The effect of prescribed burns on soil characteristics and plant communities in Garry Oak ecosystems.

A case study on a three-year post-burn site on Tumbo Island, Gulf Islands National Park Reserve.

by

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Abstract

This research project evaluates the outcomes of returning prescribed fire to endangered Garry oak meadows as a restoration treatment. This project was done in partnership with Parks Canada and involved a case study on a three-year post-burn site on Tumbo Island in the Gulf Islands National Park Reserve. Soil chemical properties were analyzed three years post burn in the summer of 2019 and compared to pre and post-burn vegetation survey results. Analysis identified beneficial changes in soil chemistry still present three years post treatment. Invasive species occurrences increased across the site, regardless of treatment, and around half of the invasive species occurrences were recorded on burn treatments areas in 2018. Prescribed burns on shallow soil Garry oak meadow sites showed beneficial outcomes for soil chemistry, reduced conifer encroachment, increased diversity and Arbutus (*Arbutus menziesii*) seedling recruitment. These findings aid in determining restoration plans for shallow soil Garry oak meadows, highlighting the numerous benefits from prescribed fire, while also suggesting that additional treatments in conjunction with prescribed fire will be needed to control invasive plants when planning to restore these ecosystems.

Keywords: Garry oak meadows; restoration; prescribed fire; soil nutrients; invasive plant species; shallow soil

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List of Acronyms

SFU	Simon Fraser University
BCIT	British Columbia Institute of Technology
GINPR	Gulf Islands National Park Reserve
GOERT	Garry Oak Ecosystem Recovery Team
CAA	Canonical Correspondence Analysis

Figure 1. Photo of Tumbo Island research site (Pinnell 2019)

1.0 Introduction

Garry oak (*Quercus garryana)* meadow ecosystems are one of the most endangered ecosystems in Canada, with less than 5% remaining in their original state (Garry Oak Recovery Team 2018). Garry oak ecosystems provide essential habitat for over one hundred species that are endangered either provincially or federally (Pellatt et al. 2007). Garry oak ecosystems have a long cultural history of traditional management by the Coast Salish peoples (McCune et al. 2013). Regular burning, annually or biannually, by the Coast Salish peoples maintained the meadow habitat and associated species, such as camas (*Camassia* spp.), a cultural keystone species (Garibaldi & Turner 2004; Pellatt & Gedalof 2014). Since European settlement, Douglas-fir (*Pseudotsuga menziesii*) trees and invasive plants have encroached on the Garry oak meadows, as a result of changes in the disturbance regime due to fire suppression (Pellatt & Gedalof 2014; McCune et al. 2013). There are at least 147 known invasive species in Garry oak and associated habitats (GOERT 2018). These invasive plants take up space, available nutrients and light, limiting the growth and presence of native species. Many of the invasive plants have high nitrogen requirements, and explosive growth when plant available nitrogen is readily available for them (GOERT 2011). The changed disturbance regime in Garry oak meadow habitats today has resulted in increased nitrogen availability, which in turn has resulted in expansive growth of invasive plants. This has led to increased competition and often outcompeted native plants, which cannot take advantage of the increased nitrogen to grow faster. This pulse of invasive plant growth leads to an increased fuel load present in the ecosystem and thus higher intensity fire on the landscape (GOERT 2011). Douglas-fir trees have their most productive growth on moist, nitrogen-rich soils (Organisation for Economic Co-operation and Development 2008), so increased nitrogen built up in the soil supports increased encroachment. It has been suggested that returning fire to these ecosystems may restore species diversity and ecological integrity. Although research has focused on the effects of prescribed burning on the establishment of Garry oak plant communities, not enough is known about its effects on soil properties.

Fire has been linked to Garry oak meadows for thousands of years. The open structure of Garry oak meadows was maintained through frequent, low-intensity fires. Fires act as an ecological rejuvenator; they reduce competition, increase mineral nutrient recycling and maintain successional stages while creating openings (Deur & Turner 2005). The increase in open area provided by the fire, allowed for easier cultivation of camas (*Camassia* spp.), which was an important starch food source (Garibaldi & Turner 2004), on deep soil sites and created viewscapes for hunting and habitation. Prescribed fires are complex, as fire alters both the aboveground ecosystem, through changes to biomass and successional stage, and the physical, chemical and biological processes occurring in the soil (Raison et al. 1985; Neary et al. 1999). Fire changes the availability of nutrients by changing the soil pH, as well as volatizing certain nutrients and leading to the leaching and runoff of others. Ecosystems such as Garry oak are disturbance driven systems that rely on short interval return times of fire to maintain the habitat and subsequently the species composition.

This case study examines the plant community ecology and its changes overtime with a prescribed fire treatment. Examining the outcome using plant community ecology allows for a holistic approach to the restoration treatment, rather than focusing on a desired endangered species or detrimental invasive species (Gillet et al. 2012). Furthermore, plant species have direct and indirect impacts on other plant species through facilitation, allopathy and competition, which makes an individualistic approach to ecosystem restoration ineffective (Lortie et al. 2004). Restoration treatments generally manipulate environmental factors (light availability through thinning, nutrient availability through prescribed fire) and these changes cause a cascade of impacts through the plant community, with different species reacting differently. For this research, plant community ecology analysis will showcase the overall impacts of a prescribed fire treatment on the plant community as a whole. This approach to view community changes give a better indication if the ecosystem will be able to support the various species that rely on it and fulfill its ecosystem functions.

This case study evaluates the impacts of returning fire to a shallow soil Garry oak meadow site. The research was conducted at a Parks Canada research site on Tumbo Island in the Gulf Islands National Park Reserve (GINPR), BC. This research site underwent a prescribed burn in September 2016 with pre and post vegetation monitoring. Field work was conducted in the summer of 2019 to study the post fire impacts on the soil nutrients and the associated vegetation communities. Understanding soil conditions may be key to restoring Garry oak meadows. Garry oak ecosystems are naturally nitrogen poor, and when nitrogen levels increase the prevalence of invasive species increases as well (GOERT 2011), furthering the loss of the ecosystem. In this study the term ‘invasives’ will be used to refer to any non-native plant species, thus referring to both exotic and more noxious invasive plants together. Chemical analysis of the soil carbon, nitrogen and pH between burned and unburned plots and their respective vegetation communities can increase the understanding of the outcome of management practices on these endangered ecosystems.

Assessing the effects of a prescribed burn after a period of three years will help us determine the effectiveness of prescribed burns and the longevity of their impact on the soil characteristics, as well as the native and invasive plant populations. The goal of this project was to increase the understanding of the management techniques being used and determine best management practices for Garry oak meadow ecosystems, with a specific focus on shallow soil sites. This work will contribute to baseline data for the Tumbo Island research site and help inform future restoration plans for all shallow soil Garry oak meadows.

2.0 Objectives

The primary goal of this study was to increase the understanding of the effects of prescribed fire on soil characteristics and plant communities in Garry oak ecosystems. The objectives for this study were three-fold. First, this study determined the effect of fire on soil chemical characteristics. Total carbon, total nitrogen, ammonium, nitrate and pH were analyzed. Then the changes in the plant communities pre and post burn were examined. Finally, the soil variables for burned and unburned plots were compared to vegetation data from the same plots to ascertain the best management practices for these sites.

Garry oak ecosystems are under serious threat and should be a priority for restoration efforts. By increasing the understanding of the effects of prescribed burns through this case study, future burns conducted by Parks Canada and other organizations can be most effectively conducted to increase the success of restoration activities in these important ecosystems. Furthermore, most research focuses on deep soil Garry oak meadow ecosystems when using prescribed fire for restoration, where as this study focuses on shallow soil Garry oak meadow ecosystems, giving more information to this habitat type.

2.1 Sub objective 1: To determine the effect of fire on soil chemical characteristics.

Hypothesis: Prescribed burns result in lower nitrogen due to volatilization during burning. The plant available forms of nitrogen, ammonium and nitrate, will be measured, as well as total nitrogen (plant available and unavailable forms).

Hypothesis: Prescribed burns result in lower total carbon due to combustion during burning.

Hypothesis: Prescribed burns result in higher soil pH due to the ash by-product which decreases the acidity of the soil.

The soil chemistry data was compared between treatments (burned and unburned) for each variable to test the null hypothesis. Determining the effect of fire on the soil chemical characteristics is important as soil is the growing medium for the ecosystem. This study examines the effect of the fire three years post burn to see if the treatment has lasting effects, which will aid in determining the best frequency of prescribed fire treatment.

2.2 Sub objective 2: To determine the effect of fire on plant communities.

Hypothesis: If prescribed burning results in decreased nitrogen in burned plots, native plant frequency will increase, and invasive plant frequency will decrease in burned plots.

Determining the effect of fire on plant communities is vital to understanding the effectiveness of prescribed fire as a restoration treatment for shallow soil Garry oak meadows. By examining the changes in species occurrences (native and invasive), as well as the diversity, decision makers will have an increased grasp of the potential outcomes of using this restoration treatment on similar habitats.

Sub objective two tested the hypothesis by comparing the species composition between treatment types and plot diversity between treatments pre and post burn. This experiment aids in determining the effectiveness of using prescribed fire as the main restoration treatment for shallow soil Garry oak meadow habitats.

3.0 Methods

3.1 Study Site

Tumbo Island is one of the southern and eastern most islands in the Strait of Georgia and part of the Gulf Islands in British Columbia (Figure 2). The study site is located on the southeast corner of Tumbo Island. Tumbo Island was a homestead in the 19th century but has been uninhabited since before Parks Canada acquired it in 1997, where it was subsequently included in GINPR in 2003 (Kenney et al. 1988; Parks Canada 2017). Tumbo Island was the location chosen by Parks Canada to conduct their prescribed burn experiment. Tumbo is uninhabited by humans, reducing property risk associated with the burn, but the site is visible by the nearby populated eastern portion of Saturna Island, which allowed the burn to also be an educational experience for locals as they could witness a burn with no risk to themselves.

Tumbo Island is part of the Coastal Douglas-fir moist maritime biogeoclimatic zone, characterized by dry summers and mild wet winters (Government of BC 2018; Nuszdorfer, Klinka & Demarchi 1991). The site has an average slope of 25% (Barlow 2018) covered with a shallow soil layer and exposed bedrock. Tumbo Island is located in the Nanaimo Lowland subdivision of the Georgia Depression which is characterized by steep hills that erode into gentle slopes (Kenney et al. 1988). Minimal soil mapping has been conducted for Tumbo Island. It was included in the Experimental Farm Service (1958) map and the whole island was delineated as being of the series ‘rocky mountainous land’. It was studied in greater detail in the 1988 soil survey but was amalgamated into the results of Saturna and lesser islands (Kenney et al. 1988). The soil is classified as part of the Dystric Brunisol soil great group (Nuszdorfer, Klinka & Demarchi 1991), denoting it has had minimal horizontal development and is early in its evolution from its parent material. The Dysrtric great group indicates that the soil generally has a pH less than 5.5 and an organic A horizon less than 10cm in depth (University of Saskatchewan n.d.).

The habitats found on the Tumbo research site can be divided into Douglas-fir and shallow soil Garry oak communities. The northern approximately 50-75% of each plot can be characterized as Douglas-fir communities (Barlow 2018). Sites with deep enough soil can transition to Coastal Douglas-fir dominated areas within a few decades with suppression of natural disturbance pressures usually present in Garry oak ecosystems (GOERT 2011). The southern 25% of each plot is an exposed coastal shallow soil bluff that can best be characterized as a Garry oak-Grey rock-moss-Wallace's selaginella plant association (Qgrm; Erickson & Meidinger 2007). The shallow soil area of the site has exposed bedrock, steep cliff faces and is xeric (Erickson & Meidinger 2007).

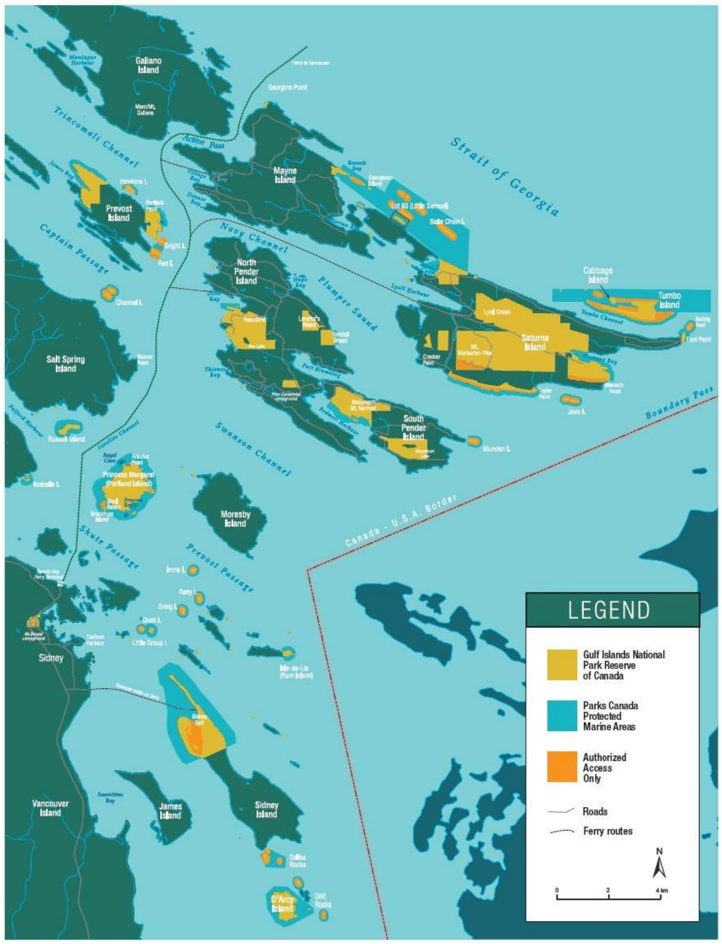

Figure 2. Gulf Islands National Park Reserve Map (Parks Canada 2017).

Figure 3. Aerial view of study site highlighting experimental plots on Tumbo Island in the GINPR (Pellatt 2016).

Parks Canada established eight permanent study plots on the southeast corner of Tumbo Island. These 50 m by 50 m plots are lettered alphabetically (A-H), running from the east to the west. Four of these plots received a prescribed burning treatment in September 2016 (A,C,E,G), and four were left unburned as controls (B,D,F,H) (Figure 3). The burn treatment was applied to every second plot. Two six-by-six m deer exclosures were placed in each plot pre-burn. Each plot contains 20 one-by-one m sampling quadrants, randomly placed within each plot with a minimum distance between quadrats of five metres.

