Effect of mowing on *Sphagnum* regeneration in a disturbed peat bog

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Abstract

Bogs are important ecosystems, which provide carbon sequestration, unique biodiversity, and material/cultural resources. Bogs have been degraded worldwide by human activity, and it will be necessary to restore much of what has been degraded in the next century in order to reduce the negative impacts of climate change and preserve biodiversity. The Garden City Lands in Richmond, BC are a slice of the historic Lulu Island bog which were recently acquired by the City of Richmond for purposes including bog ecosystem restoration. The Garden City Lands Peat Bog is mowed annually to control invasive birch, but this practice may negatively impact *Sphagnum*. A Randomized Complete Block experiment was designed to test the effects of mowing cessation on *Sphagnum* regeneration. After 3 years, *Sphagnum* regeneration was found to be significantly higher in unmowed plots despite significantly lower soil moisture. This increased *Sphagnum* growth was likely due to the effects of the maturing shrub canopy on the *Sphagnum* desiccation rate, as well as reduced physical disturbance. Implication for management is that mowing should cease in areas of low birch density to promote *Sphagnum* regeneration.

Introduction

Peatlands

Bogs are unique ecosystems characterized by ombrotrophic conditions (i.e the only water and mineral input to the ecosystem is from precipitation) and poor drainage. These conditions result in an acidic, nutrient-poor environment, where organic matter decomposition is slower than the rate of deposition; this results in thick layers of organic material (peat) which accumulate over thousands of years. This organic matter acts as a significant carbon store; despite spanning only 3% of earth's landmass, peatlands (ombrotrophic bogs and minerotrophic fens) make up 30% of the earth's soil carbon reserves (Kreyling et al, 2021; Landry & Rochefort, 2012). Bogs also provide ecological value. They host unique specialized plant and animal species which aren't found anywhere else (Quinty & Rochefort, 2003; Landry & Rochefort, 2012; Davis & Klinkenburg, 2008).

Peatlands worldwide have been increasingly degraded in the last few centuries, both from mining peat, and draining to create suitable land for agriculture or other uses. To date, 10-15% of peatlands worldwide have been drained (Kreyling et al, 2021). Draining peatlands has various negative impacts. Most importantly on a global scale, it transforms them from a carbon sink to a carbon source, by lowering the water table and aerating peat which was previously saturated by acidic, anaerobic water and thus resistant to breakdown (Landry & Rochefort, 2012; Kreyling et al, 2021; Quinty & Rochefort, 2003). 5% of global greenhouse gas emissions are due to peat breakdown in drained peatlands, and unless substantial tracts of drained peatlands worldwide are rewetted, continued peat breakdown could contribute 14-41% of the total GHG budget intended to keep global warming beneath a +1.5-+2°C level (Kreyling et al, 2021). Bog drainage also changes the ecosystem so that unique bog species can no longer live there (Landry & Rochefort, 2012).

Garden City Lands

The Garden City Lands (GCL) is a 55 hectare lot in Richmond BC, bounded by major roadways on all 4 sides (Diamondhead Consulting et al., 2013). Prior to the arrival of European settlers in the 1860s, it formed part of the western extent of the Lulu Island Bog, much of which has been drained/degraded, with the remaining bog fragmented (Davis & Klinkenburg, 2008). The Lulu Island Bog has historically had cultural significance to Indigenous Coast Salish peoples, particularly the Musqueam, as a food, medicine, and material gathering site (Gordon et al., 2007; Davis & Klinkenburg, 2008). The GCL was used as a firing range in the early 20th century, and telecommunication towers were built in 1949 (Diamondhead Consulting et al., 2013). Heavy metal and creosote contamination from these two uses still remains (Mike Bomford, Personal communication, October 2022). About a decade ago, the land was purchased by the City of Richmond, with a loose plan to restore the bog ecosystem in the eastern half of the site, and establish community-based agriculture projects in the western half. Since then, hydrological work has taken place which has effectively sealed off the places where drainage was occurring from the bog restoration site (Mike Bomford, personal communication, october 2022). This "rewetting" is an essential first step in any drained bog restoration project, which raises the water table to again support peat-accumulating vegetation over invasive, non-bog species; it also halts decomposition of peat and thus the continued GHG emissions which come from drained peatlands (Landry & Rochefort, 2012; Kreyling et al, 2021).

