various dipwells spread throughout the Delta Nature Reserve. N=4 for each group (except Unmarked, for which N=3). Error bars indicate standard error.

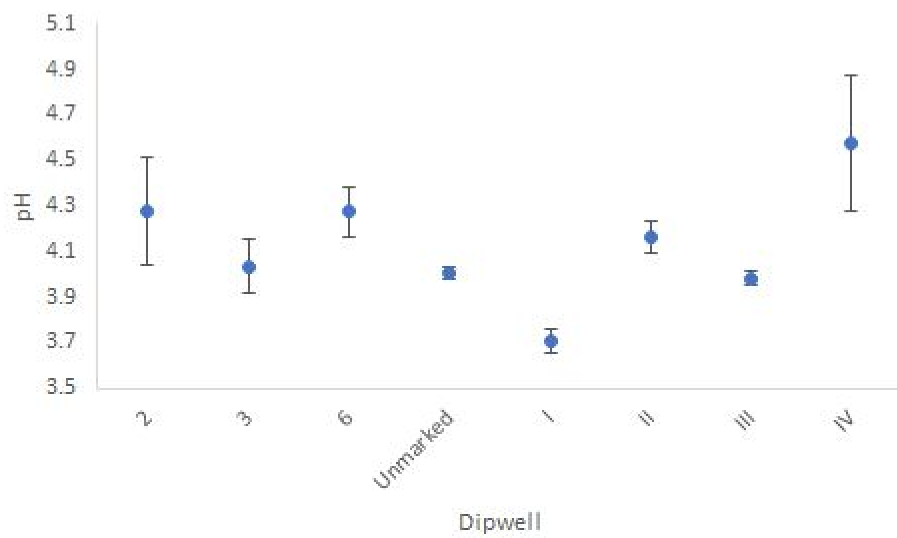


Figure 9. Mean pH values at various dipwells spread throughout the Delta Nature Reserve. N=3 for each group. Error bars indicate standard error.

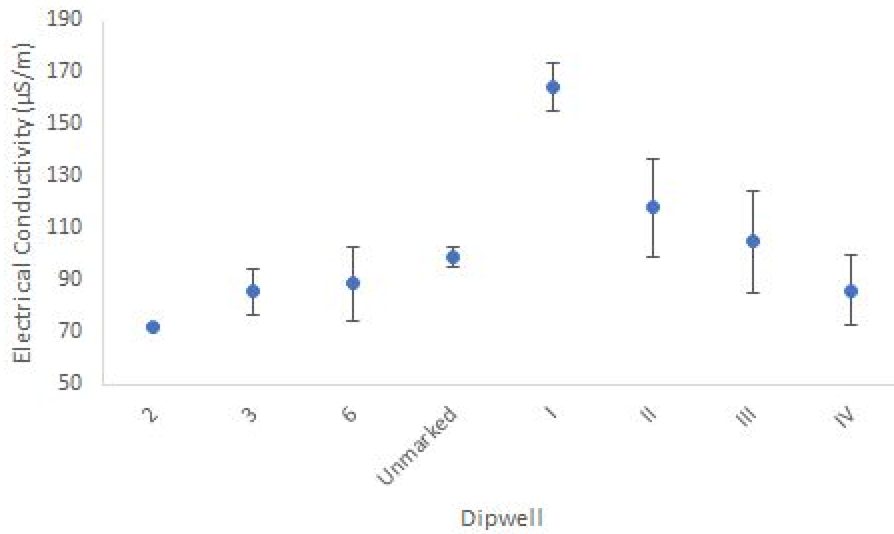


Figure 10. Mean electrical conductivity at various dipwells spread throughout the Delta Nature Reserve. N=4 for each group. Error bars indicate standard error.

Table 2. Results of a Welch's ANOVA for each of the three water parameters. There were 8 groups for each analysis. N=4 for depth (except for one group, which had N=3) and EC, and N=3 for pH.

Parameter	Numerator df	Denominator df	F-Value	P-Value
Water Table Depth	7	9.78	14.67	<0.01
pH	7	6.67	4.61	0.03
Electrical Conductivity	7	9.18	15.00	<0.01

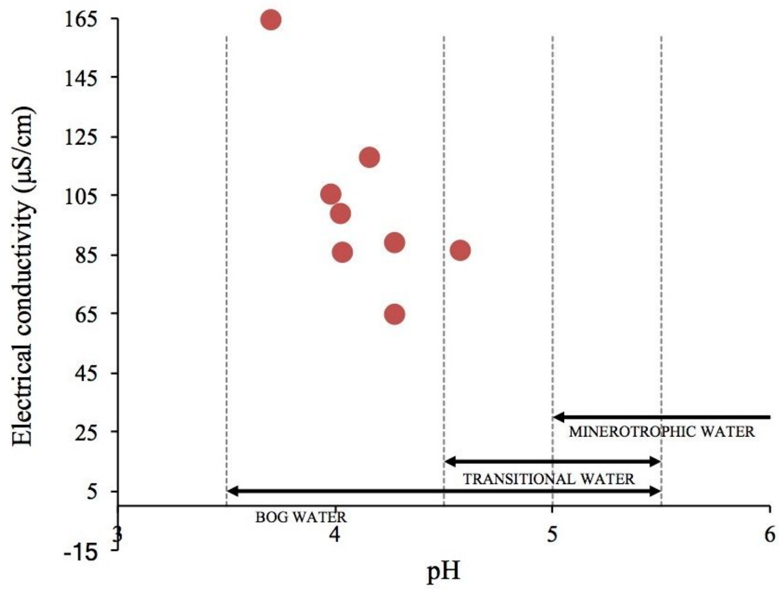


Figure 11. Mean pH vs mean electrical conductivity for all dipwells in the DNR. Ranges for different water types that were identified by Balfour and Banack (2000) and described in Howie and van Meerveld (2011) are indicated by double headed arrows: bog water (pH 3.5-5.5), transitional water (pH 4.5-6.0), and minerotrophic water (pH 5.0-8.0).

Figure 11 plots mean pH against mean electrical conductivity. Ranges for different water types (Balfour and Banack, 2000; Howie and van Meerveld, 2011) were indicated to provide a sense of where data points lie. Mean electrical conductivity values fell between 65 and 165 µS/cm, while mean pH recordings collected fell between 3.5 and 4.5, and are classified as “bog water” by Balfour and Banack (2000). No apparent correlation between pH and electrical conductivity was found.

Trampling

Selected species of each distinct ecosystem (Figure 13) show a weak pattern of increasing average percentage cover with distance from boardwalk. There is no statistical difference between the different distances from the boardwalk as suggested by standard error. However, there is a significant difference between the three distances from the boardwalk and their respective control (Figure 13). Similarly, there is also no statistical difference between distances from boardwalk for Simpson’s Diversity index (Figure 14). A Simpson’s Diversity Index of 1 suggest no diversity.