In June of 2010 and 2015, Parks Canada staff collected pre-burn vegetation data within the quadrats, and then followed up in June 2017 and 2018 for post-burn vegetation data collection. Plant data was measured by frequency, using a 1x1 m PVC quadrat subdivided into a 20 x 20 cm grid. Frequency was recorded as the number of 20 x 20 cm cells within the 1 x 1 m quadrat, that each species was present in. Plants did not have to be rooted in the cell to count as present, but tree branches/sprouts below one metre that were in the quadrat were included. This data was collected by the Parks Canada team, and was used in conjunction with the soil data collected by this study to determine the effects of prescribed fire on soil and vegetation communities.

3.2 Fieldwork

Fieldwork for this study occurred in late July 2019. Soil samples were collected from 144 quadrats, delineated from the original experimental procedure used at the site. A soil auger was used to take a 10 cm core, which was then divided into 0-5 cm and 5-10 cm portion samples. The 0-5 cm depth portion is important as differences in burned and unburned plots in other studies have found the greatest differences in soil chemistry occur in the 0-1 cm layer (Miller & Fey 2004). Savadogo et al. found that composite samples collected for 0-10 cm depth from prescribed burn treatments were not statistically different in terms of physical and chemical properties and lend support to the idea that physiochemical changes from the fire are in the top few centimeters of the profile and changes are lost when samples have too great a depth (2007). Other studies assessing physical soil changes after fire noted textural and colour changes to a depth of 1 to 8 cm, which were still present after three years (Ulery & Graham 1993). These studies supported the methodology supplied above regarding taking two cores (0-5 cm and 5-10 cm) to account of physical change over the long term, while still capturing the chemical changes.

Due to the shallow soil and exposed bedrock some quadrats only yielded a 0-5 cm sample. This resulted in ultimately having 281 soil samples. The previously mentioned deer exclosures are outside of the scope of this project due to confounding influences with the lack of herbivory pressure, and thus soil cores were not taken from quadrats within the exclosures. Originally this project proposed to compare the nematode communities present between treatments, but due to complications in identification this was not included in the final analysis. Basic information regarding genera identified and nematode numbers per plot can be found in Appendix A.

3.3 Laboratory

3.3.1 Sub objective 1: To determine the effect of fire on soil chemical characteristics.

Soil samples were air-dried and sieved to 2 mm fraction size. ~20 g of each of the 281 soil samples were sent to the BC Ministry of Environment and Climate Change Analytical Laboratory to determine the percent total carbon, percent total nitrogen and plant available nitrogen in each sample. Total nitrogen and carbon were calculated using the combustion method for the ThermoFisher Flash 2000 system, and available nitrogen was determined using a KCl extraction based on Carter SSMA 6.2. with ammonium and nitrate extracts measured colourmetrically (K.Beaudet personal communication 16 April 2019).

Samples were analyzed in the Parks Canada lab in Vancouver for pH, moisture content and percentage of coarse material. The pH was measured as pH in water and moisture content was determined using the gravimetric soil water content calculation.

$$\% \, SoilWater = \frac{weight\ of\ wet\ soil(g) - weight\ of\ dry\ soil(g)}{weight\ of\ dry\ soil(g)} x100$$

3.4 Statistics

Statistical analysis was conducted on vegetation and environmental factor data to determine the impact of the treatment on the site. Data manipulation was conducted in RStudio (R Core Team 2019) and used the sqldf R package (Grothendieck 2017). Plant diversity matrices were analyzed using vegan (Oksanen et al. 2019), and biodiversityR (Kindt & Coe 2005) R packages. Hierarchical multivariate analysis was performed using Canoco 4.5.6 software and the canonical correspondence ordination plots and biplots were created on CanoDraw v.3.0 (Microcomputer Power 2006).

3.4.1 Sub objective 1: To determine the effect of fire on soil chemical characteristics.

Soil data was analyzed to detect differences between treatment (burned) and control (unburned). Plant available nitrogen (ammonium and nitrate), total percent carbon and total percent nitrogen, pH and percent coarse material were analyzed at both 0-5 cm depth and 5-10cm soil depth. Data was analyzed using the Wilcoxon rank sum two sample test as the data were not normally distributed (Tables 1 and 2). Soil variables were compared between the plots as well as between the treatments using standard error of the mean and 95% confidence intervals (Appendix B).

3.3.2 Sub objective 2: To determine the effect of fire on plant communities.

Parks Canada vegetation data (2010, 2015, 2017 and 2018) was analyzed. Vegetation survey data was compared between years, pre burn and post burn treatment, to detect changes in vegetation community. Plant species changes were measured as changes in frequency of occurrences in quadrats totalled for each plot. Short term plant community changes were examined by comparing the 2015 pre-burn data with the 2017 and 2018 post burn data. For long term changes, the 2010 plant community data was compared to the 2018 data, to show the long-term changes at the site. Then the 2018 plant survey data was analyzed for species diversity using species accumulation curves, with a focus on change in native and invasive plant diversity by treatment.

The 2018 plant survey data was also compared to the corresponding 2019 soil sample results by each specific quadrat to investigate linkages between species and specific environmental vectors. The goal of the analysis was to see if any soil variables had a significant impact on the plant community, especially when looking at either invasive or native plant subgroups. This analysis assumes negligible change between 2018 and 2019 in environmental factors to allow the analysis to be valid.

4.0 Results

4.1 Soil Analysis

Soil chemistry results for pH, ammonium, nitrate, total percent nitrogen and total percent carbon, as well as soil physical results for percent coarse material were compared between treatments using the Wilcoxon rank sum test and summarized in Table 1 for 0-5 cm soil depth and in Table 2 for 5-10 cm soil depth.

R results for Wilcoxon rank sum test → 2 sample test

*Table 1. Results for Wilcoxon rank sum two sample test for **0-5cm soil depth**.*

Analysis	Median Value in Burned Plots	Median Value in Unburned Plots	P-value	Significant (α =0.05)	Significantly higher value in BURNED or UNBURNED
pH	5.955	5.830	0.01486	yes	Burned
Percent Coarse Material	15.41760	20.30948	0.02679	yes	Unburned
Ammonium	2.25	3.30	<0.001	yes	Unburned
Nitrate	0.36	0.21	0.02006	yes	Burned
Total % Nitrogen	0.19	0.27	0.005318	yes	Unburned
Total % Carbon	3.6	5.8	<0.001	yes	Unburned

*Table 2. Results for Wilcoxon rank sum two sample test for **5-10 cm soil depth**.*

Analysis	Median Value in Burned Plots	Median Value in Unburned Plots	P-value	Significant (α =0.05)	Significantly higher value in BURNED or UNBURNED
pH	5.97	5.84	0.08733	no	
Percent Coarse Material	17.96011	25.72089	0.07576	no	
Ammonium	1.90	2.05	0.3218	no	
Nitrate	0.420	0.235	0.08878	no	
Total % Nitrogen	0.13	0.16	0.02145	yes	Unburned
Total % Carbon	2.80	3.55	0.001931	yes	Unburned

*Lab results for ammonium and nitrate recorded as <0.1 mg/kg were analyzed as 0.1 mg/kg. Total percent nitrogen results measured as <0.05 mg/kg were analyzed as 0.05 mg/kg. These results are shown in the tables above.
*Significant differences were maintained when both <0.01 mg/kg and <0.05 mg/kg were analyzed as 0 mg/kg but with different p-values.

As shown in Table 1, the burned treatment resulted in statistically significant higher pH and nitrate at the 0-5cm soil depth. Nitrate values varied greatly within and between plots. Nitrate results ranged from <0.1 mg/kg to 43 mg/kg in unburned samples and <0.1 mg/kg to 29 mg/kg in burned samples. The unburned samples had a greater range but fewer outliers, which overly impacted the results in the Wilcoxon rank sum test. Figure 4 shows a boxplot of the nitrate sample results by treatment which illustrates the unequal spread in the data. The high number of outliers reduces the confidence in the result and thus nitrate should be analyzed again to confirm there is a significant difference between treatments.

The unburned control resulted in significantly higher percent coarse material, total percent nitrogen, total percent carbon and ammonium in the 0-5 cm soil layer (Table 1). At the 5-10 cm soil depth, unburned soil had significantly higher total percent carbon and total percent nitrogen (Table 2).

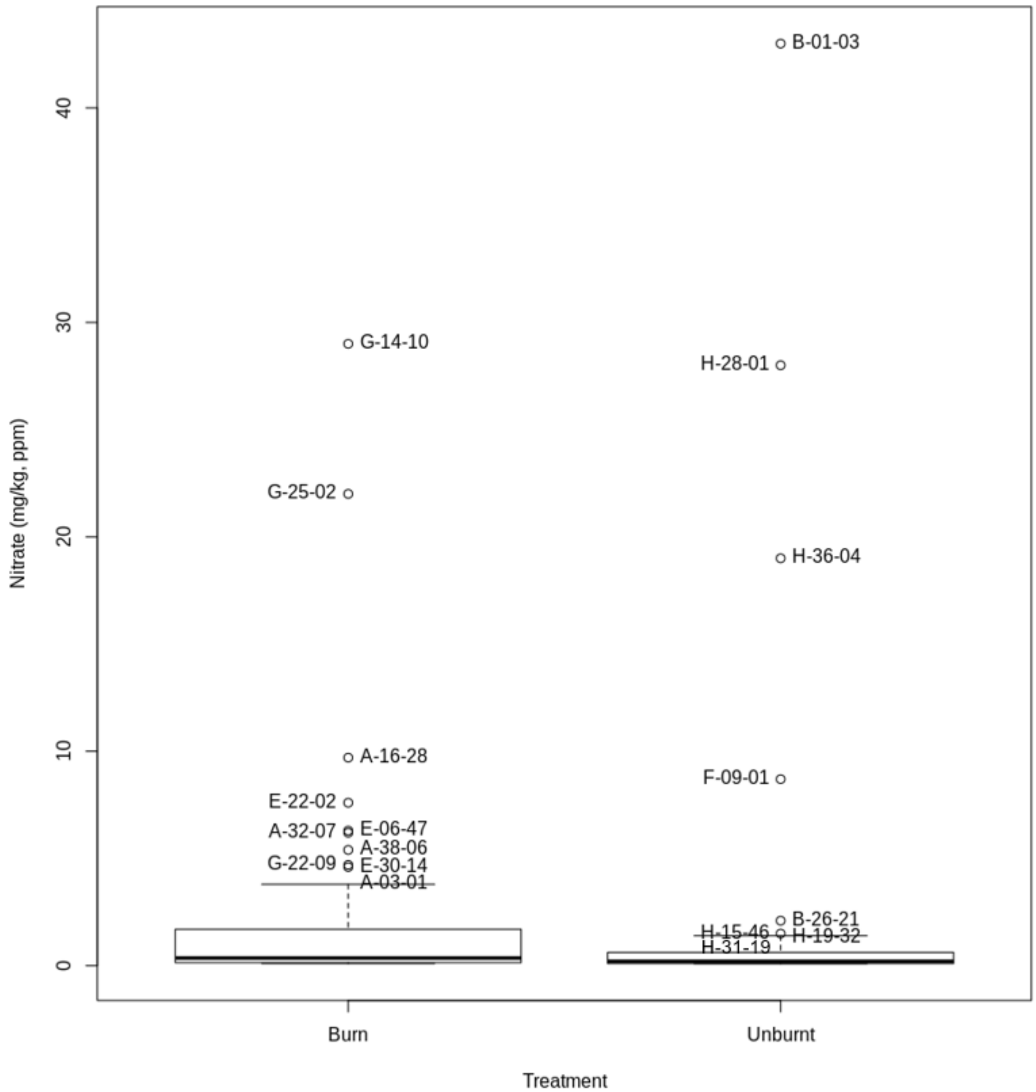

Figure 4. Boxplot of nitrate analysis results by treatment.

4.2 Vegetation Analysis

The plant surveys found a total of 107 plant species across the site and 7 land cover types (bare rock, bare soil, tree litter, deer scat, goose scat, large burned areas and small burned areas). The abundance, measured as number of 20 x 20 cm portions of each 1 x 1 m quadrat, varied by plot, treatment and plant survey year. Plant were grouped by type into seven groups (trees, native forbs, invasive forbs, native grasses, invasive grasses, shrubs and miscellaneous, and non-vascular plants and land cover) and compared over different years from the Parks Canada plant survey occurrence data as totals of the quadrats per plot.

4.2.1 Short Term Vegetation Changes

Only native tree and shrub species were found at the Tumbo Island research site. Arbutus juveniles (*Arbutus menziesii)*, and Douglas-fir seedlings (*Pseudotsuga menziesii*) were the most abundant tree species in the burn plots (Figure 5). There was a rapid peak of juvenile arbutus post burn treatment in 2017, and while still elevated in 2018 compared to pre-treatment levels (2010), they had dropped in number by 2018. This pattern is followed by Douglas-fir seedlings to a lesser degree.

* This data is property of Parks Canada and is not available for public use at this time.
Please contact Dr. MG Pellatt for further information.

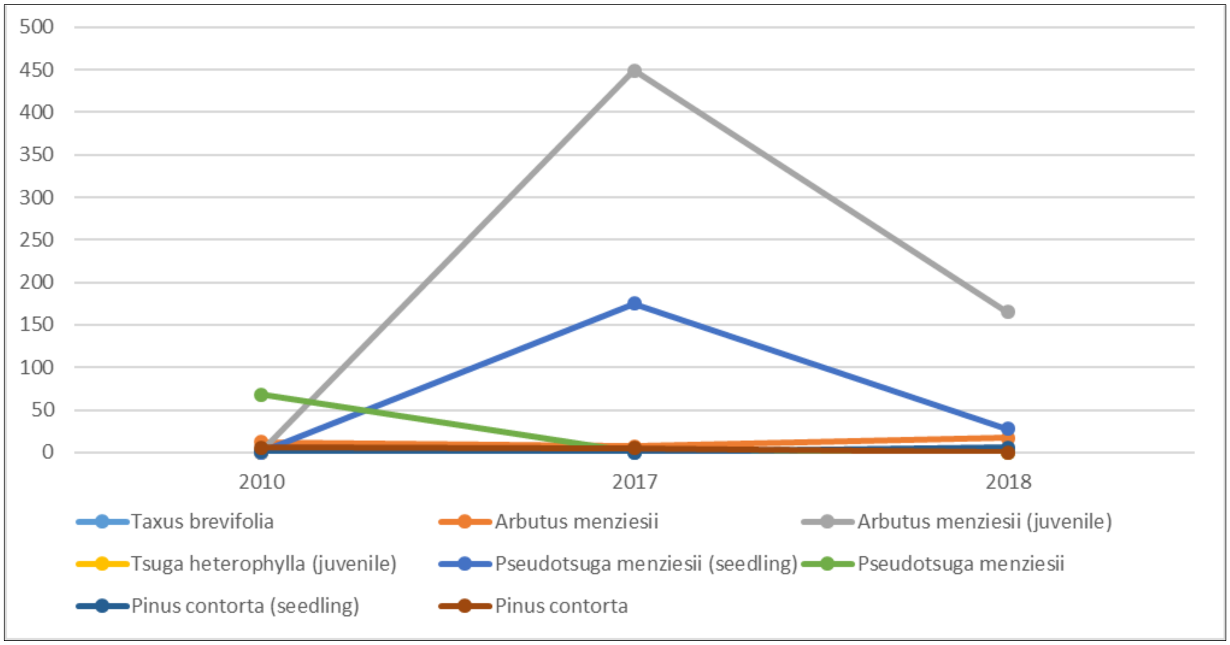

Figure 5. Sum of each tree species occurrence in all burned plots combined pre-burn (2010) and post treatment (2017 & 2018).