Currently, the site is managed by annual mowing in the Fall, a practice which has been in place for many years (Diamondhead Consulting et al., 2013). This has been successful for the purpose of preventing invasive hybrid birch (*Betula papyrifera x pendula*) from establishing. Mowing's effects on other aspects of the bog ecosystem are not well known. Mowing is a relatively recently introduced disturbance. It targets both invasive species and native plants. It also rips up the soil, annually disturbing *Sphagnum*. Populations of *Sphagnum* mosses, keystone species for bog ecosystems, continue to be very patchy across the site despite rewetting, with broad swathes of the site bare of almost any vegetation including *Sphagnum*. Existing research on the impacts of mowing on bog ecosystems, including on *Sphagnum* moss, is quite limited. A meta review of 14 studies found that annual mowing could have positive impacts on fen ecosystems, such as increased moss cover, increased plant diversity, and increase of fen- or wet-meadow- specific plants (Taylor et al., 2020). However, the effects of mowing on bogs vs fens may not be the same. One study in a European bog found that clipping competing vegetation had no effect on the growth or moisture retention of transplanted *Sphagnum* (Robroek et al., 2009).

In order to inform the management of the site in the interest of restoring as near to a healthy native bog ecosystem as possible, it was seen as necessary to examine the impacts of mowing on the bog ecosystem, including on *Sphagnum* growth.

Objective and hypotheses

The study was designed in order to examine the effects of mowing cessation on the bog ecosystem. This particular paper looks at the effects of mowing cessation on soil moisture and *Sphagnum* regeneration specifically, stated in the following hypotheses:

H_0: Mowing cessation will have no effect on soil moisture and/or *Sphagnum* regeneration

H_a: Mowing cessation will have an effect on soil moisture and/or *Sphagnum* regeneration

Methods

Site selection

Study site was located in the portion of the Garden City Lands Peat Bog south-east of Kwantlen Polytechnic University's GCL research and teaching farm. The site was selected because it was located in one of the only portions of the bog restoration site which had a relatively healthy population of *Sphagnum* in Fall of 2019. *Sphagnum* moss and hardhack (*Spirea douglasii*) were variably distributed throughout the study area.

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A Randomized Complete Block Design was used, with 2 treatments and 12 replicates/blocks (24 plots total). Study area consisted of a 50 x 20 metre rectangle, divided into a 3x8 grid of square plots with ~6m long sides (fig. 1.). Treatments were blocked in pairs to account for differences in *Sphagnum* and hardhack coverage across the study area. Treatments were mowed (control), and unmowed. Treatments were assigned randomly within paired plots by coin toss.

In November 2019, green coverage (which was mostly *Sphagnum*) was assessed in order to establish whether there was any difference in *Sphagnum* coverage between plots before the beginning of the experiment. Leaf litter was removed from plots using a leaf blower. Each plot was photographed from 3 standardized locations at a set height, and photos were processed using Canopeo smartphone application to give % green coverage. Percent coverage was analyzed, and no significant difference was found in sphagnum coverage between treatments. A significant replicate effect was found, with more *Sphagnum* towards the north and east.

On 21 November 2019, 31 October 2020, and 31 October 2021, plots assigned mowing treatment were mowed using a flail mower attached to a walk-behind tractor. This was to emulate the standard mowing practice that the GCLPR receives every Autumn. Plots assigned unmowed treatment were left undisturbed.

Data collection

Moisture readings
On 20 October 2022, soil moisture data was collected. Data was collected prior to the beginning of the rainy season in order to assess soil moisture at the driest time of year. using a soil moisture meter (Brand? TDR) with 20cm prongs. 3 readings were taken per plot at ~2.1 m, ~4.2 m, and ~6.4 m along a southwest-northeast diagonal line across each plot.

***Sphagnum* regeneration**

On November 2 2022, *Sphagnum* regeneration was assessed. Data was collected after a period of rain, which was necessary in order to tell which *Sphagnum* had survived the dry season, and to compare *Sphagnum* vigour. Transect sampling was chosen due to the patchiness of *Sphagnum* and due the dense hardhack shrubbery in unmowed plots.