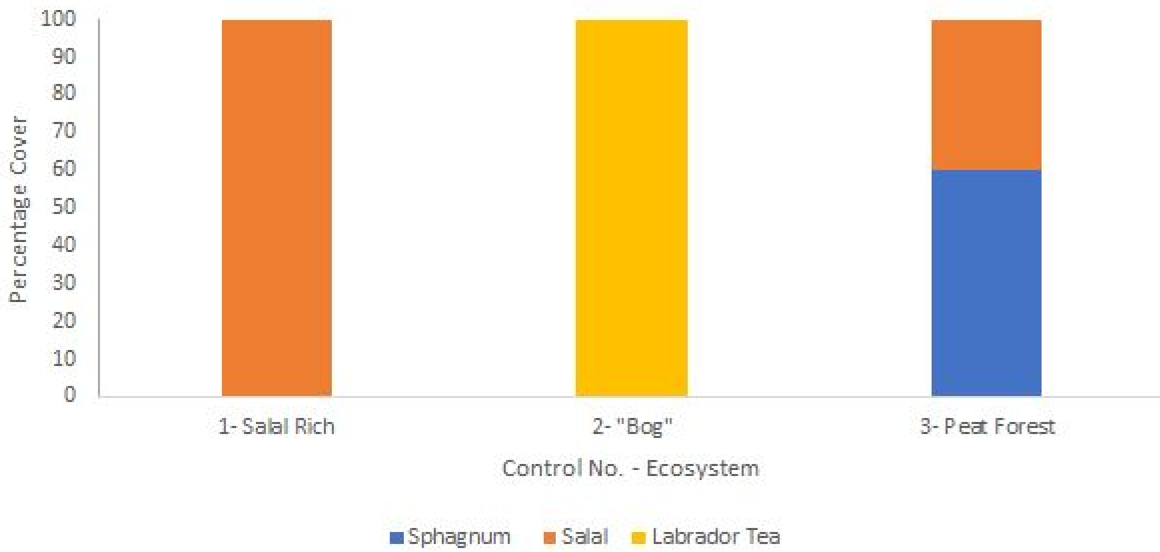
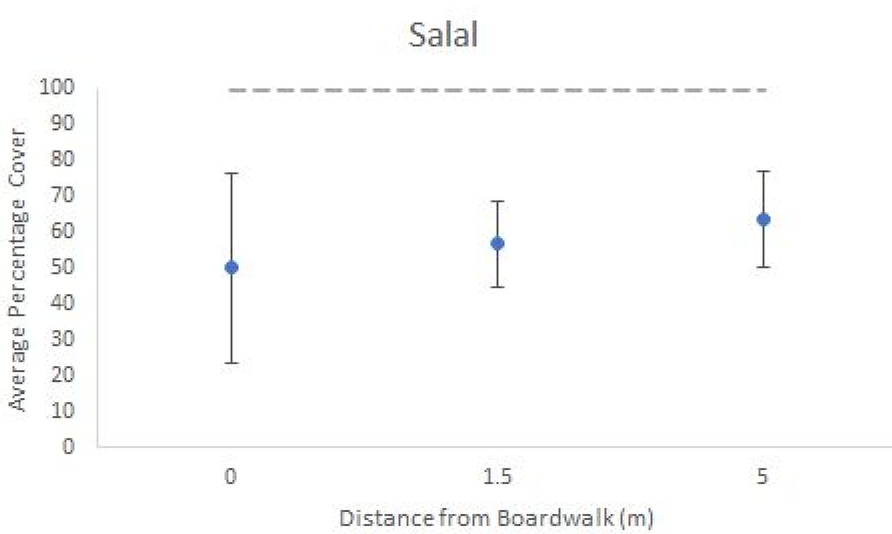
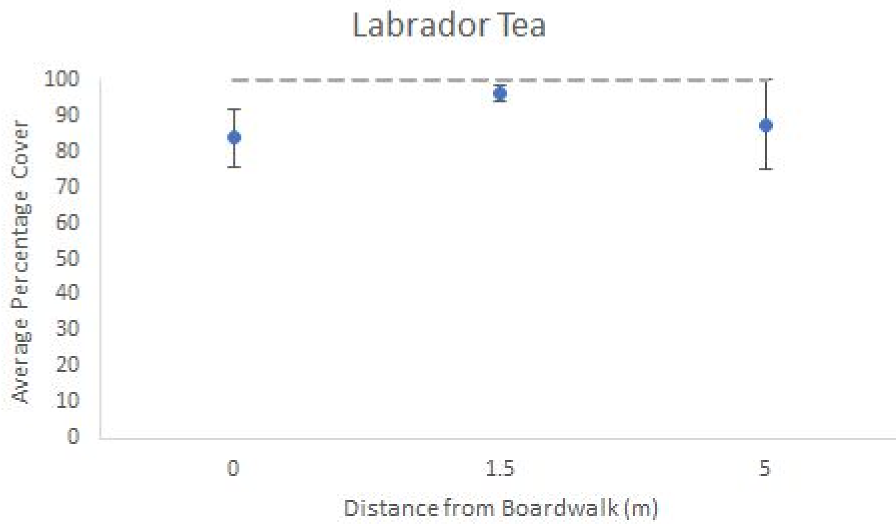


Figure 12. Species composition at 8 meters from the boardwalk of the 3 control groups, representing the 3 distinct ecosystems.



a



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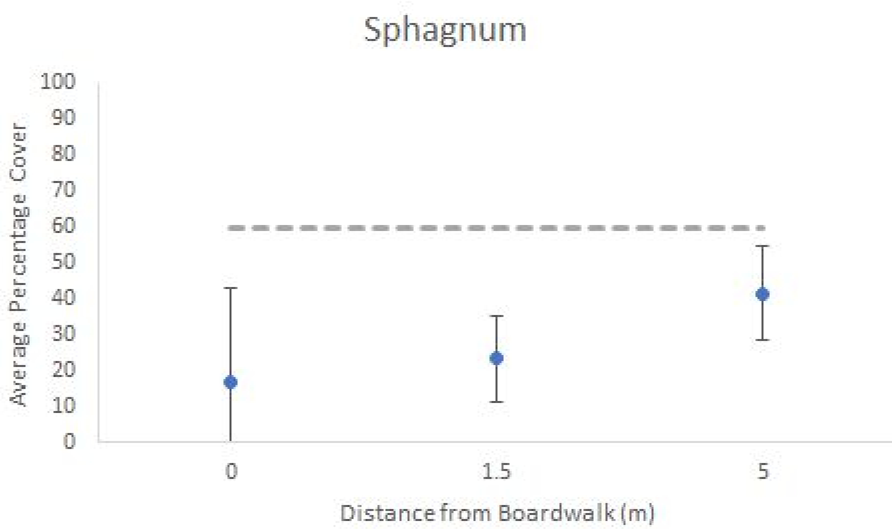