Invasive grass species occurrences increased site wide across all plots, treatment and control, over time in the plant surveys. Figure 6 illustrates that invasive grasses appear to have higher occurrence numbers in plots in later years, and generally higher in burned treatment plots (A,C,E,G).

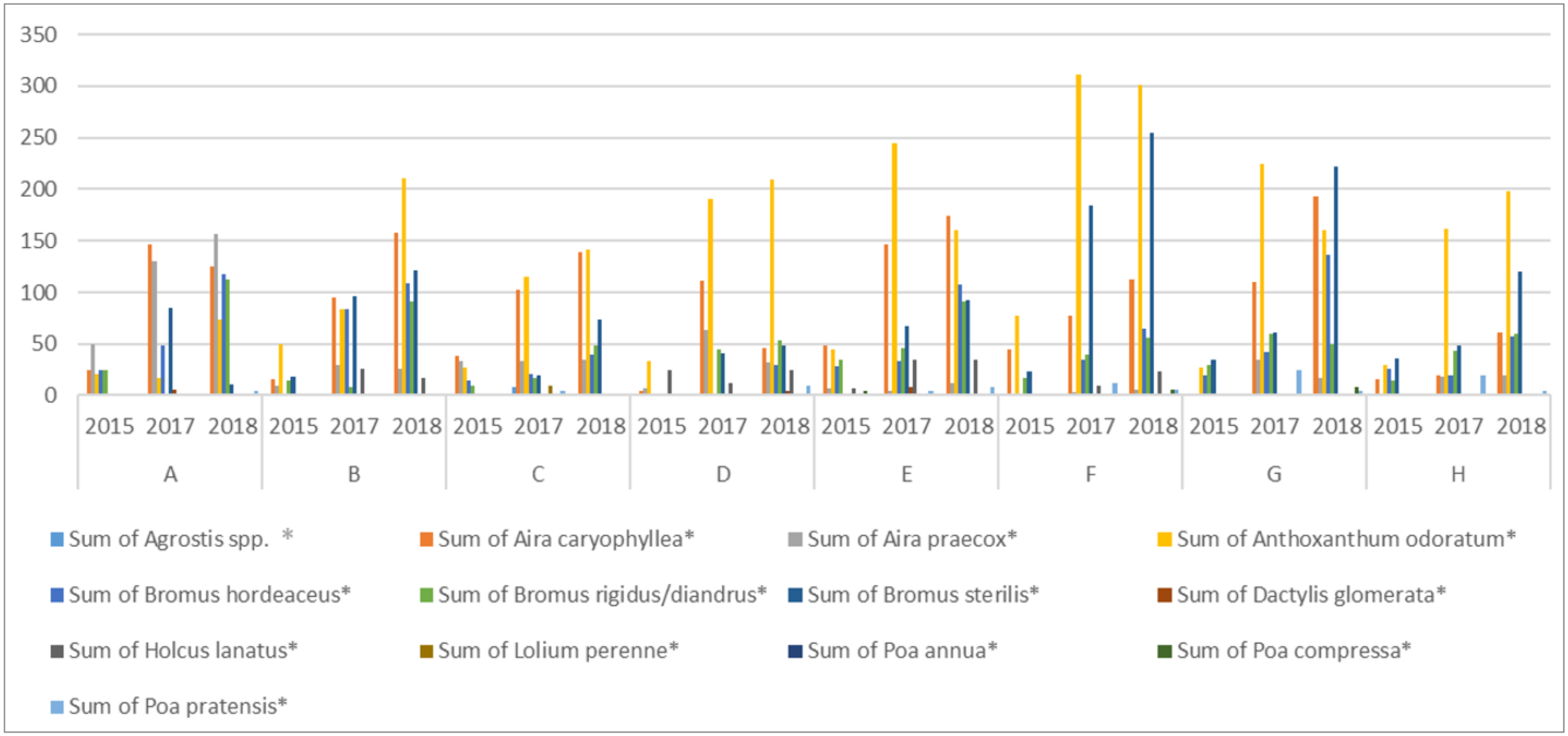

Figure 6. Invasive grass species occurrences in all plots (burned and unburned), pre-burn (2015) and then post treatment in 2018 and 2018. Asterisks denote invasive species.

Generally, there is a pattern of increased invasive plant diversity with fire, as shown in burn treatment plots following the burn treatment in 2016 (Figure 7). Specifically, silver hairgrass (*Aira caryophyllea*), sweet vernalgrass (*Anthoxanthum odoratum*), and barren brome (*Bromus sterilis*) increased greatly after the prescribed fire treatment.

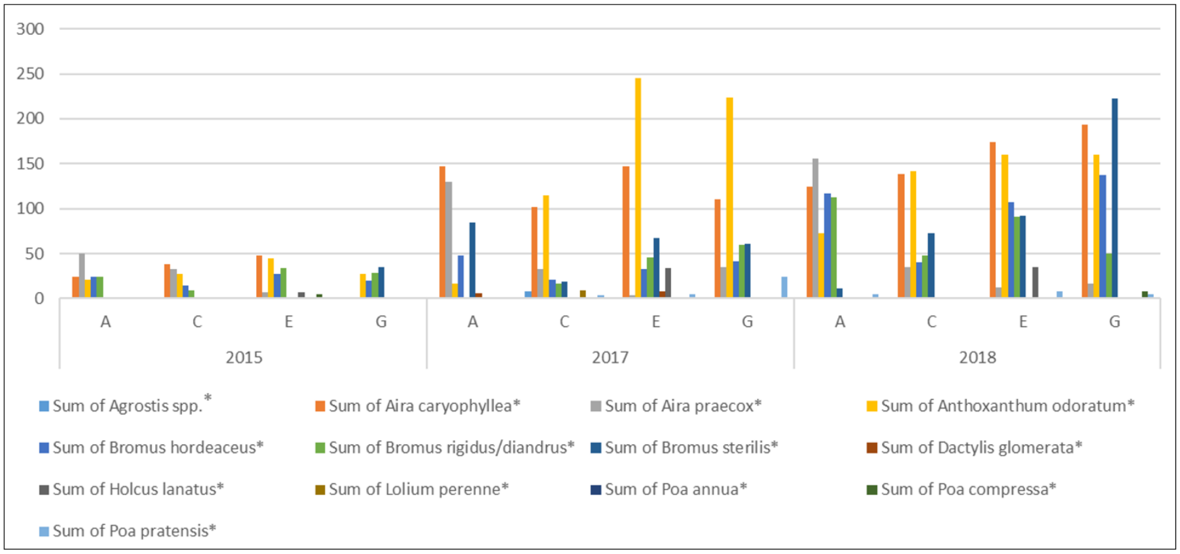

Figure 7. Invasive grass species occurrences across burned plots pre and post treatment. Asterisks denote invasive species.

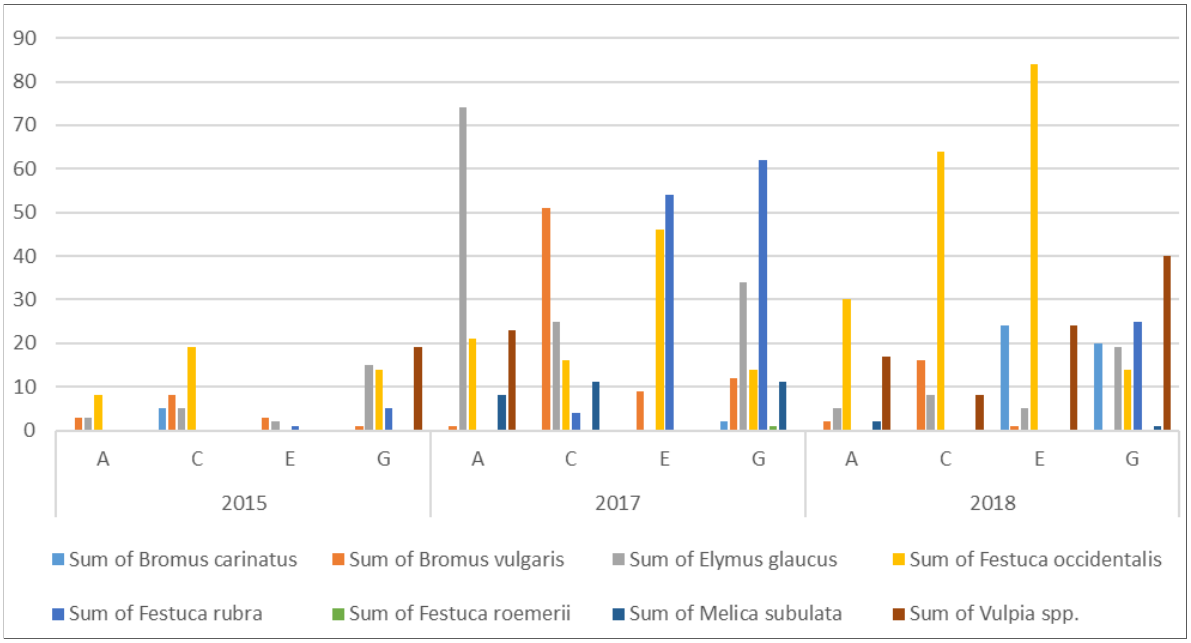

Figure 8. Native grass species occurrences in burn treatment plots pre and post burn.

Native grass species, as shown above in Figure 8, have a general trend of increasing in plant richness and occurrences of each species post burn treatment in 2017 and 2018. There is a greater grass diversity, both native and invasive, with fire.

4.2.2 Long Term Vegetation Changes

There was some concern about the validity of the 2015 plant data due to potential inconsistencies in the collection method (M.Pellatt personal communication 10 March 2020). As such an overall comparison of the research site's changes was conducted using the 2010 and 2018 data to evaluate the long-term vegetation community changes.

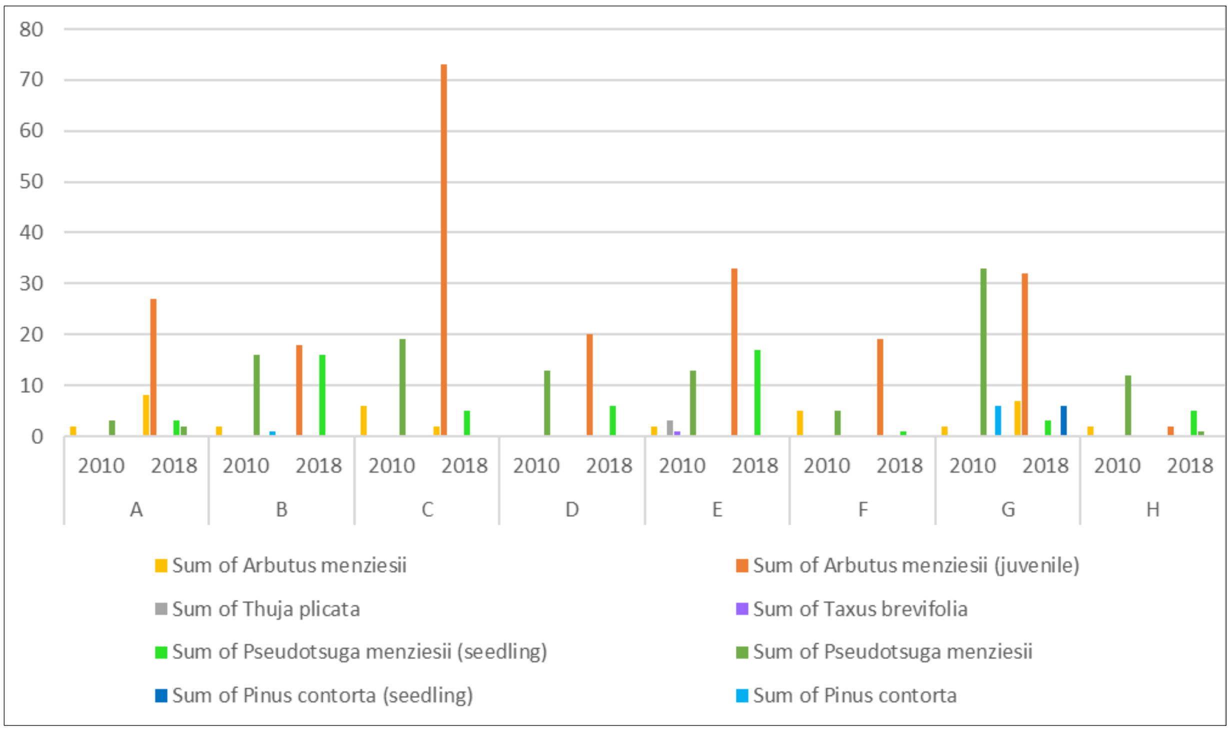

Figure 9. Tree species total occurrences by plot in 2010 (pre-burn) and 2018 (post-burn).

The pattern seen in Figure 5 with an increase in desired tree species (Arbutus) and decrease in mature Douglas-fir overtime is clearly shown in Figure 9. In 2018 there is a marked increase in the number of seedlings for *Arbutus menziesii* as well as to a lesser extent *Pseudotsuga menziesii* seedlings. There is visually a large decrease in the number of mature *Pseudotsuga menziesii,* especially in the burn plots of C and G.