Three types of data were collected from each observation (*Sphagnum* patches intersected by the transect):

1. The start and end point of each intersection of a *Sphagnum* patch by the transect measuring tape, measured in metres
2. The estimated density of intercepted *Sphagnum*, measured in percent coverage
3. The estimated average quality of intercepted *Sphagnum* on a scale of 1-5, with 1 being barely alive and 5 being as very green and healthy looking with no room for improvement

Additionally, the distance of plot boundaries along each transect (m) was recorded, since the length of a transect over each plot varied due to the draping of the measuring tape over hardhack brush and uneven topography.

Data was collected from 6 transects. Plot specific data was desired, but for ease of sampling, transects crossing 8 plots were set up, and data for each plot was separated during analysis. For each east-west row of plots, a measuring tape was run through the midpoint of plots, and another at the midpoint of the first transect and the northern edge of the row of plots. Data collection occurred from east to west.

Data processing and analysis

All statistical analyses were carried out using jamovi (The jamovi project, 2021; R Core Team, 2021).

Moisture readings

Means were compiled from readings in each plot. Normality was assessed with q-q plots and Shapiro-Wilk test. A paired samples t-test was carried out on treatment means.

***Sphagnum* regeneration**

Observations from transects were matched with their corresponding plot. Data from within 0.5m of a plot boundary was removed to eliminate edge effects.

A *Sphagnum* Regeneration Index (SRI) was calculated for each observation according to the following formula:

$SRI = (d_2-d_1) \cdot (C/100) \cdot V \cdot 6/(p_2-p_1)$

Where SRI=*Sphagnum* Regeneration Index
d_1=starting point of observation
d_2=ending point of observation
C=percent coverage
V=Vigour
p_1=starting point of plot
p_2=ending point of plot

SRI values of observations were summed for each plot to give total plot SRI.

Normality of plot SRIs was assessed using q-q plots and Shapiro-Wilk test. No transformation could be found to fit data to a normal distribution, so a mixed-effects model analysis was chosen.

A mixed-effects model analysis was carried out, with treatment as the fixed effect, replicate as a cluster variable, and SRI as a dependent variable. Bonferroni and Holm's post-hoc tests were conducted. Kolmogorov-Smirnov and Shapiro-Wilk tests were conducted for normality of residuals.

Results

Moisture

For every replicate, mean moisture in mowed plots was greater than in paired unmowed plots (fig xxx). Normality of data was confirmed with Shapiro-Wilk test ($p=0.402$). Mowed and unmowed treatment means differed significantly, with mowed volumetric moisture significantly higher than unmowed ($p<0.01$,).