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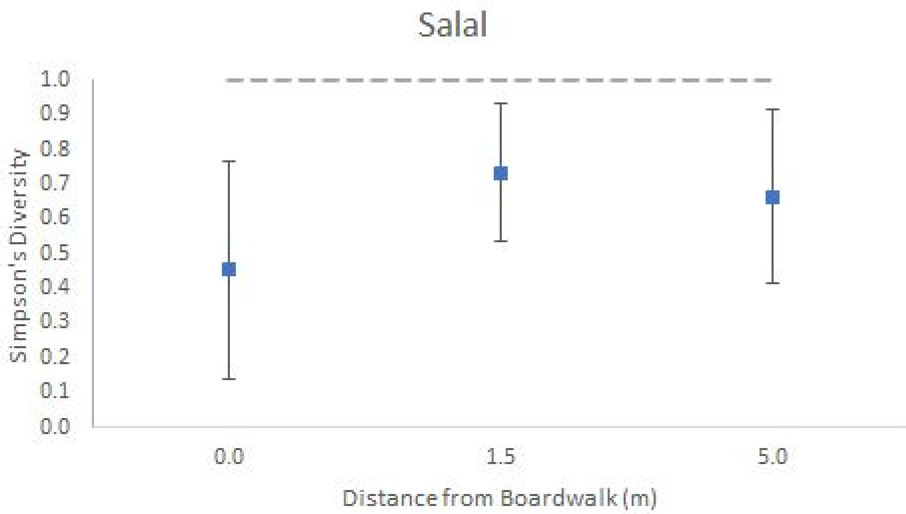
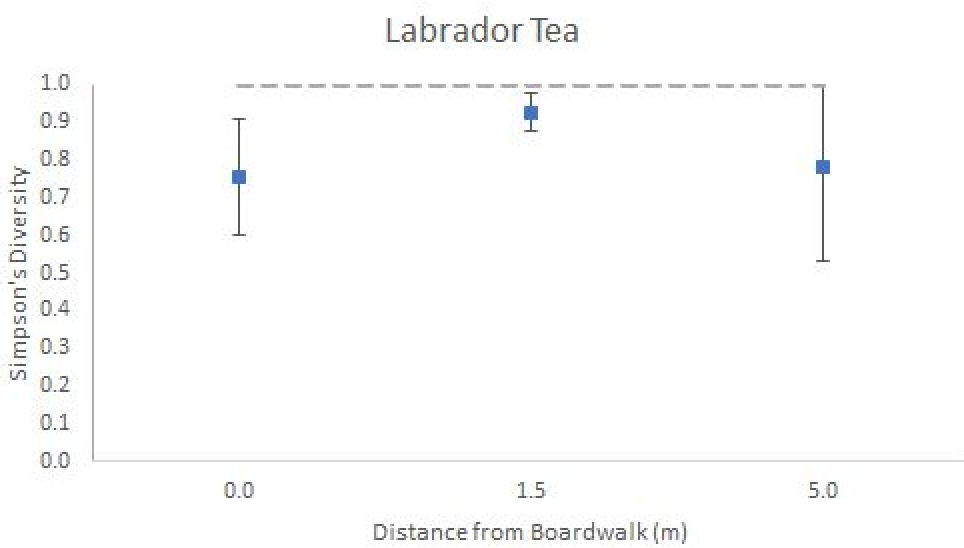
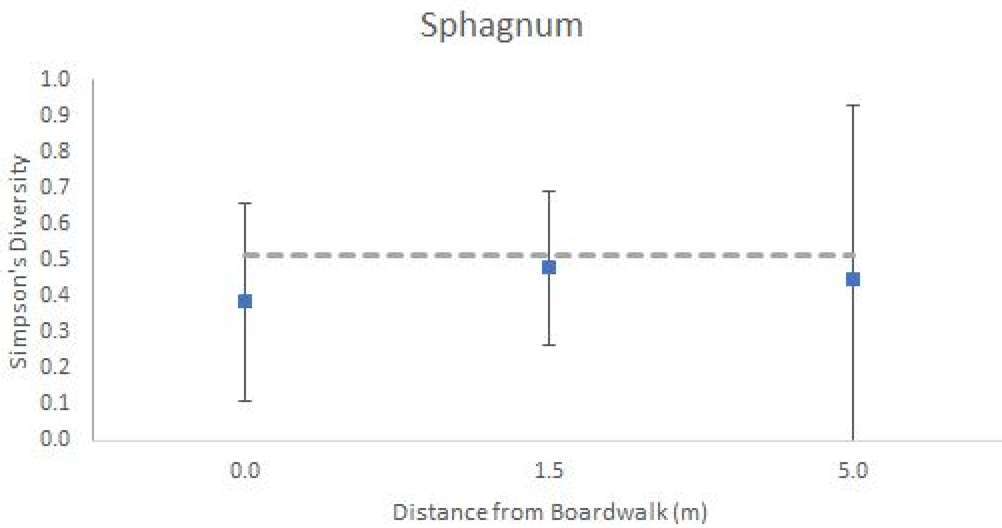
Figure 13. Average percentage cover with increasing distance from boardwalk in the three distinct ecosystems: a) Salal - Salal-rich b) Labrador Tea - "Bog" c) Sphagnum - Peat Forest. Error bars represent standard error of the mean (N=3). Dotted line represents the value seen 8 m away from the boardwalk. Species representative of each ecosystem were chosen based on the dominant species in each control.


Salal
Simpson's Diversity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
1.5
5.0
Distance from Boardwalk (m)

a


Labrador Tea
Simpson's Diversity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
1.5
5.0
Distance from Boardwalk (m)

b



c

Figure 14. Simpson's Diversity indices of different distances from boardwalk of the three ecosystem in the three distinct ecosystems: a) Salal - Salal-rich b) Labrador Tea - "Bog" c) Sphagnum - Peat Forest. Error bars represent standard error of the mean (N=3). Dotted line represents the value seen 8 m away from the boardwalk.

<u>Invasive Species Removal Literature Review</u>

Removal methods viable for the DNR were compiled into a table (Table 3), and listed with their various benefits and drawbacks.

Table 3. Invasive species removal literature review results for reed canary grass and policeman's helmet.

Reed Canary Grass		
Removal Method	**Pros**	**Cons**
Hand-pulling	Small infestations – ensures removal of whole plant when completed in spring-early summer	Unrealistic with large infestations, can spread seeds if done when plant seeds mature
Shading/Mulching	Prevents vegetative regrowth of RCG	Non-selective, kills native species present as well
Mowing	If done when seeds not mature, removes bulk of plant - stubs can be mulched to prevent regrowth	If done when seeds mature, will spread seeds. Stubs will regrow if not dealt with
Plowing	Suitable for when native species present to recolonize	Can release seedbank, further spread invasive species growth
Fire	Can be used before herbicide treatment to lessen vegetation cover	Not useful on its own; can release seedbank
Herbicides	Will effectively prevent regrowth from seeds and rhizomes	Can harm stream ecosystem if proper surfactant not used
Policeman's Helmet		
Removal Method	**Pros**	**Cons**
Hand-pulling	Small infestations. Should be done in spring before seeds develop	Regrowth can occur if plant parts not disposed of properly (bagged and removed from site)
Mowing	Good for larger infestations – cut below lowest node to prevent regrowth	Seeds can get into stream and spread – place barriers along stream while mowing to prevent this
Herbicides	Can be used to spot-treat regrowth after mowing or hand-pulling	Can harm stream ecosystem if proper surfactant not used

DISCUSSION

<u>Hydrology</u>

Comparisons with past studies

In order to assess how characteristic our results were of the DNR and whether any changes have occurred, we compared our data to other similar studies conducted in the past. Owen (2015) also carried out a hydrology study, with measurements collected weekly, at the Delta Nature Reserve between August 2013 and February 2014. While they did measure from the same dipwells used in our study, their data was spatially averaged across all the dipwells to get one mean depth to water table value for the entire DNR. They observed mean depth to water table values (Table 4) across the whole DNR of 8.5 cm in January 2014, and 13.7 cm in February 2014. These high water table values were due in part to heavy rains, particularly on the week of January 17th and February 14th. In comparison, we measured depth to water values of 19 cm in January 2017 and 15.1 cm in February 2017. During these periods, we experienced heavy snowfall rather than rain, which could explain the differences between values in 2014 and 2017 for the same months. From this alone, it is hard to conclude whether the water table values we obtained are "characteristic" of the DNR or whether significant changes occurred simply because of the different weather conditions and their influence on the groundwater. Furthermore, our study completely excludes summer months that could be compared with Owen (2015)'s data, wherein summer months show a drastic increase in the depth to water table (signifying a deeper water table), with a mean value of 49.5 cm for August 2013.

Table 4. Summary of monthly mean depth to water table values from August 2013 to February 2014, as reported in a 2015 report on the Hydrology of the DNR (Owen, 2015).

Paper	Month	Mean Depth to Water Table (cm)
<u>Owen (2015)</u>	August 2013	49.5
	September 2013	48.2
	October 2013	22.4
	November 2013	17.6
	December 2013	15.8
	January 2014	8.5
	February 2014	13.7

Figure 15. Map of the Delta Nature Reserve with pink markers indicating numbered dipwells and white markers indicating locations of transects sampled by Howie (2012).