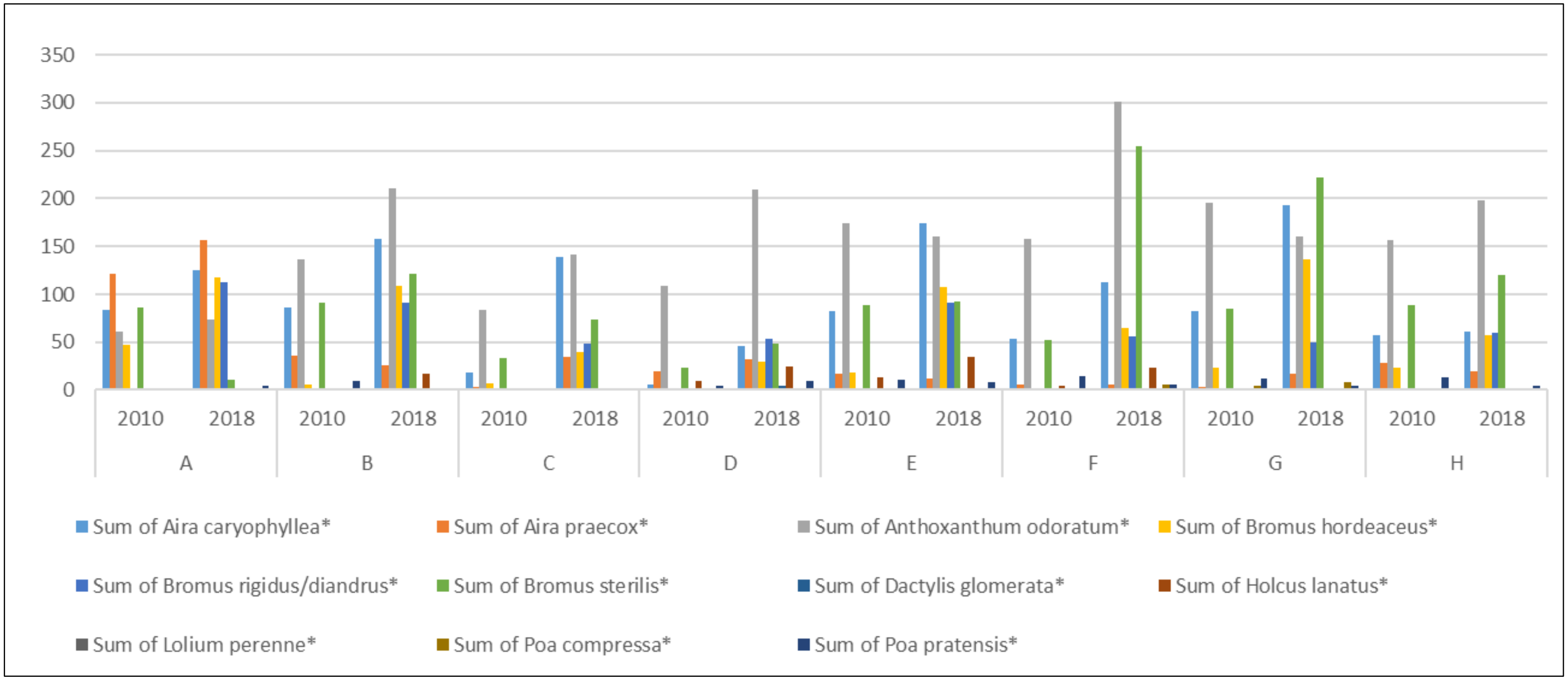

Figure 10. Invasive grasses occurrences by plot in 2010 and 2018.

Grasses were examined by category (Figure 10 invasive and Figure 11 native) and compared by number of recorded occurrences by plot in each plant survey (2010 and 2018). Figure 10 shows a pattern of increased diversity of species and number of occurrences per species across all plots in 2018 compared to 2010. Through a visual comparison there does not appear to be a noticeable difference between burned plots (A,C,E,G) and unburned plots (B,D,F,H). In Figure 11, there does not visually appear to be any appreciable patterns in native grass species occurrences either over time, or from the burn treatment,

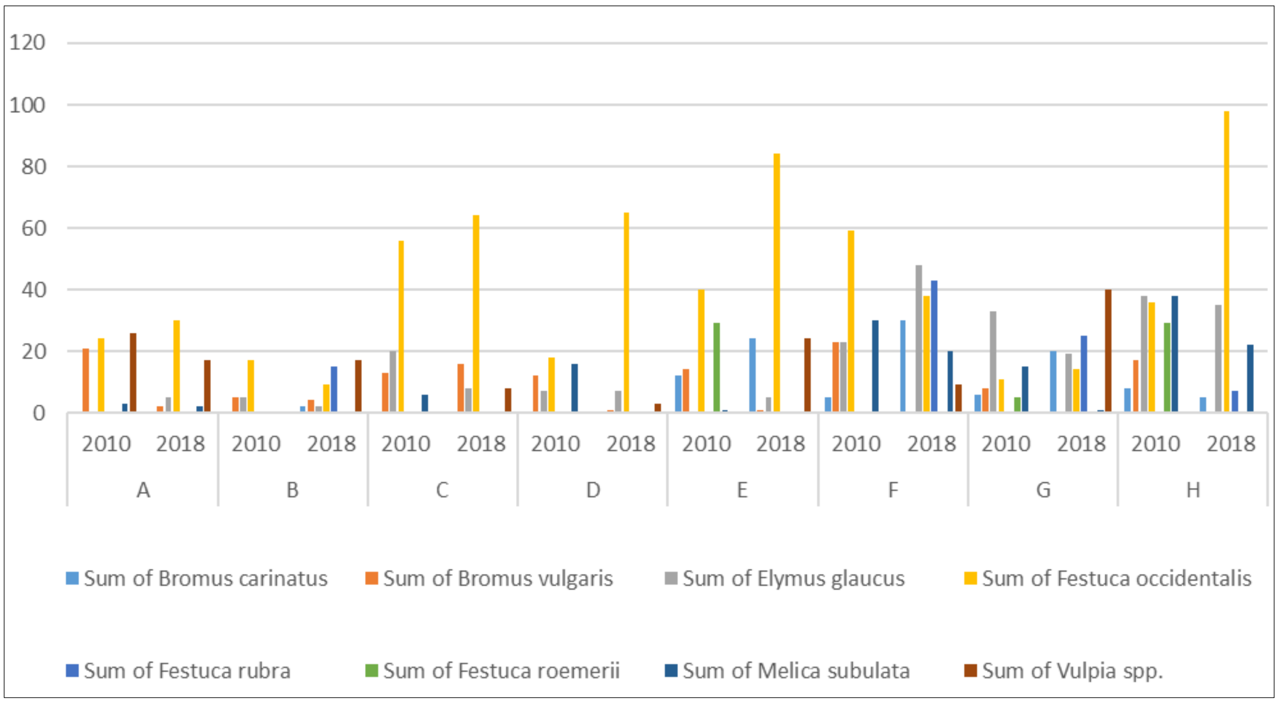

Figure 11. Native grasses by occurrence in all plots in 2010 and 2018.

4.2.3 Species abundance and diversity analysis

Further analysis into the species abundance and diversity present on the site was conducted to track the overall changes in native and invasive species. Overall species abundance was calculated using species accumulation curves (Figure 12). This analysis measures the impact of the treatment (burn) on the species richness as a whole rather than by groups of plants.

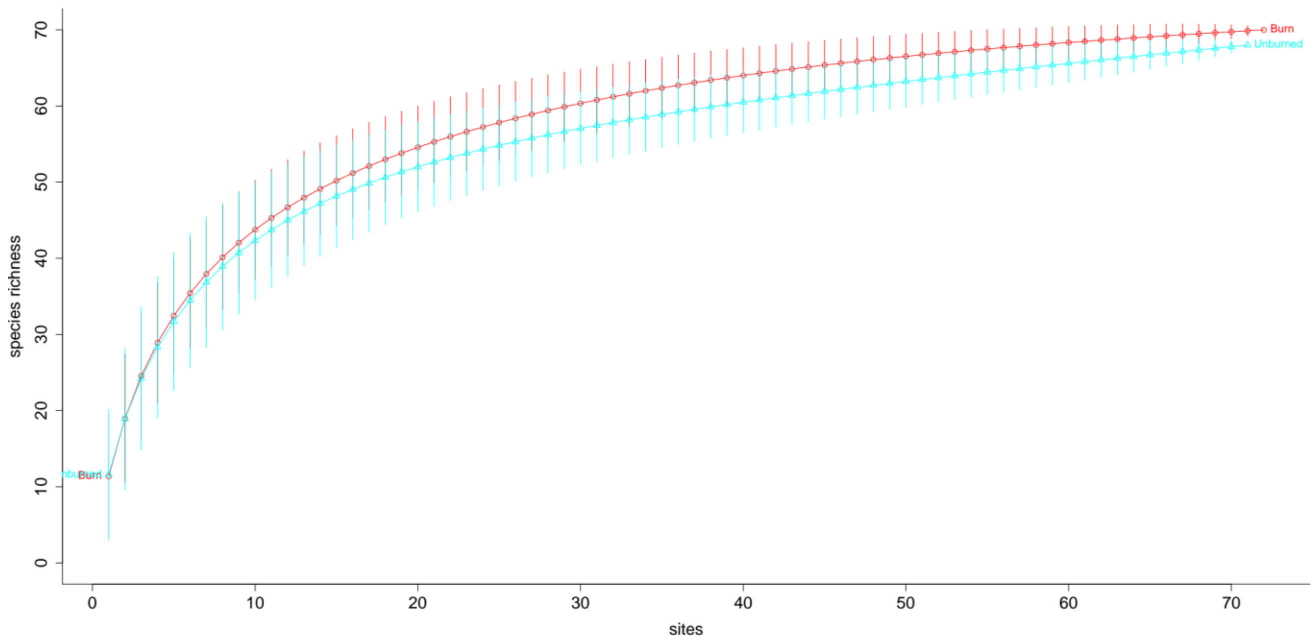

*Figure 12. Species accumulation curve showing **total** species richness by treatment. X-axis is measuring quadrats. Points on the curve show the mean species richness and bars represent variation depending on order in which quadrats are examined. Blue is unburned and red is burned.*

This diversity indices compares species richness between burned and unburned sites. The averaged pooled species richness accounts for the different combinations of sites with different species richness (Kindt & Coe 2005). As shown in Figure 12, for the middle range of sites, there is a greater species richness on burned than unburned sites. As the sites approach the maximum, the difference in species richness between treatment and control is reduced.

Further analysis of the species richness based on treatment but divided by invasive species (Figure 13) and native species (Figure 14) illustrates that the difference seen between treatments in Figure 12 comes largely from the species richness differences in invasive species. There is minimal difference in species richness in native species between treatment and control. This takes into account all native plants, not just grasses as shown in Figures 8 and 11. The species accumulation curve for invasive species levels off with burned sites having slightly more invasive species per site than unburned sites.

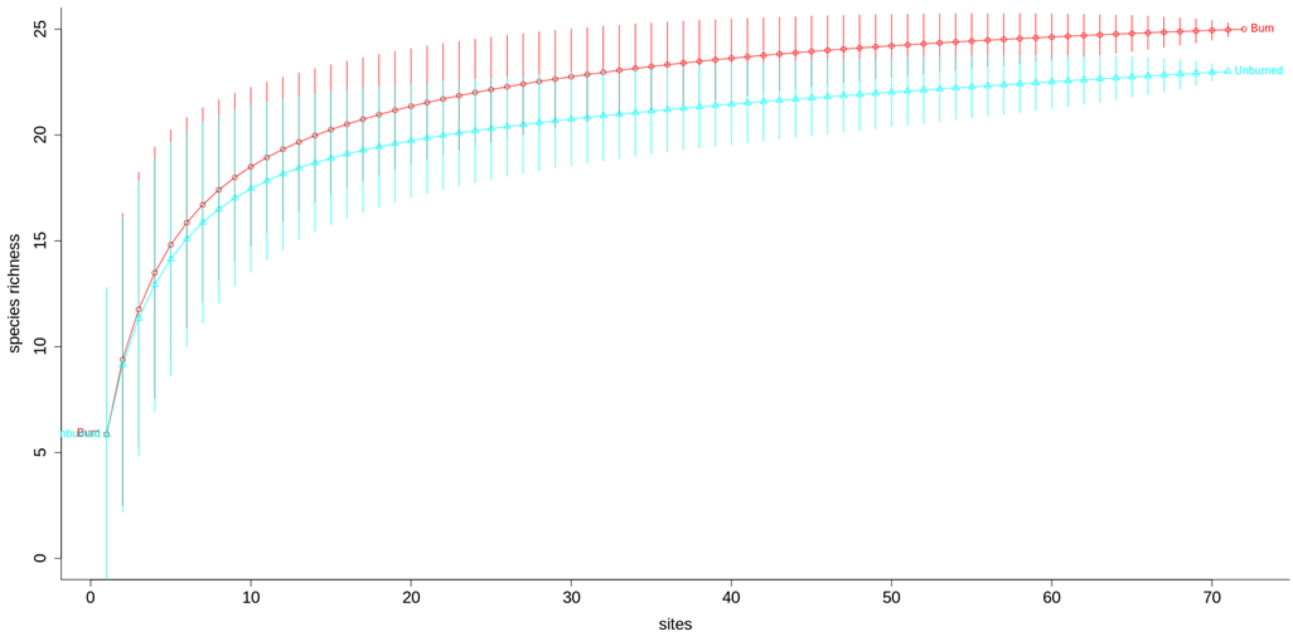

*Figure 13. Species accumulation curve showing **invasive** species richness by treatment. X-axis is measuring quadrats. Points on the curve show the mean species richness and bars represent variation depending on order in which quadrats are examined. Blue is unburned and red is burned.*