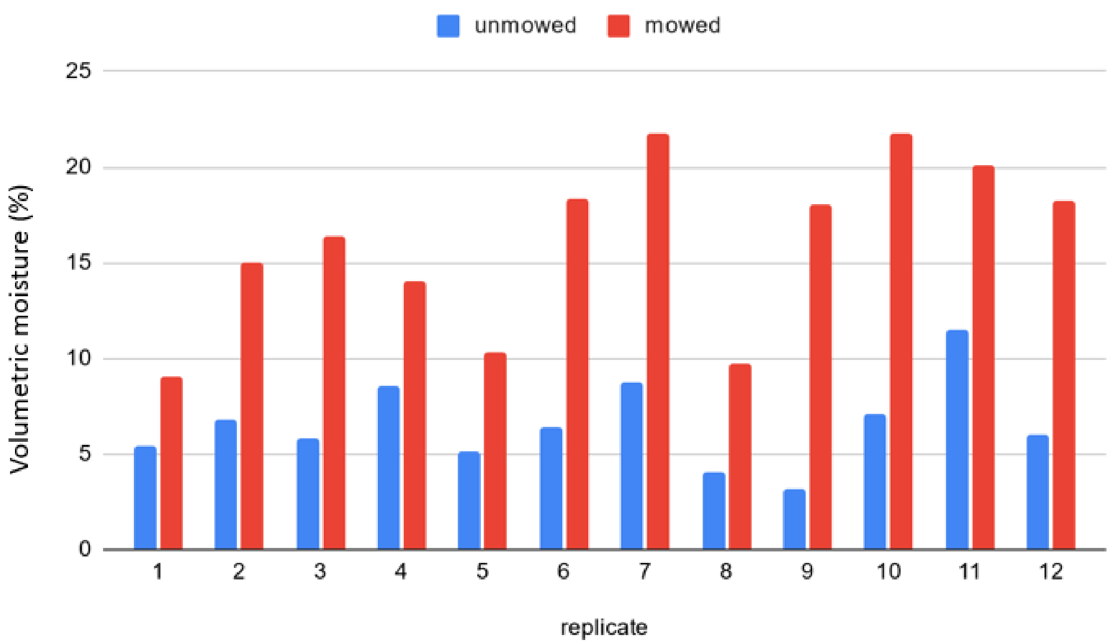

Figure 1. Soil volumetric water (%) in mowed-unmowed plot pairs (graph generated using google sheets)

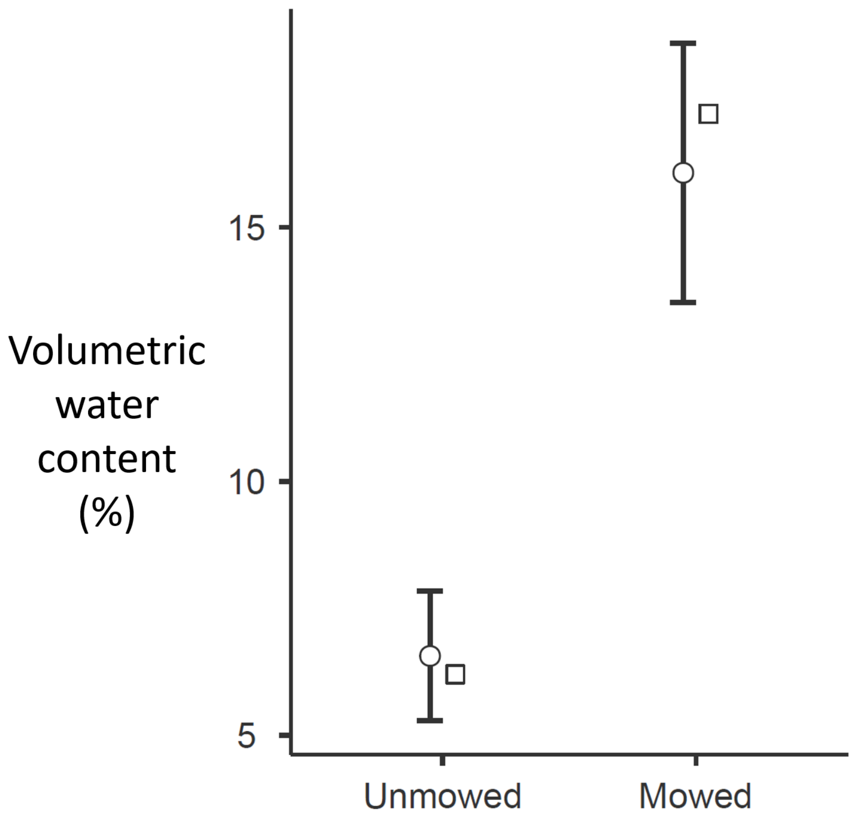

Figure 2. Soil moisture in mowed and unmowed plots. Error bars denote 95% confidence interval around mean (n = 12). Small squares show medians. Treatments differ significantly (t-test, $p < 0.05$).

***Sphagnum* regeneration**

For every replicate, mean SRI values in unmowed plots was greater or equal to those in paired mowed plots (fig xxx). Normality of data was rejected (mowed $p<0.001$; unmowed $p=0.023$). Mowed and unmowed treatment means differed significantly ($p=0.002$; fig xxx). Post-hoc tests showed mowed SRI was significantly lower than unmowed SRI (difference=9.59±SE2.33; $p_{bonferroni}=0.002$; $p_{holm}=0.002$). Normality of residuals was confirmed ($p_{Kolmogorov\text{-}Smirnov}=0.327$; $p_{Shapiro\text{-}Wilk}=0.101$).