Howie (2012) observed three study transects (Figure 15) to the east of Highway 91 in the Delta Nature Reserve labelled as Lagg 1 (*Spiraea* thicket lagg), Lagg 2 (Peaty forest lagg), and Mineral (area beside the railway). They recorded values for depth to water table, pH and electrical conductivity (Table 5). Since their transects do not directly correspond to any of the dipwell locations that we sampled from, we can only compare values from the closest possible dipwell to the transect in question.

The Lagg 2 (Peaty forest) area corresponds to the area about 100 m north-east of DW I and 100 m north-west of DW II. Values at this transect were measured to be less than 10 cm for the sampling period of January 2011 to March 2011. On the other hand, our values at DW I ranged from 22.3 cm to 36 cm from the surface, while our values at DW II ranged from 8.1 cm to 17. cm from the surface. If values at Lagg 2 are taken as a proxy for DW I and DW II, 2017 values suggest that the water table at DW I is lower than the past, while DW II does not seem to differ much from the past measurements.

The Lagg 1 (*Spiraea* thicket) area corresponds to the area about 74 m southwest of where DW 6 is installed. Here, they measured depth to water table values between 20 cm and 30 cm for the sampling period of January 2011 to March 2011. In comparison, our values at DW 6 ranged from about 16.5 cm to 23 cm below the ground surface. Taking Lagg 1 values as a proxy for DW 6 values, comparisons with Howie (2012) seem to indicate that the water level is now higher than before.

Table 5. Summary of mean depth to water table, pH and electrical conductivity values at the DNR, as reported in an unpublished report (Howie, 2012) and a Ph.D Thesis (Howie, 2013).

Paper	Area	Mean Depth to Water Table (cm)	Mean pH	Mean EC
Howie (2012)	*Bog*	0-32	4.09-4.36	101-122
	Lagg 1	-14-58	4.17-4.57	66-81
	Lagg 2	13-57	5.20-5.39	78-165
	Mineral	-17-48	5.51-5.72	106-168
Howie (2013)	*Spiraea Thicket*	-14-58	*Winter:* 4.49	*Winter:* 68
			Summer: 4.35	*Summer:* 66
	Peaty Forest	13-57	*Winter:* 5.39	*Winter:* 105
			Summer: 5.34	*Summer:* 165

Howie (2012) measured pH and electrical conductivity every 2 months at the Delta Nature Reserve from September 2010 to December 2011. Average winter pH values were 4.49 at Lagg 1, and 5.35 at Lagg 2. Our values at similar sites were 4.27 (DW 6), 3.71 (DW I), and 4.16 (DW II), respectively. Average winter electrical conductivity values were 68 µS/cm at Lagg 1 and 105 µS/cm at Lagg 2. In comparison, our electrical conductivity values were 88.65 µS/cm (DW 6), 164.4 µS/cm (DW I), and 117.82 µS/cm (DW II). Comparisons with Howie (2012)'s data show that while their pH leans more towards a characteristically minerotrophic water pH (Howie and Meerveld 2011), our pH values were noticeably more acidic and "bog-like" (Figure 11), especially at DW I. Similarly, our electrical conductivity values were also noticeably different, especially in comparing the Lagg 1 value to DW6 and the Lagg 2 to DW I.

While it seems that changes have occurred from 2011 to 2017, it is difficult to say whether these differences point towards an underlying problem as there are many factors that could explain why the values seem to significantly differ. Values may simply differ because the distances between the comparison points are far enough that groundwater characteristics differ as well. Additionally, the weather conditions during Howie (2012)'s study are unknown, and if these were to differ significantly from the weather conditions during our study, this could also explain the differences in values obtained.

Spatial Distributions

From Figure 5, we can observe a general trend of increasing depth to water table from the northeastern part of the DNR towards the southwestern part, where the main bog is cut off by Highway 91. This is a similar pattern to Howie (2012)'s study, where they described a higher depth to water table in the Peaty forest lagg and lower depth to water table at the *Spiraea* thicket area to the west. It is possible that these areas of high depth to water table are due to a denser cover of trees (Howie, 2009). Tree height is said to be related to water table, wherein one would find taller trees in areas with a higher measured depth to water table (Howie, 2009). Lower depth to water table values at the northern part of the DNR could be due to flooding of the creek leading to increased water levels at adjacent dipwells. Howie (2012) also mentions a higher depth to water table in the "Mineral area" (Figure 15; an area of higher soil mineral content adjacent to the railway), however, we were unable to measure here due to dipwells not being installed in this area of interest.

From Figure 6, we observe increasing electrical conductivity values towards the southern part of the DNR. This figure suggests that electrical conductivity increases with decreasing pH values. However, the expected pattern should be a decrease in electrical conductivity towards the bog, as water farther away from the stream should have less minerotrophic influence and therefore a lower concentration of dissolved solutes (Howie, 2013). Despite this, Howie (2013) also mentions that when pH values are lower than 5.0, electrical conductivity values can be significantly affected by conductance due to hydrogen ions. Naturally, lower pH values translate to higher amounts of hydrogen ions in solution. However, this correction led to some of our values becoming negative, so we could not use these values. This led to questions regarding the validity of our measured pH values.

From Figure 7, the general trend in pH values is a decrease from the northeastern DNR to the southwestern region. This pattern is to be expected as the northeastern part is adjacent to an urbanized area, as well as an active railway, which are both potential sources of minerotrophic runoff (Howie, 2013). As the creek adjacent to the railway floods during heavy rain periods, this could increase mineral content further into the lagg zone, causing higher pH values in the areas most affected. Neighbouring industrial areas can also be a source of mineral deposition as dust precipitates over areas at the margin of the DNR (Howie, 2013). On the other hand, the southwestern region is further from such external influences, thus explaining the pH values leaning towards characteristically acidic soil water values of an undisturbed bog.

Sources of Error and Limitations

Possible sources of error include weather effects and instrumental error. Sampling was carried out during a period of heavy snow and some flooding, which is uncharacteristic of Vancouver and may have affected our measurements. During heavy periods of rain, some malfunctioning would occur with the pH readings, which led to values being extremely underestimated. This occurred during our January 29th sampling day, where there was severe rainfall, leading us to completely exclude any pH values collected. While precipitation was lighter on other sampling days, it is still possible that this same underestimation effect may have affected our readings to some degree. But judging from the similarity of our data with that of the aforementioned studies, this underestimation effect may not have been too significant. Additionally, the electrical conductivity probe would sometimes display unusually high values under these conditions, however, this was mostly corrected by recalibrating the instrument in the field.

Patterns observed during this study may possibly be restricted to the wet season, due to flooding of the stream being mainly due to heavy rains. The main input of water into the DNR comes from precipitation (Hebda, 2000). While winter months like our sampling period are characterized by wet conditions, the DNR has been shown to experience a moisture deficit during the summer months (Hebda, 2000). Evapotranspiration, the primary water removal process (Hebda, 2000), is relatively low in the winter as vegetation are in their dormant phase (Oishi *et al.,* 2010). However, in the summer, evapotranspiration is at its peak as vegetation is at the height of photosynthetic activity (Iroumé *et al*., 2005). Therefore, summer months should also be investigated to examine whether there is a change in spatial distribution and mean values of parameters compared to the wet season.

<u>Trampling</u>

Figure 13 displays average percentage cover of each control in the three distinct ecosystems. The average percentage cover of the selected species for each ecosystem showed no significant difference between distances from the boardwalk. However, percentage cover of dominant species at the different distances for each ecosystem are significantly less than its control. Therefore, it can be concluded that trampling is apparent but the extent to which species composition is affected with increasing distance within 5 meters is insignificant.