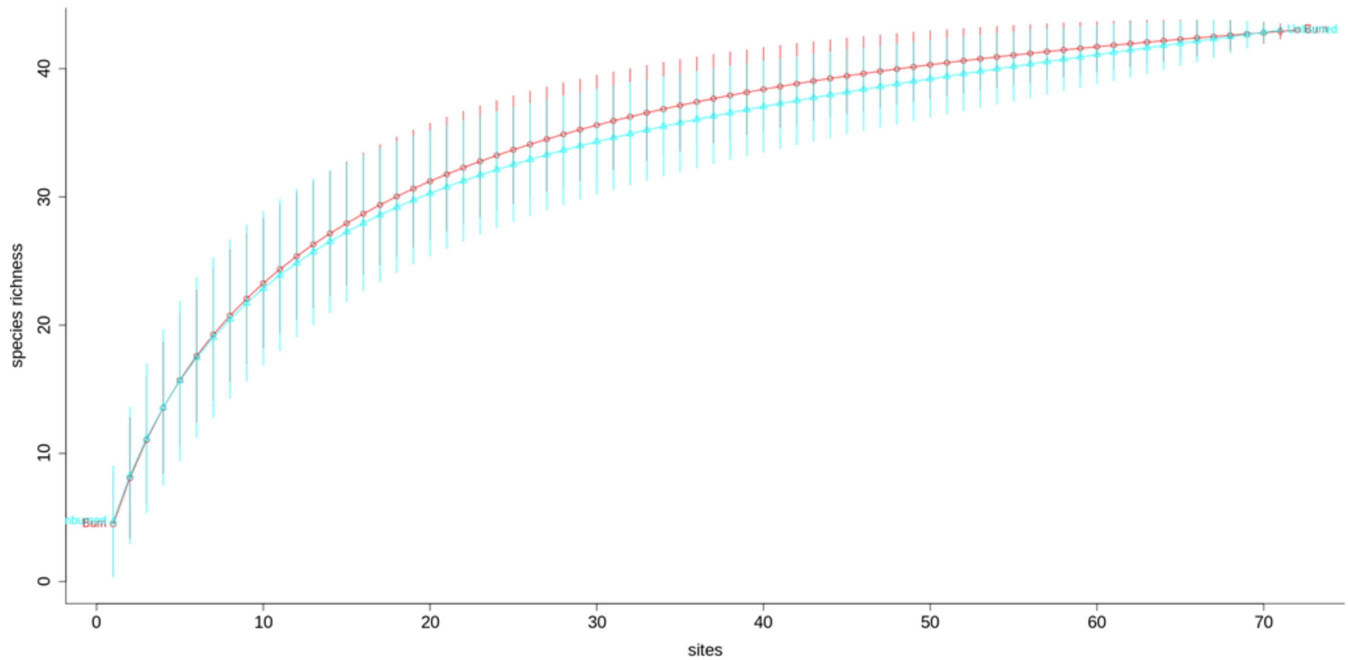

Figure 14. Species accumulation curve showing ***native*** *species richness by treatment. X-axis is measuring quadrats. Points on the curve show the mean species richness and bars represent variation depending on order in which quadrats are examined. Blue is unburned and red is burned.*

4.2.3.1 Invasive Plant Species

Invasive species found during the 2018 plant survey were analyzed by rank abundance by occurrence per quadrat, both by focusing only on burned plots as well as across the total study site (summarized in Table 3). The cumulatively top six most abundant invasive plant species found at the Tumbo Island experiment site three years post burn were the same for the burned plots and the total study site, just in a slightly different order of predominance. *Aira caryophyllea, Anthoxanthum, Hypochaeris radicata, Bromus horeaceus, Bromus sterilis,* and *Bromus diandrus* were the dominant invasive plants, and had at least one third to over one half of their total occurrences in burned plots in the 2018 plant survey (Figures 15 & 16).

Table 3. List of invasive species found on burned plots and across total study site by rank abundance in 2018. Abundance calculated as number of occurrences per 20 x 20 cm portion of each 1 x 1 m quadrat per plot. Species information from BC Species and Ecosystem Explorer (Province of BC 2020) and GOERT Invasive Species List (2003a).

Rank Abundance of Species on Totalled Burned Plot Quadrats	Invasive Species	Common Name	Plant Type	Total Number of Occurrences in Burned Plot Quadrats	Rank Abundance of Species Across Total Study Site	Total Number of Occurrences in Total Study Site Quadrats
1	***Aira caryophyllea***	**Silver hairgrass**	**Grass**	**613**	**2**	**988**
2	***Anthoxanthum odoratum***	**Sweet vernalgrass**	**Grass**	**528**	**1**	**1388**
3	***Hypochaeris radicata***	**Hairy cat's ear**	**Forb**	**428**	**3**	**959**
4	***Bromus hordeaceus***	**Soft brome**	**Grass**	**383**	**5**	**644**
5	***Bromus sterilis***	**Barren brome**	**Grass**	**378**	**4**	**901**
6	***Bromus diandrus***	**Rip-gut brome**	**Grass**	**298**	**6**	**559**
7	*Aira praecox*	Early hairgrass	Grass	220	**11**	303
8	*Trifolium dubium*	Small hop-clover	Forb	189	**8**	339
9	*Cerastium glomeratum*	Sticky chickweed	Forb	171	**9**	314
10	*Rumex acetosella*	Sheep sorrel	Forb	164	**10**	313
11	*Teesdalia nudicaulis*	Shepherd's cress	Forb	154	**7**	372
12	*Plantago lanceolata*	Ribwort plantain	Forb	116	**12**	244
13	*Vicia sativa*	Common vetch	Forb	58	**13**	164
14	*Galium aparine*	Cleavers	Forb	56	**17**	61
15	*Myosotis discolor*	Common forget-me-not	Forb	46	**18**	51
16	*Veronica arvensis*	Wall speedwell	Forb	46	**14**	131
17	*Holcus lanatus*	Common velvet-grass	Grass	36	**15**	100
18	*Hypochaeris glabra*	Smooth cat's ear	Forb	23	**16**	100
19	*Poa pratensis*	Kentucky bluegrass	Grass	18	**19**	38
20	*Geranium molle*	Dovefoot geranium	Forb	13	**21**	13

21	*Centaurea melitensis*	Maltese star-thistle	Forb	8	**23**	9
22	*Poa compressa*	Canada bluegrass	Grass	8	**20**	14
23	*Vicia hirsuta*	Hairy vetch	Forb	7	**22**	12
24	*Cirsium vulgare*	Bull thistle	Forb	1	**25**	1
25	*Dactylis glomerata*	Orchard grass	Grass	1	**24**	5

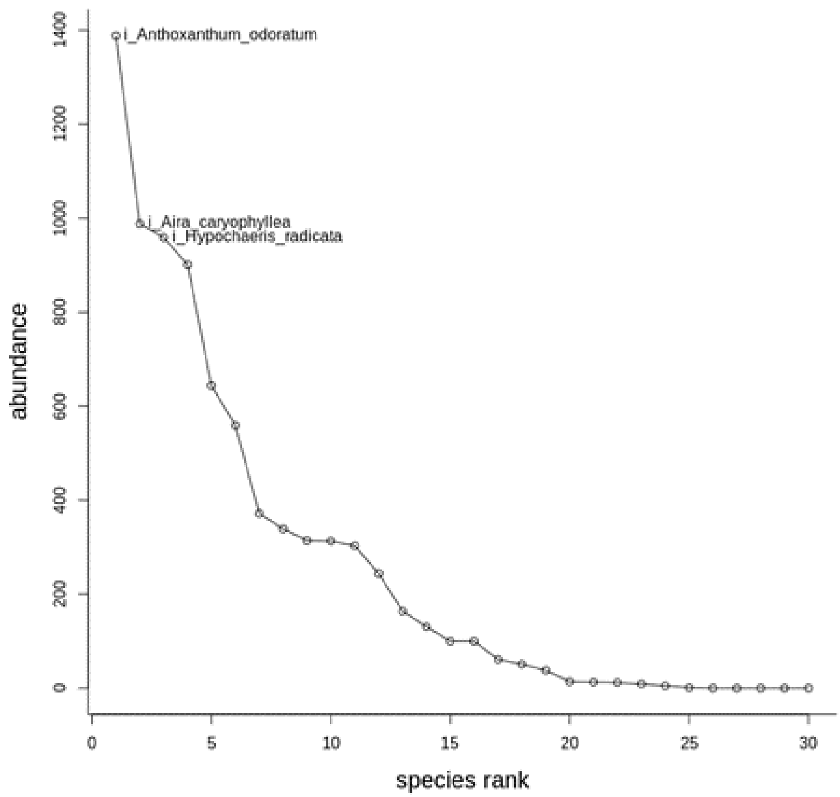

Figure 15. Rank abundance curve ***of total invasive species occurrences on Tumbo Island study site*** *plant surveys in 2018. Y-axis range of 0 to 1400.*

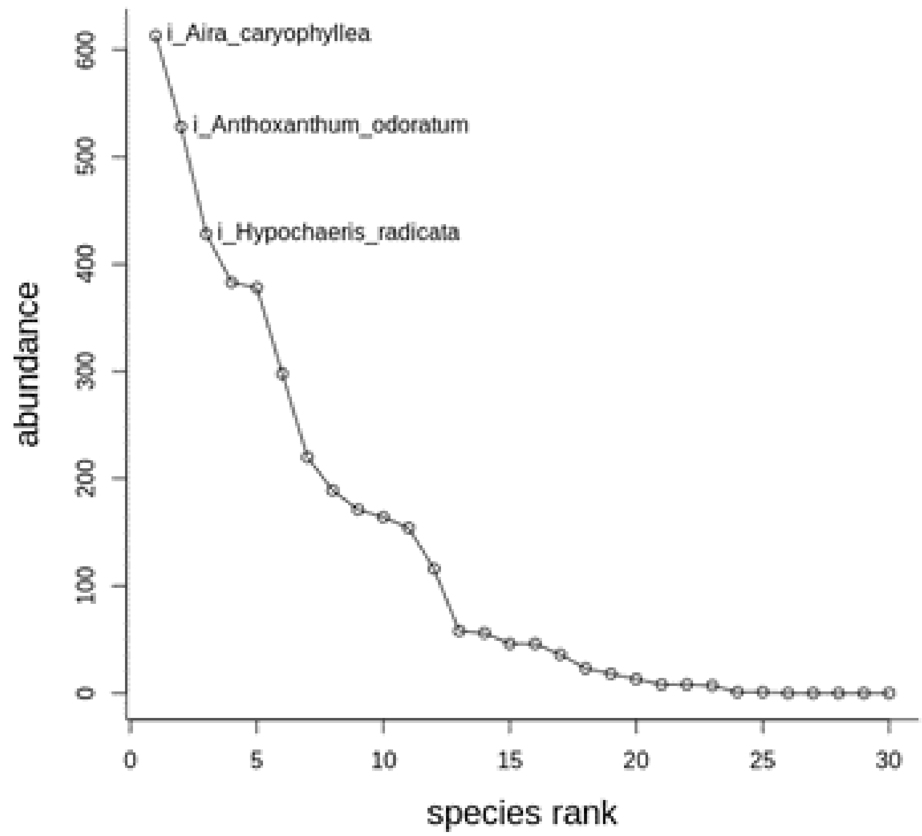

*Figure 16. Rank abundance curve of **invasive plant species in burned plot quadrats** in 2018 plant survey. Y-axis range of 0 to 600.*

4.2.3.2 Native Plant Species

Native plant species occurrence analysis between burned plots and the total site from the 2018 plant survey is shown in Table 4. Rank abundance curves for native plants are in Appendix C. The same 5 native plant species were most abundant, in the same order, in both the burned plots and for all the plots together. There were only four native species found solely in the control plots (*Eriophyllum lanatum, Lonicera ciliosa, Goodyera oblongifolia* and *Lathyrus nevadensis).* An interesting finding in the native plants was that 74% of all juvenile Arbutus trees were found in the burned plots, which is noteworthy as they are an iconic, much loved species associated with Garry oak meadows. Similarly, lodgepole pine saplings (*Pinus contorta)* were found exclusively on burn sites in the 2018 survey. Wallace's selaginella (*Selaginella wallacei*), which is a key plant association for the southern portion of the site (Grey-rock-moss-Wallace's-selaginella plant association), had only 40% of its recorded occurrences in the burned plots.

Table 4. List of native species found on burned plots and across total study site by rank abundance in 2018. Abundance calculated as number of occurrences per 20 x 20 cm portion of each 1 x 1 m quadrat per plot. Species information from BC Species and Ecosystem Explorer (Province of BC 2020). Species of special note are highlighted in blue.

Rank in Burned Plots	Species	Common Name	Number of Occurrences in Burned Plots	Rank in Total Plots	Number of Occurrences in Total Plots
1	*Lonicera hispidula*	Hairy honeysuckle	265	**1**	785
2	*Gaultheria shallon*	Salal	246	**2**	522
3	*Festuca occidentalis*	Western fescue	192	**3**	383
4	***Arbutus menziesii* (juvenile)**	**Arbutus juvenile**	**165**	**4**	**224**
5	*Cladonia rangiferina*	Reindeer lichen	103	**5**	187
6	*Vulpia* spp.	Silver grass spp.	89	**11**	118
7	*Lupinus bicolor*	Two-coloured lupine	87	**8**	140
8	*Luzula comosa*	Pacific wood-rush	72	**6**	179
9	*Trifolium microcephalum*	Small-headed clover	64	**10**	119
10	*Trifolium microdon*	Thimble clover	58	**13**	85
11	*Bromus carinatus*	California brome	44	**14**	81
12	*Galium trifolium*	Fragrant bedstraw	41	**16**	79
13	*Elymus glaucus*	Blue wildrye	37	**9**	120
14	*Carex inops*	Long-stoloned sedge	33	**7**	172
15	*Lepidium densiflorum*	Prairie pepper-grass	31	**26**	38
16	*Cardamine oligosperma*	Little western bittercress	31	**17**	58
17	*Pseudotsuga menziesii* (juvenile)	Coastal Douglas-fir juvenile	28	**18**	56
18	*Mahonia nervosa*	Dull Oregon grape	23	**25**	39
19	*Daucus pusillus*	American wild carrot	21	**27**	36
20	*Galium* sp.	Small bedstraw	20	**28**	26
21	*Bromus vulgaris*	Columbia brome	19	**29**	24
22	*Sanicula crassicaulis*	Pacific sanicle	18	**23**	41
23	*Arbutus menziesii*	Arbutus	17	**31**	17
24	*Cerastium arvense*	Matted field chickweed	17	**12**	93
25	*Festuca rubra*	Fescue spp.	16	**15**	81
26	***Selaginella wallacei***	**Wallace's selaginella**	**16**	**24**	**40**
27	*Trifolium* sp.	Clover spp.	16	**30**	19

28	*Clinopodium douglasii*	Yerba buena	15	**19**	55
29	*Trifolium willdenowii*	Tomcat clover	12	**20**	55
30	*Madia madioides*	Woodland tarweed	9	**21**	54
31	*Trifolium variegatum*	White-tipped clover	8	**34**	10
32	*Trientalis borealis* ssp. *latifolia*	Broad-leaved starflower	7	**35**	7
33	***Pinus contorta* (juvenile)**	**Lodgepole pine (juvenile)**	**6**	**36**	**6**
34	*Holodiscus discolor*	Oceanspray	3	**40**	3
35	*Melica subulata*	Alaska oniongrass	3	**22**	45
36	*Osmorhiza berteroi*	Mountain sweet-cicely	3	**32**	15
37	*Mahonia aquifolium*	Oregon grape	2	**33**	12
38	*Pseudotsuga menziesii*	Coastal Douglas-fir	2	**41**	3
39	*Brodiaea coronaria*	Harvest brodiaea	1	**38**	4
40	*Polypodium glycyrrhiza*	Licorice fern	1	**44**	2
41	*Rubus ursinus*	Trailing blackberry	1	**45**	2
42	*Rumex maritimus*	Golden dock	1	**46**	2
43	*Vicia americana*	American vetch	1	**42**	3
NA	*Eriophyllum lanatum*	Woolly sunflower	NA	**37**	5
NA	*Lonicera ciliosa*	Western trumpet	NA	**39**	4
NA	*Goodyera oblongifolia*	Western rattlesnake plantain	NA	**43**	2
NA	*Lathyrus nevadensis*	Purple peavine	NA	**47**	1

4.3 Plant Community Ecology Analysis

2019 environmental data (percent coarse material, percent gravimetric soil water content, ammonium, nitrate, pH, total percent carbon and total percent nitrogen) were used to analyze various plant groups (forb, grass, trees & shrubs, and other (sedge, vine, rush, non-vascular)) to identify which environmental factors could have the greatest impact on the plant community. The soil samples from each specific quadrat were plotted against the 2018 plant survey for that plot. Canonical correspondence analysis was used for these analyses. The length of the environmental vector arrows and their angle represents the strength and direction of the relationship between the environmental variable and the plant species (Pieper 2012).