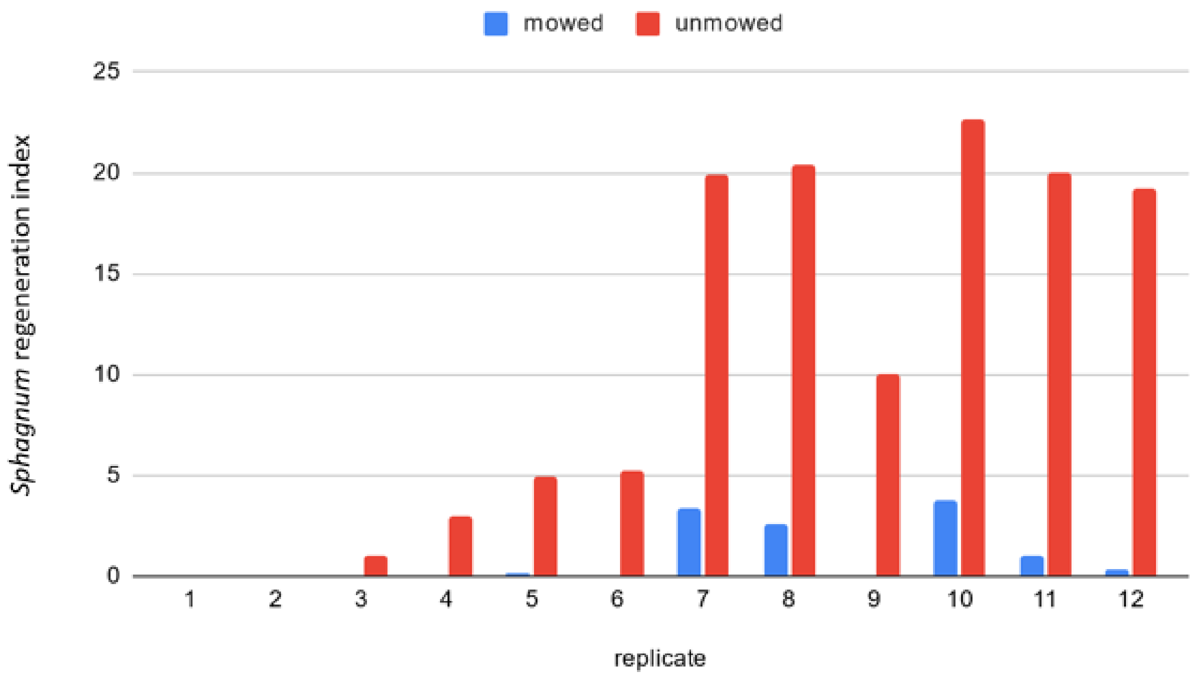

Figure 3. *Sphagnum* regeneration index in mowed-unmowed plot pairs (graph generated using google sheets)

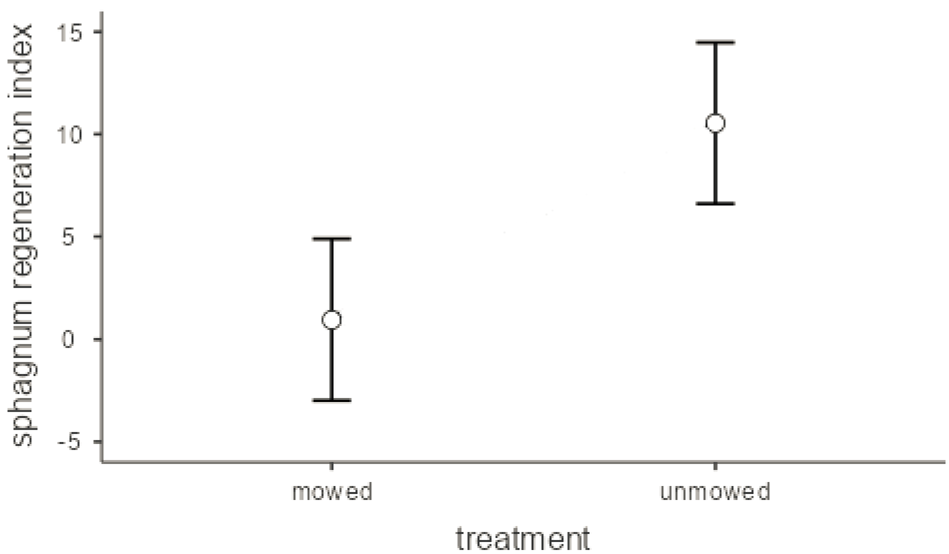

Figure 4. SRI in mowed and unmowed plots. Soil moisture in mowed and unmowed plots. Error bars denote 95% confidence interval around mean (n = 12). Treatments differ significantly (mixed model, $p < 0.05$).