The degree to which trampling affects each species varies. This may be due to the general structure, branches and leaves of the plant species that affect the magnitude of response toward trampling. For example, in the Bog ecosystem (Control 2), Labrador tea is the dominant species. Figure 13b (Bog ecosystem) suggest almost no difference of percentage cover at different distance with its control, thus relative cover also remaining constant. With its tall branches and structure, it is difficult to step off the trail in this region, therefore may be subject to less trampling.

Simpson's Diversity indices of the three ecosystems showed no observable pattern (Figure 14) with increasing distance from boardwalk. The values at different distances of each ecosystem varied randomly. However, they are significantly less than its control. This may suggest that the extent to which trampling is occurring does not have a significant impact on species diversity until 5 meters from the boardwalk. The three controls, display higher values of Simpson's Index therefore suggesting lower species diversity.

A more effective approach for assessing the impact of trampling is isolating the effect of the amount of trampling from other confounding variables. During the experiment a number of observations were made. These include, noticing that many dogs were not on a leash and ventured in areas away from the boardwalk. Therefore, for future studies a comparative analysis of human and dog trampling can be conducted, to accurately determine the source of trampling. In addition, the use of hiking sticks was observed, however, the extent to which it affects vegetation is unknown. Other response variables to trampling can also be studied such as litter, rock and soil abundance. Accurately determining the resistance and resilience of each species to trampling pressure can determine areas which are most sensitive that may require more attention. However, measurements may be needed to be conducted after one year to determine recovery of vegetation. Including the use of aerial photography and computerised image analysis, can accurately document and monitor changes of land cover resulting in better understanding of cause and effect of species cover.

Invasive Species Removal Literature Review

With the issue of reed canary grass, the potential reasons why it infiltrated the streambank in the first place should be addressed; the stressors that disturbed the ecosystem to allow for reed canary grass to colonize should be removed if still at work. More ecologically diverse sites respond to restoration efforts better, so if possible, the establishment of native species should also be completed so that native species can take over areas where reed canary grass has been removed. Hand-pulling is not a viable option for the removal of reed canary grass, as the abundance of the species is too high. Herbicide use is also not recommended due to the adjacency of the salmon-bearing creek. Mowing of invaded sites should be completed in spring to early summer, before seeds have developed. After the grass has been mowed, stalks should be covered in mulch or plastic to prevent regrowth. Continued monitoring and treatment would be required for up to 5-10 years to ensure complete removal of reed canary grass (Tu, 2004). Along with long term monitoring, an adaptive management approach should be utilized in order to effectively remove the species (Tu, 2004).

Policeman's helmet is more easily removed through physical means such as hand-pulling, though it must be ensured that all of the plant parts are removed and properly disposed of. Barriers should be placed along the stream as removal takes place to ensure that no seeds or plant matter enter the waterway, as seeds can persist in water for many months. As with reed canary grass, removal should be completed before seeds have fully developed, in spring or early summer. Mowing can also be utilized for larger infestations, and is most successful when plants are cut below their lowest nodes to prevent regeneration. As with reed canary grass, long-term monitoring should be implemented in order to maintain complete eradication.

CONCLUSIONS

Hydrology

Overall, pH values were observed to be characteristically acidic, as expected in a bog or lagg zone environment. The observed spatial distributions of the three water parameters may indicate contamination from the stream during flooding periods, but more data will need to be collected, especially during the summer months when flooding is not occurring, to make definite conclusions. Additional dipwells will also need to be installed in the northeast corner of the Delta Nature Reserve to better depict the spatial distribution of the different parameters. The measured depth to water table data does not seem to reflect values that would suggest any issues. However, one should take into account that data was collected during an odd winter that included heavy snowfall and very cold temperatures. Future measurements should be conducted at least once a month, which accounts for seasonal variations while still being feasible for the BBCS as a monitoring period. Annual data should also be compiled, with comparisons made between past and subsequent years, in order to better assess long-term trends before deducing that a particular deviation is indicative of an underlying problem.

Trampling

To our knowledge, this is the first study conducted in the Delta Nature Reserve that demonstrates that trampling increases species diversity (lower Simpson's Diversity-D than control) and decreases relative cover of the selected species in each ecosystem. This emphasizes the importance to consider mechanical disturbances from recreational activities in the bog. Increasing the number of signs alerting visitors to stay on the boardwalk, leash their dogs and to be considerate of the vegetation around the area can possibility decrease the effects of trampling. If needed, a monetary penalty may be enforced to increase the level of deterrence. In addition, further information regarding the need to prevent trampling may be included areas along the boardwalk.

Invasive Species Removal

Reed canary grass, which is found in high abundances along the stream in the Delta Nature Reserve, has high seed counts and can reproduce both sexually and vegetatively through rhizome growth; these factors make it extremely difficult to completely eradicate. If possible, the establishment of native species should be done in synchrony with the removal of reed canary grass to help prevent its continued monoculture on the stream banks. Since reed canary grass is observed in such high quantities, mechanical removal such as hand-pulling is not feasible for the Delta Nature Reserve. Mowing is a viable option, as long as mowed stalks are then shaded out with plastic or mulch in order to prevent vegetative growth. Long-term monitoring and removal would be required to ensure the complete removal of the invasive species.

Policeman's helmet can be removed in a more straightforward approach. The species is more easily removed through physical means such as hand-pulling, though it must be ensured that all of the plant parts are removed and properly disposed of. Barriers should be placed along the stream as removal takes place to ensure that no seeds or plant matter enter the waterway, as seeds can persist in water for many months. Mowing can also be done and is most successful when plants are cut below their lowest nodes to prevent regeneration. As with reed canary grass, long-term monitoring should be implemented in order to maintain complete eradication.

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APPENDICES

Appendix 1.

Coordinates for dipwells in DNR that were used in this study.

Dipwell #	Latitude N	Longitude W
2	49º 8’ 42.998”	122º 56’ 1.000”
3	49º 8’ 39.999”	122º 56’ 0.999”
6	49º 8’ 31.001”	122º 55’ 51.998”
Unmarked	49º 8’ 33.999”	122º 55’ 55.997”
I	49º 8’ 28.000”	122º 55’ 42.999”
II	49º 8’ 30.000”	122º 55’ 35.000”
III	49º 8’ 35.999”	122º 55’ 42.998”
IV	49º 8’ 38.687”	122º 55’ 48.256”

Appendix 2.

Mean values for Water Table, pH, and electrical conductivity.

Dipwell #	Depth from Surface (cm)	pH	electrical conductivity (µS/cm)
2	20.07	4.28	64.73
3	19.85	4.03	85.55
6	20.62	4.27	88.65
Unmarked	28.38	4.03	98.72
I	30.95	3.70	164.40
II	13.40	4.16	117.80
III	25.98	3.98	105.00
IV	14.00	4.57	86.00
Overall	21.65	4.13	98.24

Appendix 3.

Locations of trampling transects

Control/ Ecosystem	Transects
1- Salal Rich	4E, 5E
2- "Bog"	10W,12W/E,14W/E
3- Peat forest	19W, 23E, 28W

Appendix 4.

Raw values for species cover for the west side of the boardwalk

Transect No. / Species	10			12			14			19			28		
Distance from Boardwalk (m)	0	1.5	5	0	1.5	5	0	1.5	5	0	1.5	5	0	1.5	5
Sphagnum	0	0	0	5	0	0	0	5	0	0	30	5	0	0	80
Salal	90	50	50	0	0	0	30	5	50	10	10	0	0	5	0
English Holly	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0
Labrador Tea	0	5	10	95	100	100	60	90	50	0	0	0	0	0	0
Western Red Cedar	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0
Spiny Wood Fern	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Step Moss	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0
No Vegetation	10	45	40	0	0	0	10	0	0	75	55	55	100	95	20
Sum	90	55	60	100	100	100	90	100	100	25	45	45	0	5	80
Relative Cover	0.9	0.55	0.6	1	1	1	0.9	1	1	0.3	0.5	0.5	0	0.1	0.8

Appendix 5.