The sites were also compared to the environmental variables based on treatment (burned and unburned) and location (north half of plot and south half of plot) using biplots. There were no appreciable groups formed and instead there was just a very tight cluster of all the sites together. Additional details and biplots are in Appendix E.

The environmental variables varied in their ranges recorded across the study site. pH ranged from 4.34 to 7.79 as measured as pH in water. Percent coarse material ranged from 1.8% - 78% and gravimetric soil water ranged from 0.12% - 39.75% in the samples. Plant available forms of nitrogen ranged from <0.1 mg/kg to 43 mg/kg for nitrate and <0.1 mg/kg to 27 mg/kg for ammonium. Total percent nitrogen ranged from 0.057% to 1.8% and total percent carbon ranged from 1.3% to 52%.

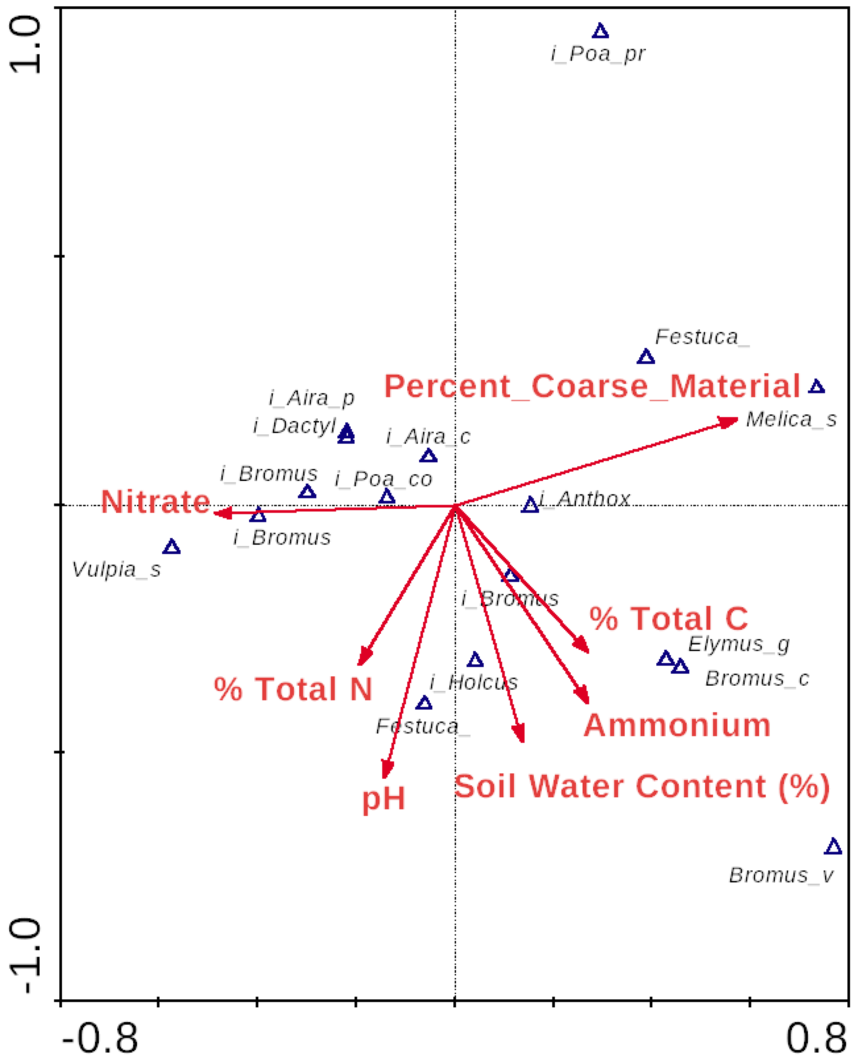

Figure 17. Canonical correspondence analysis of 2018 total grass species occurrence data using 2019 0-5cm depth environmental data. 'I' prior to species name, denotes an invasive species. Nitrate and ammonium are measured in ppm. 'Soil Water Content' is gravimetric soil water measure as percent. pH is measured as pH in water.

Table 5. Summary of CCA of 2018 grass species and 2019 0-5cm depth environmental values.

Axes	1	2	3	4	Total inertia
Eigenvalues	: 0.180	0.074	0.051	0.020	3.632
Species-environment correlations	: 0.626	0.519	0.435	0.318	
Cumulative percentage variance					
of species data	: 5.0	7.0	8.4	8.9	
of species-environment relation	: 49.7	70.1	84.1	89.7	
Sum of all eigenvalues					3.632
Sum of all canonical eigenvalues					0.362

Figure 17 and Table 5 show the results of the CCA for 2018 grass species on the site and the 2019 environmental variables. Many of the invasive grass species are grouped around the higher end of the nitrate vector (*Aira caryophyllea, Dactylis glomerate, Bromus sterilis* etc.). Many of the native grass species appeared to be located at the furthest extent of the other environmental variable vectors, but with no clear pattern. The two ordination axes represented on the plot only account for 18 and 7.4 percent respectively of the common structure between the matrices.

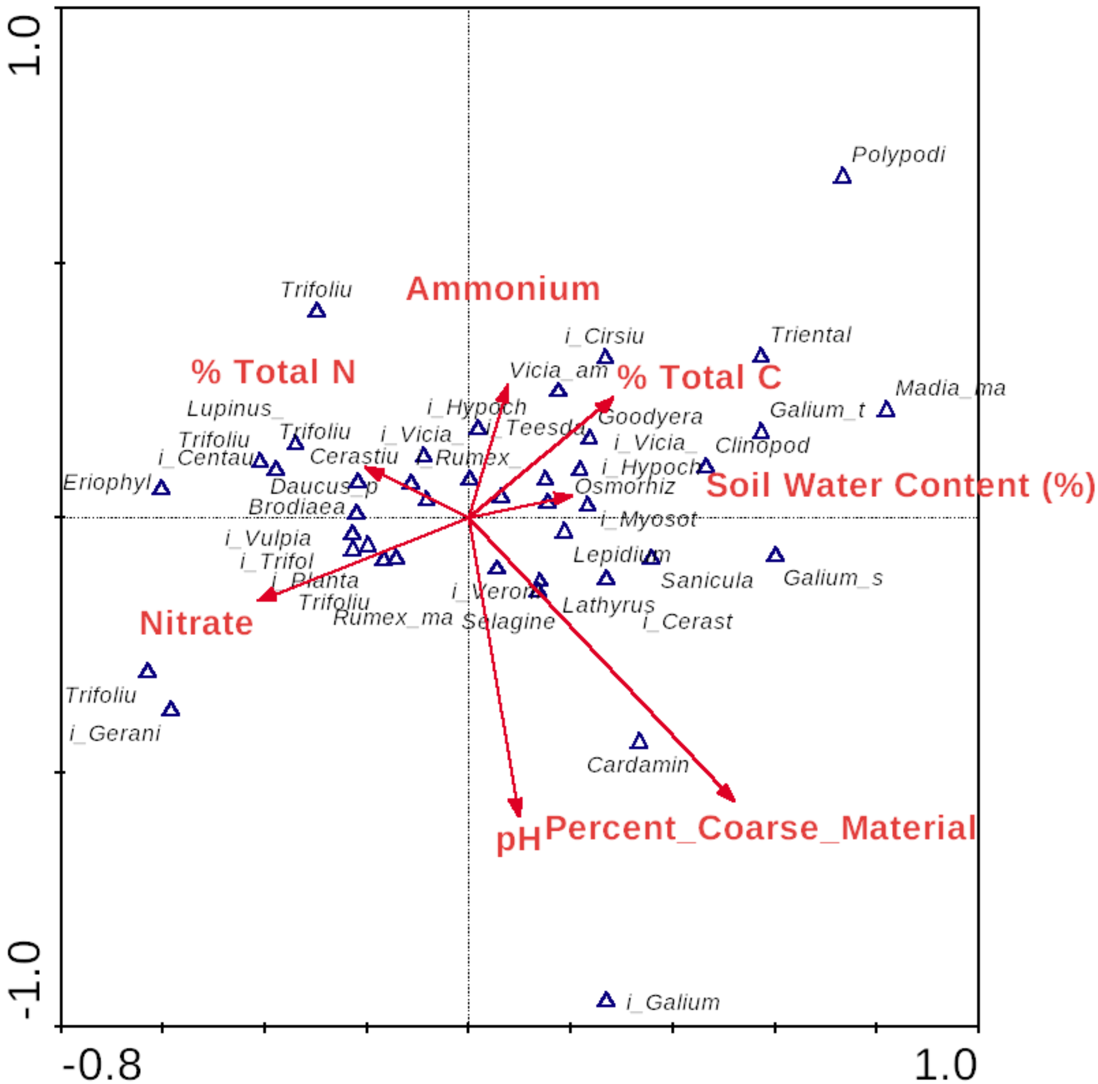

Figure 18. Canonical correspondence analysis of 2018 total forb species occurrence data using 2019 0-5 cm depth environmental data. 'I' prior to species name, denotes an invasive species. Nitrate and ammonium are measured in ppm. 'Soil Water Content' is gravimetric soil water measure as percent. pH is measured as pH in water.

Table 6.Summary of CCA of 2018 forb species and 2019 0-5 cm depth

Axes	1	2	3	4	Total inertia
Eigenvalues	: 0.290	0.114	0.076	0.054	8.378
Species-environment correlations	: 0.722	0.473	0.536	0.487	
Cumulative percentage variance					
of species data	: 3.5	4.8	5.7	6.4	
of species-environment relation	: 46.6	65.0	77.1	85.8	
Sum of all eigenvalues					8.378
Sum of all canonical eigenvalues					0.623

CCA of forb species with 2019 environmental variables produced Figure 18 and Table 6. There is no clear grouping of either native or invasive species around a particular vector. This analysis produced eigenvectors of 29% and 11.4% for the ordination plot in Figure 18.

CCA of 2018 trees and shrubs species with 2019 environmental variables produced Figure 19 which shows a much more concentrated cluster of the species. There were only native tree and shrub species found at the site during the 2018 plant survey. The species are clustered at the low end of the vectors. The pH vector is by far the longest of the environmental variables dictating it is the most important in relation to the species, and the species are all clustered at the lower end of the arrow, meaning a more acidic pH. There is one outlier, *Lonicera hispidula,* which is roughly one standard deviation away from the cluster of all tree and shrub species.

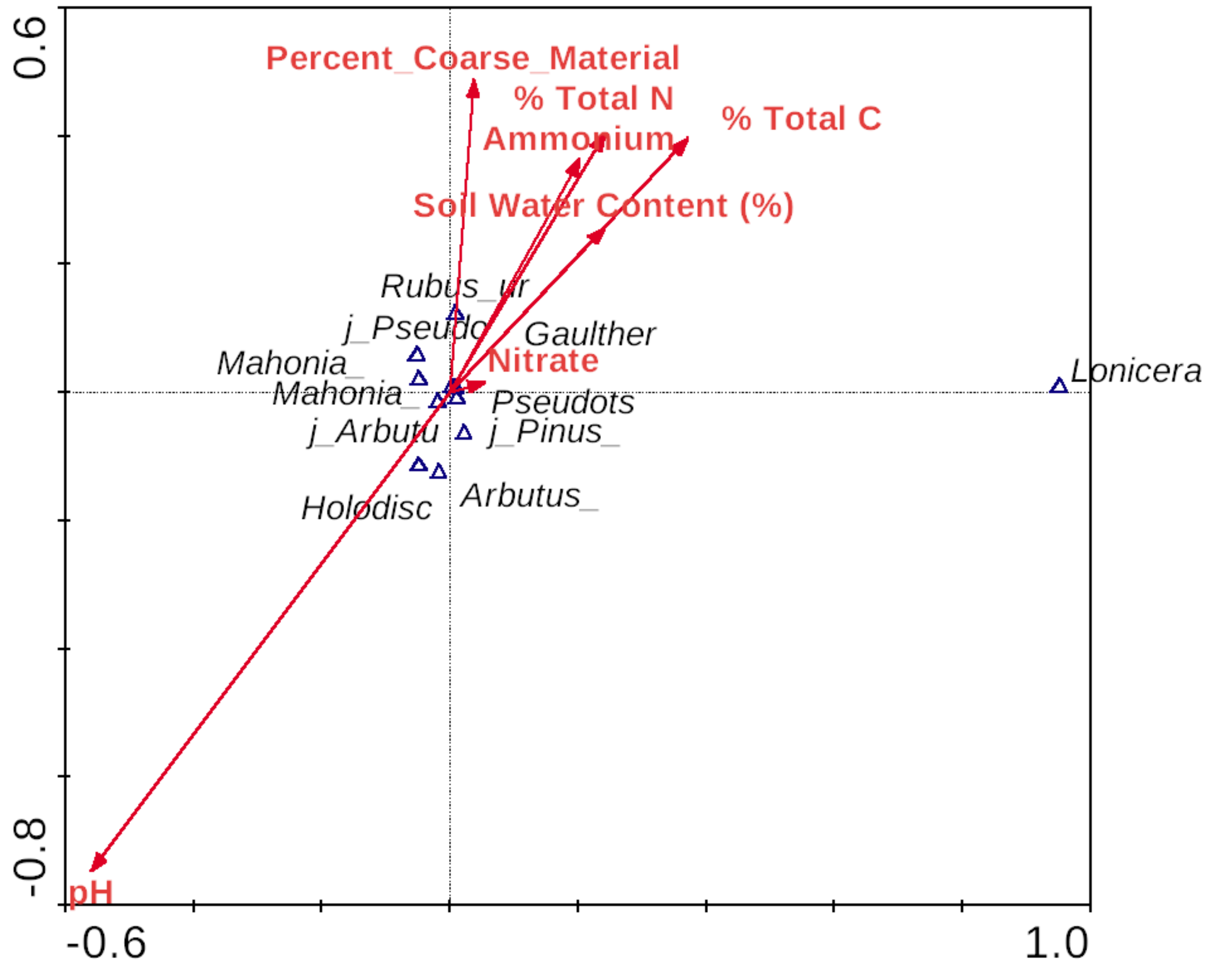

Figure 19. Canonical correspondence analysis of 2018 total trees and shrubs species occurrence data using 2019 0-5cm depth environmental data. 'I' prior to species name, denotes an invasive species. Nitrate and ammonium are measured in ppm. 'Soil Water Content' is gravimetric soil water measure as percent. pH is measured as pH in water. 'j' represents juvenile individuals of the species.