Discussion

Significantly higher SRI in unmowed plots shows that cessation of mowing will likely have a positive effect on *Sphagnum* abundance and vigour at the GCLPB. Several factors may have contributed to increased *Sphagnum* regeneration:

1. Shading from developing shrub canopy would have reduced both desiccation and UV damage resulting from direct sunlight
2. Transpiration from developing shrub canopy would have increased relative humidity around *Sphagnum*, slowing desiccation rate
3. Shrubbery would have reduced airflow around *Sphagnum*, slowing desiccation rate
4. Cessation of physical disturbance of mowing, which may have been destroying established *Sphagnum* every year

Heijmans et al. (2001) found the presence of vascular plants with *Sphagnum* resulted in lower evapotranspiration than *Sphagnum* monoculture, and this effect was dependent on wind conditions, indicating that reduced air circulation is a primary mechanism by which vascular plants support good growing conditions (moist environment) for *Sphagnum*. They also speculate that shading plays a role.

The significantly lower levels of volumetric soil moisture in unmowed plots is notable in that it indicates that soil moisture alone is not a main factor in *Sphagnum* regeneration, and *Sphagnum* can survive virtually complete desiccation of its substrate in the absence of mowing, likely due to the aforementioned shading and wind-reducing effects of vascular plant cover.

These results have implications for the future management of GCLPB. Cessation of mowing could encourage growth of *Sphagnum* mosses and subsequently improve overall bog ecosystem functioning through return of healthy keystone species populations. Due to continued concerns over invasive birch, this should at least occur in areas where birch population is low and could reasonably be controlled in the absence of mowing by manual removal. Unmowed areas would need to be monitored for other invasive species as well, since domestic blueberries have been known to create “blueberry deserts” in the Lulu Island Peat Bog (Davis & Klinkenburg, 2008).

Further data can be collected from the experiment in future years in order to learn more about the impacts of mowing and mowing cessation on the bog ecosystem. Potentially useful areas of inquiry include looking at total plant diversity, diversity of invasive vs native plants, and peat deposition rate. Soil moisture readings taken with both 10cm and 20cm prongs could give more information on moisture gradient near surface. Longer term study on the impacts on *Sphagnum* growth will be important in order to ensure that *Sphagnum* doesn’t eventually get shaded out by a mature shrub canopy.

Further study would be needed to inform management of areas with high levels of birch and other invasives which couldn’t be reasonably controlled manually.

Birch pressure is highest in the most degraded sections of the bog, and does not establish in areas where boglike conditions (high water table, low pH) are more intense (Davis & Klinkenburg, 2008). It’s possible that if mowing cessation in areas of low birch pressure tips the ecological balance in favour of more boglike conditions, there could be a positive feedback loop with edge effect which could eventually change conditions enough in birch-dense areas that birch pressure will decrease and mowing can be ceased without any other human intervention.

Historically, fire was a natural disturbance in the Lulu island peat bog which contributed early-successional herb-dominated clearings in an otherwise tree and shrub dominated bog, and fires were deliberately set by Indigenous Coast Salish people to promote certain bog plants (Davis & Klinkenburg, 2008). However, invasive plants have been observed quickly moving into recently burnt areas, and fire can favour more minerotrophic vs ombrotrophic plant species (Davis & Klinkenburg, 2008). There is an overall paucity of data when it comes to the impacts of fire on bog ecosystems (Heinemeyer & Ashby, 2021). It may be fruitful to investigate whether controlled burns could be a viable strategy to manage dense patches of invasive birch without mowing. This should occur in partnership/collaboration with local Indigenous groups if there is an interest.

Conclusion

Mowing cessation increased *Sphagnum* regeneration despite lower soil moisture levels. This implies that mowing cessation in areas of low birch density could be the appropriate management choice to promote bog ecosystem restoration. Further study is needed to inform mowing practices in birch-dense areas.

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