Raw values for species cover for east side of the boardwalk

Transect No. / Species	4			5			12			14			23		
Distance from Boardwalk (m)	0	1.5	5	0	1.5	5	0	1.5	5	0	1.5	5	0	1.5	5
Sphagnum	0	0	5	0	0	0	0	0	0	0	0	0	50	40	40
Salal	0	40	50	60	80	90	10	5	0	10	0	0	20	30	40
English Holly	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Labrador Tea	0	0	0	15	15	10	90	95	100	90	100	100	0	0	0
Western Red Cedar	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0
Spiny Wood Fern	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Step Moss	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0
No Vegetation	100	50	25	25	5	0	0	0	0	0	0	0	30	30	20
Sum	0	50	75	75	95	100	100	100	100	100	100	100	70	70	80
Relative Cover	0	0.5	0.8	0.8	1	1	1	1	1	1	1	1	0.7	0.7	0.8

Appendix 6.

Simpson's diversity index by ecosystem

Salal						
Distance from Boardwalk (m)	0.0		1.5		5.0	
Plant species	**ni**	**ni(ni-1)**	**ni**	**ni(ni-1)**	**ni**	**ni(ni-1)**
Sphagnum	1.50	2.24	0.00	0.00	0.05	0.00
Salal	0.00	0.00	1.70	2.87	1.90	3.59
English Holly	0.15	0.02	0.00	0.00	0.00	0.00
Labrador Tea	0.00	0.00	0.20	0.04	0.20	0.04
Western Red Cedar	0.00	0.00	0.10	0.01	0.00	0.00
Spiny Wood Fern	0.00	0.00	0.00	0.00	0.05	0.00
Step Moss	1.35	1.81	0.00	0.00	0.15	0.02
Total	3.00		2.00		2.35	
Simpson's Diversity	0.4532		0.7337		0.6645	

Bog						
Distance from Boardwalk (m)	0.0		1.5		5.0	
Plant species	**ni**	**ni(ni-1)**	**ni**	**ni(ni-1)**	**ni**	**ni(ni-1)**
Sphagnum	0.05	0.00	0.05	0.00	0.00	0.00
Salal	0.50	0.25	0.10	0.01	0.50	0.25
English Holly	0.00	0.00	0.00	0.00	0.00	0.00
Labrador Tea	3.35	11.19	3.85	14.78	3.50	12.22
Western Red Cedar	0.00	0.00	0.00	0.00	0.00	0.00
Spiny Wood Fern	0.00	0.00	0.00	0.00	0.00	0.00
Step Moss	0.00	0.00	0.00	0.00	0.00	0.00
Total	3.90		4.00		4.00	
Simpson's Diversity	0.7538		0.9270		0.7807	

Peat Forest						
Distance from Boardwalk (m)	0.0		1.5		5.0	
Plant species	**ni**	**ni(ni-1)**	**ni**	**ni(ni-1)**	**ni**	**ni(ni-1)**
Sphagnum	0.50	0.25	0.70	0.48	1.25	1.55
Salal	0.30	0.09	0.45	0.20	0.40	0.16
English Holly	0.05	0.00	0.05	0.00	0.00	0.00
Labrador Tea	0.00	0.00	0.00	0.00	0.00	0.00
Western Red Cedar	0.00	0.00	0.00	0.00	0.40	0.16
Spiny Wood Fern	0.00	0.00	0.00	0.00	0.00	0.00
Step Moss	0.10	0.01	0.00	0.00	0.00	0.00
Total	0.95		1.20		2.05	
Simpson's Diversity	0.3841		0.4783		0.4452	

Appendix 7.

The Restoration and Recovery of the Delta Nature Reserve: a Literature Review

Introduction

Burns Bog, located in Delta, BC, is the only estuarine raised peat bog found in western Canada. The bog acts as a large carbon sink, and also provides a habitat for many vulnerable and endangered species. The resilience of this fragile, rare ecosystem is vital in order to ensure it persists far into the future. There are many hydrological and biological factors that must be taken into consideration when analysing the health of the ecosystem and its potential restoration. This literature review will act as a foundation of knowledge necessary to work towards the restoration of the Delta Nature Reserve. This will be achieved through the review of past studies in similar ecosystems.

A second item of concern within this ecosystem is the observed presence of invasive species along the periphery of the Delta Nature Reserve, specifically on the banks of the stream that flows there. The two main invasive species that have been observed are *Phalaris arundinacae,* or reed canary grass, and *Impatiens glandulifera,* or policeman's helmet. These two plant species display all of the qualities of an invasive species that make them difficult to eradicate - effective dispersal, fast reproduction, and quick growth rate. The process of complete removal of the two invasive species from the Delta Nature Reserve must also aim to minimize damage to the surrounding ecosystem. This literature review aims to pinpoint both economically and ecologically feasible removal strategies of reed canary grass and policeman's helmet from the Delta Nature Reserve.

Background Information

Burns Bog, due to its hydrological, biological, and topographical features, is classified as a raised peat bog. These features include an internal water mound, nutrient-poor and acidic water from precipitation, a two-layered composition, and peat-forming biological communities (Howie *et al.,* 2011). The Burns Bog lagg zone within the Delta Nature Reserve is located at the bog perimeter on the north side. The lagg zone acts as a buffer between the higher nutrient waters surrounding the bog and the nutrient-poor waters within. This buffering system is crucial in maintaining the unique biological communities within the bog, such as *Sphagnum* moss. Along with water chemistry, a high water table is critical to peat communities. Therefore inflows of water from precipitation must meet water amounts lost to evaporation, transpiration, and runoff (Howie *et al.,* 2009).

Over the span of the UBC Environmental Sciences community project, one focus was to begin monitoring the water table height, pH, and electrical conductivity of the groundwater within the Delta Nature Reserve. This was done in order to set a framework for the continued monitoring of the hydrology in the lagg zone of Burns Bog. The pH and electrical conductivity are useful indicators for monitoring the ecological succession of the lagg zone in response to recovery efforts (Gorham *et al.,* 2003). There are several restoration strategies that focus on restoring the water table, including blocking ditches, bunds and terracing, and using mulch (Howie *et al.,* 2011). It is our hope that this foundation of data, along with a proposed plan for monitoring in the years to come, can be used to help educate others and preserve the Delta Nature Reserve.

Bog hydrology also has a large impact on the biology of the area, as does human activity. One of the most influential species present in the Delta Nature Reserve is *Sphagnum* moss, which is a species that is responsible for almost half of the carbon accumulation in peatlands (Thompson and Waddington, 2008). Studies observe that *Sphagnum* cover and production is at its highest when the bog's water table is sufficiently high (Potvin *et al.,* 2015), which displays the dependence of *Sphagnum* moss on a moist environment. In the Delta Nature Reserve, a lowered water table would lead to a decrease in *Sphagnum* abundance, allowing for the growth of other native species such as Salal. This increase in the abundance of Salal has already been observed in parts of the Delta Nature Reserve.