Table 7. Summary of CCA of 2018 tree and shrub species and 2019 0-5 cm depth environmental values.

Axes	1	2	3	4	Total inertia
Eigenvalues :	0.621	0.100	0.082	0.031	4.994
Species-environment correlations :	0.892	0.397	0.343	0.272	
Cumulative percentage variance					
of species data :	12.4	14.4	16.1	16.7	
of species-environment relation :	71.3	82.7	92.1	95.7	
Sum of all eigenvalues					4.994
Sum of all canonical eigenvalues					0.871

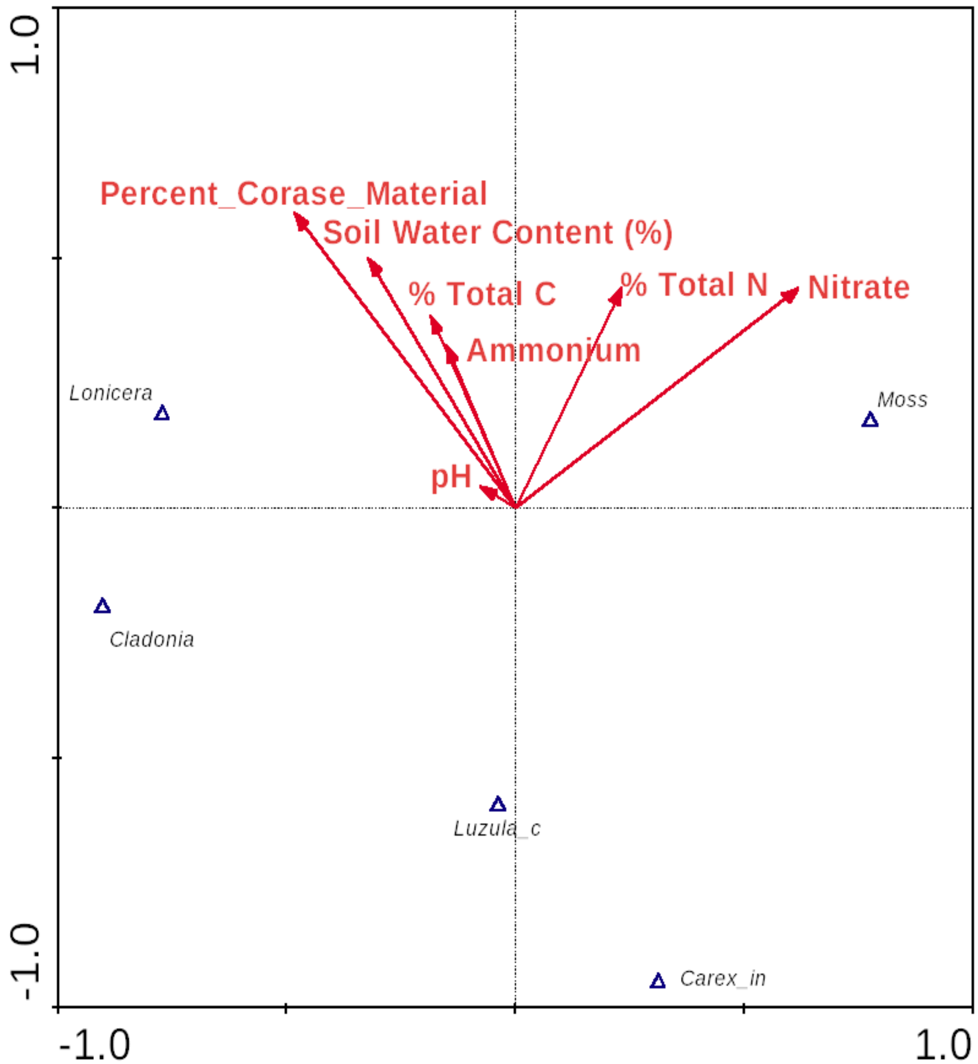

Figure 20. Canonical correspondence analysis of 2018 total other species (vine, sedge, and non-vascular) occurrence data using 2019 0-5cm depth environmental data. Nitrate and ammonium are measured in ppm. 'Soil Water Content' is gravimetric soil water measure as percent. pH is measured as pH in water.

Table 8. Summary of CCA of 2018 vine, sedge and non-vascular species and 2019 0-5 cm depth environmental values.

Axes	1	2	3	4	Total inertia
Eigenvalues	: 0.146	0.034	0.011	0.006	1.888
Species-environment correlations	: 0.490	0.267	0.149	0.134	
Cumulative percentage variance					
of species data	: 7.7	9.5	10.1	10.4	
of species-environment relation	: 74.2	91.6	97.1	100.0	
Sum of all eigenvalues					1.888
Sum of all canonical eigenvalues					0.196

Figure 20 shows the CCA for the remaining plant species in the 2018 plant survey (various non-vascular plants, vines and sedges). For this species grouping, there does not appear to be any environmental vectors that have a strong relationship with any of the species and the plots eigenvectors only account for 14.6% and 3.4% of the common structure between the matrices.

5.0 Discussion

The Tumbo Island research site shows the potential outcomes of using a prescribed burn as the sole restoration treatment for a shallow soil Garry oak meadow ecosystem. This studies objectives were to: 1) determine the effect of fire on soil chemical characteristics, 2) track the changes in the plant community, and 3) compare the environmental variables collected from the soil to the vegetation data from the same plots to ascertain the best management practices for these sites. The findings can be applied to other areas where restoration is actively being conducted.

5.1 Objective 1- Soil Chemistry Change After Burning

The study showed positive chemical changes present in the soil three years after the fire. The results from this study show the longevity of the impact of prescribed burns on the top five centimeters of the soil profile. Historically, prescribed burns conducted by indigenous peoples on Garry oak ecosystems were performed annually or biannually (Pellatt & Gedalof 2014), and the results of this study indicate that when using a prescribed burn as a restoration treatment, a longer time interval can be used. Further studies should be conducted to determine the longevity of the persistence of the chemical changes in the soil.

This experiment specifically examined three hypotheses. The first hypothesis was that prescribed burns result in lower nitrogen due to volatilization during burning. This experiment was not able to reject the null hypothesis. Total percent nitrogen and plant available nitrogen in the form of ammonium was significantly lower in the burned treatment, but plant available nitrogen in the form of nitrate was not. As shown in the results, there were many outliers that could have overly skewed this outcome, and this should be further investigated. The second hypothesis tested was that prescribed burns result in lower total carbon due to combustion during burning. This study rejects the null hypothesis as total percent carbon in both the 0-5 cm soil layer and the 5-10 cm soil layer was found to be significantly lower in burned plots than unburned, showing that the fire had a significant impact on the carbon. The final soil hypothesis tested was that prescribed burns result in higher soil pH due to the ash by-product, which decreases the acidity of the soil. The pH results in this experiment showed a significantly higher pH in the burned treatment than the unburned, which leads to the rejection of the null hypothesis.

Three years post-burn soil has a reduced percent total carbon, percent total nitrogen and mg/kg of ammonium present at burn sites, as well as an elevated pH. The percent coarse material was also significantly lower in burned sites which was likely a result of the combustion of the organic matter during the fire. The Garry Oak Ecosystem Recovery Team states that Garry oak meadow ecosystems are traditionally low nitrogen systems, so these altered soil characteristics post-fire are beneficial to maintaining the ecosystem (2011).

5.2 Objective 2- Vegetation Change After Burning

There were various vegetation changes over the eight-year period which the plant survey data covered. The most noteworthy changes in the vegetation in the burn treatment involve the increase of invasive plants, and the changes in sapling recruitment and conifer encroachment.

5.2.1 Invasive plants

Contrary to the beneficial soil results seen from this study, there appears to be some detrimental impacts to the plant community at the research site on Tumbo Island following the prescribed burn. The research site has no record of being ever used as pasture and is separate from the historic homestead located in the central area of the island, reducing the possibility of invasive grass seeds in the seedbank from previous land use. There is a marked increase in the invasive grass species present on the research site on all plots through time (Figure 6). The species accumulation curve for invasive species using the 2018 plant survey found a greater abundance of invasive plants in burned than unburned areas, and without any appreciable difference in the species richness of native plants on the same sites.

5.2.1.1 Invasive plants and fire

Prescribed fire acts as a disturbance which creates ideal conditions for colonizers to rapidly spread across the newly opened area. The main immediate outcome on the landscape from a prescribed burn is the increase in ground level light and open mineral soil. Most literature regarding invasive species notes an increased response in invasive plants with increased disturbance intensity (Bartuszevige & Kennedy 2009). Some invasive plants can have allelopathic effect on surroundings plants (Aarssen 1981) as well as alter the ecosystem dynamics (Bartuszevige & Kennedy 2009). The experimental prescribed fire on Tumbo was aimed at being a low intensity burn but it had patches of higher intensity.

MacDougall studied the impact of various disturbances on shallow soil Garry oak habitat at the Cowichan Garry Oak Reserve. His study found that native plant recruitment was limited by dispersal, and that the pre-existing invasives restrict this further (2002). *Anthoxanthum odoratum,* which was the second most abundant invasive in burned areas at the Tumbo Research site, had a similar voracious nature at the Cowichan Reserve where it increased from 10% to 22% cover in the shallow soil sites following disturbance (MacDougall 2002). Invasive grasses are especially difficult to control as they have the highest seedling establishment following disturbance, which results in a suppressive effect on native plant recruitment (MacDougall 2002). Other invasives that were also present at the Tumbo site, such as *Myosotis discolor, Trifolium dubium, Veronica arvensis, Vicia hirsuta, Vicia sativa* and *Poa pratensis* either increased in percent cover or were unchanged following disturbance at the Cowichan Reserve (MacDougall 2002). Other studies investigating invasive species percent cover following thinning treatments to remove Douglas-fir also found a significant increase in invasive grass cover and some invasive forbs cover with no significant change to native grasses and forbs in five years following the treatment (Devine, Harrington & Peter 2007).This alludes to the persistent nature of these invasive species and suggests that their ability to flourish with disturbance overpowers native plants, even when soil and light conditions are changed to better match native plant historic conditions.

Prescribed fire treatment was used at this site to mimic the pre-European disturbance regime; however, it does not account for aggressive behaviour and abundance of invasive species present in today's landscape (Keeley 2006). Invasive plants present at the site are able to rapidly spread and outcompete native plants following disturbance. To control the wide diversity of invasive plants present at the site, alternative treatments will be needed to reduce invasive species colonizing and seed dispersal ability, in conjunction with native plant seeds application to increase native plant recruitment and competitive advantage (MacDougall 2002).

5.2.1.2 Study site potential impacts on invasive species

There are also many potential confounding factors that could have led to the unexpected increase in invasive species on burn treatment areas. Firstly, the study site was designed with alternating plots located adjacent to each other. The 50 x 50 m plots were side by side, leading to a minimal distance for invasive species to spread from control plots, either vegetatively or through seed dispersal, after a three-year period post burn. *Anthoxanthum odoratum* for example produces up to 1250 seeds per plant per year which can be disperse by the wind to neighbouring plots (GOERT 2003b). Key characteristics of invasive species involve their rapid colonizing potential, especially after disturbance. Another potential vector supporting the invasive species spread and native species suppression would be herbivory pressure. The Gulf Islands are greatly overpopulated with deer, both the native Black-tailed deer (*Odocoileus hemionus*) and possibly also the exotic fallow deer (*Cervus dama)* (Martin et al. 2011). Overpopulation is primarily due to the lack of natural predators on the Gulf Islands. During data collection, it was not unusual to see up to thirteen deer together on the approximately 1.5km island (L.Pinnell personal observation July 2019). Martin et al. noted that the deer herbivory on the island archipelago contributed to simplified native plant communities and facilitated the introduction of invasive plants (2011). Martin et al. looked at the Gulf Islands and San Juan Islands, so it is likely that on Tumbo, the deer, as well as the plethora of Canadian geese present on the island, could be supressing native species, such as Arbutus and Garry oak seedlings. Furthermore, these animals could be vectors spreading invasive seeds through their movement and excrement across the study site.

Another factor potentially influencing the species and their status (native or invasive) could be that the research was conducted at a shallow soil site, which is not ideal for prescribed burns. Erickson and Meidinger identified that xeric, shallow soil Garry oak sites, such as the southern half of the study area, are very low priority for burning (2007, Table 9). Fire adapted plants usually have various life strategies that allow them to survive fire. One major adaptation that is often used, is the strategy of below ground biomass, that allows these plants to quickly bounce back, flourish and often reproduce after fire (Hamman et al. 2011). The very shallow soil found at the research site, some areas less than 10 cm of soil on top of bedrock, may have disallowed native plant species from using this life strategy effectively, ultimately leaving the newly opened the landscape ripe for invasive plant species domination. These potentially cumulative factors could explain the reason for the increased invasive species presence on burn treatment areas three years after the prescribed burn on Tumbo Island.

5.2.2 Encroachment and Recruitment

The prescribed fire treatment had a direct impact on the tree community present on the site, through the increase in recruitment and reduction in encroachment. The high recruitment levels of Arbutus noted in burned areas post prescribed burn treatment matches the outcomes noticed following wildfire with significant post-fire sprouting (Lazzeri-Aerts & Russell 2014). In conjunction with the increase in saplings post-treatment, there was a rapid reduction in the number of mature Douglas-fir sampled in burned plots post treatment. Douglas-fir are considered a fire-adapted climax species and mature trees have thick bark that is resistant to ground fires (Organisation for Economic Co-operation and Development 2008). During the prescribed fire treatment, the intensity increased in some areas due to the high fuel load which made it intense enough to kill the mature Douglas-fir. Encroachment of Douglas-fir is one of the key stressors for Garry oak ecosystems, so this reduction was a positive outcome of the treatment.