Restoration of Hydrology

In most North American raised peat bog restoration projects, those involved have concentrated on the re-establishment of *Sphagnum* moss without addressing the main stressor, dry conditions. For bog vegetation to persist, a high water table must be present, and therefore the restoration of bog hydrology should begin if not prior to then along with vegetation restoration (Howie and van Meerveld, 2011). There are a variety of methods that have been used in bog rewetting, including ditch-blocking, bund and dyke construction, and excavating water retention basins (Bönsel and Sonneck, 2011; Howie *et al.,* 2009; Rochefort *et al.,* 2003). Removal of tall trees can also be done, as they utilize much of the water resources within the area. Along with these alterations of the habitat, extensive long-term monitoring must take place in order to assess the successes of the restoration project.

The Delta Nature Reserve is a fragile, relatively small ecosystem located close to residential and industrial areas, and has a small salmon-bearing creek running along its periphery. These factors must be considered when deciding which hydrological restoration methods to undergo. Methods involving large, heavy machinery may not be feasible or may do more harm to the ecosystem than good, such as excavation of water retention basins or dyke construction. However, there are alternative methods of hydrological restoration that could suit the specific needs of the Delta Nature Reserve that would not require heavy machinery. Within Burns Bog proper, Howie *et al.* (2009) completed a project involving ditch-blocking to restore parts of the bog's hydrology and *Sphagnum* communities. Plywood that was secured with wooden stakes was used to block ditches, and were covered in peat and at times native vegetation (Howie *et al.,* 2009). Supplies were brought to the problem areas on foot (Howie *et al.,* 2009). To assess the long-term success of this project, water table and bog surface elevation samples have been obtained monthly since 2005 (Howie *et al.,* 2009). Potential draining ditches around the Delta Nature Reserve would have to be assessed in order to analyse whether this is a valuable method of hydrological restoration. Methods such as these that minimize further damage to the ecosystem could be utilized in the Delta Nature Reserve to restore the area's hydrological function.

Restoration of *Sphagnum* Moss Communities

Once a plan is underway to restore the area's hydrological function, the successful restoration of *Sphagnum* moss can be completed. *Sphagnum* moss relies heavily on a moist environment, and therefore requires an environment in which the water table is sufficiently high. There have been many restoration studies completed in which *Sphagnum* moss readily re-established once the bog hydrology had been restored. In the study completed by Bönsel and Sonneck (2011), ditch-blocking was completed in order to simulate a return to moist bog conditions. Site monitoring of water levels and vegetation began before the restoration attempts began to form an appropriately large collection of data (Bönsel and Sonneck, 2011). It was found that after the ditch-blocking occurred, continuous high water levels were established, and a diverse *Sphagnum* community was able to establish itself (Bönsel and Sonneck, 2011). In addition to *Sphagnum* communities re-establishing, tree cover significantly decreased due to high water level and increased acidity released into the soil from *Sphagnum* moss (Bönsel and Sonneck, 2011). This project is one example of how the proper restoration of bog hydrological features can aid in the restoration of the highly important bog species, *Sphagnum.*

In some situations, *Sphagnum* moss communities are unable to establish on their own, and additional steps must be taken in order to ensure their establishment. Natural colonization of *Sphagnum* moss can be supplemented with transplanting from other natural bog locations, seeding, or dispersing *Sphagnum* diaspores (Howie and van Meerveld, 2011). In a study completed by Rochefort *et al.* (2003), following hydrological restoration, *Sphagnum* was re-established through collecting the top 10 cm of natural bog cover to obtain diaspores for spreading. Diaspores were then covered by straw mulch, in order to improve temperature conditions and water availability for the growing *Sphagnum* (Rochefort *et al.,* 2003). Additionally, in some areas phosphorus fertilization was done, which encourages the growth of vascular plants, in turn stabilizing the bare peat surface and acting as a habitat for establishing *Sphagnum* (Rochefort *et al.,* 2003).

In the Delta Nature Reserve, it has been observed that Salal has been encroaching on *Sphagnum* communities. This could possibly be due to an overall drying out of the area, allowing vascular plants to take root and preventing *Sphagnum* from competing effectively. The Corporation of Delta, alongside the Burns Bog Conservation Society, would have to decide if removing Salal to allow for the growth of *Sphagnum* moss is within their interests. Another option would be to allow the native Salal to continue growing in areas previously inhabited by *Sphagnum,* as it is not an invasive species and simply signifies a transition in the ecological composition of the area from bog-like to forest-like. Patches of *Sphagnum* that have died due to drying out or human trampling could be restored using methods mentioned above, such as broadcasting diaspores and using fertilization, or simply allowed to re-establish on their own. An important step in the restoration process would, again, be to address the stressors that cause *Sphagnum* to die. In this case, those stressors are likely a low water table and trampling of *Sphagnum* near the boardwalks by Reserve visitors. Once the stressors have been addressed, the restoration of a diverse *Sphagnum* community should be straightforward and successful in the Delta Nature Reserve.

Reed Canary Grass

Figure 16. Reed canary grass in seed. Picture retrieved from: http://www.friendsofthewildflowergarden.org/pages/plants/reedcanarygrass.html

Along the Northeast side of the Delta Nature Reserve runs a North-flowing man-made stream that drains the residential neighbourhoods above it. This stream, though originally excavated as a method of drainage, has become a salmon-bearing stream and supports a small ecosystem. However, because of human disturbances, invasive species have spread along its banks in close proximity to the fragile ecosystem of the bog within the Reserve. One in particular, *Phalaris arundinacea,* or reed canary grass, has the ability and tendency to form dense, monotypic stands in areas it has colonized (Bahm *et al.,* 2014). Reed canary grass is a perennial, and can reproduce both sexually through seeds and asexually through vegetative rhizome growth (Canadian Wildlife Service, 1999). Reed canary grass, once established, has been shown to be extremely difficult to eradicate, and because of the sensitivity of the surrounding ecosystem, removal methods must be effective yet minimally toxic. The above-ground biomass, rhizomes, and seed bank must be targeted for complete, long-term eradication (Gillespie and Murn, 1992).

According to Bahm *et al.* (2014), hand-pulling of reed canary grass can be a successful means of removal, requires a significant time investment and is better suited to small infestations. Plowing is a method suited to when native species are present in sufficiently high numbers to establish in the place of reed canary grass (Bahm *et al.,* 2014). Fire can be used as tool to reduce litter, making herbicide treatment more effective; however, herbicide treatment is, again, only truly successful when there are native species present to take over (Bahm *et al.,* 2014).

In a study completed by Baugh *et al.* (2011), the herbicide Glyphosate was applied to uncut flowering reed canary grass stems in June and July. The herbicide was broadcast over monocultures of reed canary grass, and in transition zones, the grass was first cut, then allowed to regrow to about 50 cm in height, then sprayed (Baugh *et al.,* 2011). This method used in transition zones allowed for precise application of the herbicide in order to minimize impact on native species (Baugh *et al.,* 2011). Small infestations of the grass were either removed by hand or spot-treated with Glyphosate (Baugh *et al.,* 2011). Since the treatments, long-term monitoring has been underway to observe for resprouts or seedling emergence (Baugh *et al.,* 2011). It has been found that so far, there has been a near-complete kill of reed canary grass in areas sprayed with Glyphosate (Baugh *et al.,* 2011). The combined method of herbicide spray and mechanical removal seems to be effective in this mountain bog.

Herbicide use was also discussed by the Canadian Wildlife Service (1999), who state it seems to be the most effective if applied at the right time of year. This depends on the herbicide used - some are best used in the dormant season, and others in flowering season (Canadian Wildlife Service, 1999). As mentioned previously, herbicides are the most effective when there are native species present to colonize the area, otherwise nearby stands of reed canary grass could replenish the treated area. According to Gillespie and Murn (1992), herbicides can only be used near aquatic systems if they contain a surfactant that is approved for aquatic systems. In the Delta Nature Reserve, the health of the salmon-bearing stream would have to be taken into consideration if the chosen method of eradication were to be herbicide use.

A series of other possible removal methods of reed canary grass are outlined by Gillespie and Murn (1992), including burning, excavation, planting vegetation, mowing, altering hydrology, and mulching or solarizing. Burning is beneficial as it removes biomass and litter of reed canary grass, and may kill seeds on the surface, but could also release the seed bank of undesirable species and stimulate dormant buds of reed canary grass to resprout (Gillespie and Murn, 1992). Excavation removes plant rhizomes and the seed bank, but also removes sediment and nutrients, and can alter hydrology (Gillespie and Murn, 1992). Planting vegetation such as trees and shrubs can shade out reed canary grass, and adds structure and diversity to the ecosystem, but reed canary grass must be managed for the 3-5 years it would take for plant seedlings to establish (Gillespie and Murn, 1992). Altering hydrology prevents reed canary grass germination and kills plant rhizomes, but high water levels would need to be maintained throughout the growing season (Gillespie and Murn, 1992). These high water levels could also encourage the growth of native species such as cattails and bulrush. Finally, mowing and solarizing kills adults and rhizomes, but is non-selective and can have an impact on soil microorganisms (Gillespie and Murn, 1992). It is possible that some of these removal methods could be used in the Delta Nature Reserve to aid in the eradication of reed canary grass.

Much like the *Sphagnum* restoration, with the issue of reed canary grass, the potential reasons why it established in the first place should be addressed; the stressors that disturbed the ecosystem to allow for reed canary grass to infiltrate should be removed if still present. More diverse sites respond to restoration efforts better, so if possible, the establishment of native species should also be done so that they can take over areas where reed canary grass has been removed. Continued monitoring and treatment would be required for up to 5-10 years to ensure complete removal of reed canary grass (Tu, 2004). Along with long term monitoring, an adaptive management approach should be utilized in order to effectively remove the species (Tu, 2004).

<u>Policeman's Helmet</u>

Figure 16. Policeman's helmet in bloom. Picture retrieved from: http://www.kingcounty.gov/services/environment/animals-and-plants/noxious-weeds/weed-identification/policemans-helmet.aspx

A second invasive species of concern along the periphery of the Delta Nature Reserve is *Impatiens glandulifera,* also known as Himalayan balsam, or more commonly in Canada, Policeman's helmet. The species was originally introduced to North America as an ornamental plant, and proceeded to spread (KCNWCP, 2010). Policeman's helmet is an annual plant typically found in riparian habitats, and prefers moist soils and partially shaded to sunny environments (KCNWCP, 2010). The plant grow to a height of between 3-8 feet, and has pink or purple flowers that resemble a policeman's helmet (Clements *et al.,* 2008). Seeds are dispersed explosively from parent plants, and can remain viable for up to 18 months as they are dispersed along adjacent waterways. The negative impacts of Policeman's helmet are plentiful - the large plant tends to shade out native species, compete for pollinators such as bees, and cause stream bank erosion after it dies out in the fall (Kelly *et al.,* 2008). Stands of Policeman's helmet have been observed in the Delta Nature Reserve.

For the most part, physical removal of Policeman's helmet has been shown to be a successful means of removal due to the plant's modest root system (IUCN, 2015). Small infestations can easily be hand-pulled or dug up, which should be done in the spring or early summer when seeds have not yet fully developed (KCNWCP, 2010). Plant parts should be properly disposed of to minimize the risk of recolonization; flower heads should be cut and bagged, and disposed of in the garbage (KCNWCP, 2010). Stems can be piled upon tarps (to prevent rooting) and composted (KCNWCP, 2010).

Larger infestations can be controlled through mowing - plants should be cut below their lowest nodes in order to prevent regrowth (Kelly *et al.,* 2008). Continued monitoring is required to identify areas of plant regrowth; these areas can be hand-pulled or mowed once more (KCNWCP, 2010). While larger infestations can be controlled through the use of the herbicide Glyphosate, this is not advisable in riparian areas as the herbicide does not contain suitable surfactants (Clements *et al.,* 2008). As with smaller infestations, all plant parts should be disposed of properly to prevent regrowth of the stands.

When completing removal, barriers should be placed to prevent removed vegetation from entering the waterway, as the plant can be further spread in this fashion (KCNWCP, 2010). Along with barriers, removal processes should be completed while attempting to minimize disturbance, along with synchronously planting native species (Clement *et al.,* 2008). The removal of Policeman's helmet has been shown to lead to an increase in species richness, and this process can be facilitated with the planting of native species (Hulme and Bremner, 2005). Planting should also be done to prevent the erosion of the stream bank (KCNWCP, 2010).

Policeman's helmet, which has been observed along with reed canary grass in the Delta Nature Reserve, can be controlled by the Corporation of Delta through physical removal and the proper disposal of plant parts. Hand-pulling of small infestations is successful if done in the spring or early summer. For larger stands, mowing has been shown to be successful, especially if plants are cut below their lowest node to prevent regeneration. Continued monitoring of the site after removal is crucial, and any signs of regrowth can be spot treated through hand-pulling or cutting. As the infestation is near a stream, barriers should be placed when removing the species in order to prevent spread of vegetative matter and seeds downstream. Through physical removal, Policeman's helmet can be removed in a relatively straightforward fashion.

Conclusions

Burns Bog, located in Delta, BC, is a very unique ecosystem, and the only estuarine raised peat bog found in western Canada. The bog provides many ecosystem services, including acting as a large carbon sink, and it provides a habitat for many vulnerable and endangered species. Throughout recent years, the ecosystem has appeared dryer than what is considered suitable for a bog environment. There has also been an encroachment of species such as Salal that prefer drier environments on bog species such as *Sphagnum* moss. Along with more Salal, the increased presence of invasive species reed canary grass and Policeman`s helmet have been observed.

While hydrological restoration methods in the Delta Nature Reserve that involve heavy machinery are not feasible, there are small-scale methods that may be possible to restore the water table. Ditch-blocking is a method that could be utilized, as used by Howie *et al.* (2009) in Burns Bog proper, using plywood and securing it with wooden stakes to block ditches. Supplies could be brought in on foot to minimize impacts on the ecosystem. A long-term monitoring project should be implemented in order to assess the success of this hydrological restoration plan. The hydrology restoration should be addressed before or alongside *Sphagnum* moss restoration, which requires suitably high water content to survive. *Sphagnum* moss restoration can also be aided through moss transplants, distributing diaspores, or fertilization.

Reed canary grass, which is found in high abundances along the stream in the Delta Nature Reserve, has high seed counts and can reproduce both sexually and vegetatively through rhizome growth; these factors make it extremely difficult to completely eradicate. If possible, the establishment of native species should be done in synchrony with the removal of reed canary grass to help prevent its continued monoculture on the stream banks. Since reed canary grass is observed in such high quantities, mechanical removal such as hand-pulling is not feasible for the Delta Nature Reserve. Mowing is a viable option, as long as mowed stalks are then shaded out with plastic or mulch in order to prevent vegetative growth. Herbicides can also mindfully be applied, but only if said herbicides contain a surfactant approved for aquatic systems. Long-term monitoring and removal would be required to ensure the complete removal of the invasive species.

Policeman's helmet can be removed in a more straightforward approach. The species is more easily removed through physical means such as hand-pulling, though it must be ensured that all of the plant parts are removed and properly disposed of. Barriers should be placed along the stream as removal takes place to ensure that no seeds or plant matter enter the waterway, as seeds can persist in water for many months. Mowing can also be done and is most successful when plants are cut below their lowest nodes to prevent regeneration. As with reed canary grass, long-term monitoring should be implemented in order to maintain complete eradication.