5.3 Plant Community Ecology Objective

Multivariate methods are an attempt to understand the wholescale ecology and not focus on a single interaction. These methods aid in understanding communities better (Gauch 1982). Canonical correspondence analysis compares a matrix of vegetation data synchronously to a matrix of environmental data (Gauch 1982). CCA is an eigenanalysis method, as such it creates a hierarchical ranking of ordination axes that illustrate the greatest commonalities between the matrices. The multivariate analysis identified the relationship between different species groups and the environmental variables. The degree to which the environmental eigenvalues explain the variance can be seen by focusing on the tables summarizing the CCA (Tables 5-8).

The CCA for the various plant categories with the environmental data do not supply a high degree of explanation of the relationships between the variables. The ‘goodness of fit’ for CCA does not have a specific equation unlike other statistical methods (Palmer n.d.). Instead, the explained inertia (‘Sum of all canonical eigenvalues’ in Tables 5-8) compared to total inertia, can be used to represent how well the species composition is explained by the environmental variables (Palmer n.d.). Using this method to represent the goodness of fit, the environmental variables collected from this study did a poor job of representing the species composition. The extraneous species (vines, sedges, non-vascular) were best represented with 0.196 explained inertia compared to 1.888 total inertia (Table 8). Next best represented were the grasses with 0.362 explained inertia of the 3.632 total inertia (Table 5). Shrubs and trees were poorly explained by the environmental variables with only 0.871 of the total 4.994 inertia explained (Table 7). Forbs were very minimally explained using the environmental variables in the study with 0.623 explained inertia of the 8.378 total inertia (Table 6).

The poor explanation of the species composition from the environmental variables could be in part due to the environmental variables collected. This study only used a small selection of soil environmental variables, and thus did not include other environmental factors that could have greatly impacted the species composition. The CCA ordination plots used percent coarse material, percent gravimetric soil water content, pH, ammonium, nitrate, total percent carbon and total percent nitrogen at 0-5 cm soil depth as the environmental variables. Other potentially important variables of soil temperature, slope, aspect, overall habitat type (Grey-rock-moss-Wallace's-selaginella or Douglas-fir forest) and microclimate were not included.

The length of the arrows in the CCA ordination plots reflect how strong the relationship is between that environmental variable and the plant community (Pieper 2012). From the CCA ordination plots, overall pH and percent coarse material had the strongest relationships with the plant community as a whole. On Figure 17 for the grass species and Figure 18 for forb species, percent coarse material and then pH had the longest vectors. For the tree and shrub species CCA in Figure 19, pH had the longest vector followed by percent coarse material and percent total carbon. Figure 20 with the remaining plant species, had percent coarse material, and then nitrate as the longest vectors. This implies that pH and percent coarse material may overall have the strongest impacts on the plant communities on the research site, however, with the low explained inertia reported in all the CCAs, other factors could be more important than pH and percent coarse material for these plant communities.

The study site is an exposed coastal bluff with shallow soil and xeric conditions. The above mentioned missing environmental variables are likely to have a strong impact on species composition on the site. The soil analysis showed that burned sites have lower total carbon, percent coarse material, total nitrogen and ammonium and higher pH, so one can interpret the ordination plots and look for species clustered in these areas to see how burning may affect species composition, in conjunction with the plant species diversity analysis.

6.0 Implications for Restoration and the Future

This study examined the effect of prescribed fire on soil characteristics and the plant community on Tumbo Island. This experiment can be viewed as a trial run of using prescribed burning as a restoration treatment for exposed coastal bluff Garry oak meadow habitat. The outcome of this experiment had mixed results. In terms of the soil, it was confirmed that a low intensity prescribed burn still had a noticeable impact on the soil characteristics three years post burn. This impact is positive as these soil changes align the ecosystem closer to its desired state (GOERT 2011). This also pushes for the recommendation that if prescribed burns are conducted with soil chemical change objectives, a frequency of three years yields beneficial outcomes. Further studies will be needed to track how long the soil chemical changes persist in the soil.

This study illustrated the persistence of invasive species and showed an unexpected level of the exotic species on burn sites. There were potential vectors of introduction (deer, geese, wind, unknown) that could have confounded the outcomes found in this study. However, the extremely high percent of the top four invasive species, by occurrence, that were found in burned plots leads to the assumption that a prescribed fire treatment alone is not a sufficient management action at this site. Silver hairgrass (*Aira caryophyllea*), sweet vernalgrass (*Anthoxanthum odoratum*), hairy cat's ear (*Hypochaeris radicata)* and soft brome (*Bromus hordeaceus*) were the top four most abundant invasive species site wide and on burned sites with 62%, 38%, 45% and 59% respectively of the occurrences occurring on the burned sites and thus require additional management to control. Invasive grasses especially managed to maintain and gain abundance following prescribed fire treatments, so they should have prioritized management.

6.1 Recommendations for Similar Sites

The Tumbo Island experimental site showed that shallow soil Garry oak meadow restoration activities will require additional restoration treatments when using prescribed burns in order to control invasive species. The prescribed burn that was conducted on the island had objectives beyond invasive species control and native plant replenishment. The burn was conducted to meet the objectives of increasing public awareness and comfort with prescribed fire in a very safe way, as well as to experiment with prescribed fire in shallow soil sites. With the primary objectives as such, the site selection met this objective but was not conducive to meeting the more common ecological objectives that a prescribed fire treatment usually has, such as increasing rare native plants and reducing invasive species.

Erickson and Meidinger created a management ranking system for each Garry oak plant association community (2007). Table 9 is a modified version of Erickson and Meidinger's ranking management for the plant association for the southern portion of the research site. This table clearly illustrates that this habitat needs to be managed, especially with the noted moderately high threats proven to be present. Erickson and Meidinger classified this habitat type as having a low potential for prescribed fire, but this study showed it was effective, especially because of the deeper soil Douglas-fire dominated forest that was encroaching upon the site. Other restoration treatments will be needed on this site, and other Garry oak-Grey rock-moss-Wallace's selaginella plant association sites, to address the high preservation and restoration priority, and to manage the threats (Douglas-fir encroachment and invasive plant species).

Table 9. Management Ranking for Garry oak- Grey rock moss- Wallace's selaginella plant association (Modified from Erickson and Meidinger 2007)

Preservation priority	**Very high**
Regeneration potential	**High**
Aesthetic appeal	**High**
Susceptibility to disturbance	**Very high**
Prescribed fire potential	**Low**
Threats	**Moderately high**
Restoration potential	**Moderately high**
Restoration priority	**High**

The first restoration treatment that should be applied at similar sites would be a thinning plan for areas with Douglas-fir encroachment. This would allow the Garry oak habitat to increase in spatial cover, without risking the influx of invasives seen from the prescribed burn. Additionally, areas dominated by climax Coastal Douglas-fir forest with dense plant material would need thinning regardless to prevent an overly intense fire (from the fuel load), which would not match the historical fire regime of the area (Murphy et al. 2019;

Organisation for Economic Co-operation and Development 2008). Switching to thinning treatments to address the encroachment of Douglas-fir could also support the plant community, as the prescribed fire caused an unexpected death toll on the mature Arbutus trees in the burn plots (M.Pellatt personal observation July 2019).

The prescribed fire resulted in the death of all conifers less than six metres tall (M.Pellatt personal communication 10 March 2020). The fire treatment also killed several large trees, which was only acceptable due to the large fire crew that was present for the burn (M.Pellatt personal communication 10 March 2020). A thinning treatment would be a safer alternative for future treatments. The reduction in conifers and especially in mature Douglas-fir (Figure 5), supports that the prescribed fire was successful in addressing the encroachment threat present at the site.

Another benefit to managing through thinning, rather than fire, would be the reduced impact on Wallace's selaginella. This plant species is supposed to be one of the key plant associations for this site, but only 40% of the occurrences occurred on burn plots post fire, which leads to the concern that the burn may be harmful to the species.

As a follow up to the outcomes from the experimental prescribed burn, an invasive species management plan should be implemented. This plan should involve monitoring the presence and extent of all the invasive plant species on the site. In particular, treatments should be applied to control the 4 major invasive species (*Aira caryophyllea*, *Anthoxanthum odoratum*, *Hypochaeris radicata* and *Bromus hordeaceus*). Aarssen found that following prescribed fire, Hairy cat's ear was one of the first colonizers and had allelopathic effects on other species (1981). Plant characteristics such as this will need to be taken into account when designing a management plan for these focal invasive species.

Another site-specific concern is the recorded presence of *Centaurea melitensis (*Maltese star-thistle). This species is a top priority for containment in BC (Parks Canada 2019). There is minimal information as to when this species became a concern in BC, but on the Tumbo Island site it was not recorded in the 2015 pre-burn plant survey. However, in the 2018 post burn survey 8 of the 9 occurrences of this high priority invasive species were in the burned plots. Further research should investigate if the higher occurrence rate in the burn plot is a by-product of the disturbance and the chemical change in the soil making the location more suitable, or if it is solely due to where the seeds first dispersed to.

An optional restoration treatment for similar sites would be to introduce locally sourced endangered plant species to the site. On the research site, the plant surveys only found yellow listed species (Province of BC 2019). The high level of invasive species present may have meant the endangered species were displaced, and thus reintroducing them once the threats have been reduced through the invasive species management plan, could support species recovery efforts.

A combination of thinning treatments, targeted invasive species controls with further monitoring and the potential introduction of species at-risk to the site would support the continued restoration of shallow soil Garry oak meadow sites similar to the Tumbo Island research site. These methods would reduce the threats to the habitat and address the ecological objectives of supporting endangered Garry oak meadow habitats into the future.

6.2 Importance for the Future

Garry oak meadow habitats are endangered ecosystems, and restoration of them should be a priority. The Gulf Islands in BC are currently at the northern extent of this ecosystem (Pellatt et al. 2012). With climate change and ongoing disturbance, Tumbo Island and other Garry oak meadow habitats in the Gulf Islands National Park Reserve may be essential in supporting this habitat in the future. Having these established habitats be preserved with a healthy and diverse species composition will help facilitate plant species migration and will be essential to the long-term preservation of these ecosystems (Pellatt et al. 2012).

7.0 Conclusions

In general, prescribed burn treatments can be an effective restoration treatment for Garry oak meadow ecosystems (Hamman et al. 2011). The prescribed burn conducted on the shallow soil site on the south-eastern edge of the Tumbo Island by Parks Canada in 2016 was effective at changing the soil chemistry with an impact lasting three years post burn. The experimental prescribed burn treatment was effective at reducing the encroachment of Douglas-fir trees, but it did not control the invasive plants.

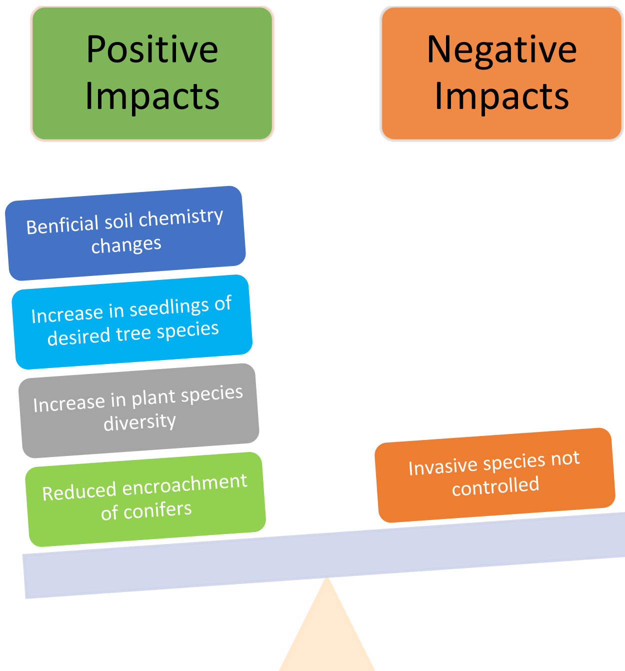

Figure 21. Matrix of positive and negative outcomes of experimental prescribed burn as restoration treatment for shallow soil Garry oak meadow at Tumbo Island.

This research can support future restoration projects on shallow soil Garry oak meadow habitats. These findings suggest that best management practices for shallow soil xeric Garry oak meadow sites may include prescribed burns over a longer return period than the historic 1-2 years, but they will need to be combined with other restoration treatments if controlling invasive plants is an objective. Restoration activities such as thinning, as well as chemical and mechanical invasive species treatments done together or in conjunction with a prescribed burn may have the highest chance of successfully restoring these Garry oak meadows for the numerous endangered species that rely on them now and in the future.

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Appendix A: Nematode Analysis

For this research project there was initially an additional research question delving into the impact of the prescribed fire on the soil biological community. Due to unforeseen difficulties, this portion of the research was not completed. What follows will be the methodology used, partial results collected and then a discussion on the difficulties associated with this work and its potential for use in future projects. Nematode community analysis is a very valuable resource to support management decisions, however it is not a feasible method to employ without having trained specialists to do the species identification. The field crew will not be able to conduct this analysis and should instead send collected samples to a laboratory for external identification. Difficulty level is site specific, but in general using nematodes as environmental indicators at a site, will require specialists.

Rationale

To complement the physical and chemical changes in the soil, biological indicators were used to gather a more robust understanding of the changes following a prescribed burn. Nematodes, as accepted environmental and biological indicators, were collected as they can be used to represent the changes and the duration of impact of a prescribed burn management action on the soil biota. By identifying nematodes to their colonizer-persister (CP) ranking, which indicates life strategies from extreme r-strategists to extreme K-strategists (Bongers 1990), the ratio of life strategies present on a site can indicate the enrichment and structure indices. These indices are representative of the belowground food web complexity and differing enrichment indices can be related to disturbances (Bonger 1990). Through the understanding that nematode communities can be environmental indicators and knowing the manipulated disturbance regime at the Tumbo site, the nematode community structure would contribute baseline data for future studies to understand the effects of prescribed burning on nematode abundance and type in Garry oak ecosystems.

Objective: **To determine the effect of fire on the biological community food web, using nematodes as biological indicators.**

Hypothesis: Burned areas will support a greater abundance of nematodes, with a higher proportion of fungal and bacterial-feeding nematodes, than unburned areas due to enrichment opportunists thriving post disturbance and the delay in predatory nematode return.

Methods- Fieldwork

A second soil core was taken from each quadrat to be used for soil biological community analysis. These cores were approximately 15 cm deep and were combined to make 16 composite samples, two for each plot (T. Forge, personal communication, 19 April 2019). Each plot was divided in half along the 25m north line in the plot to create northern and southern subplots. Plots were divided in this way to account for the variation in the pre-burn habitat type where Douglas-fir habitat was predominant in the north and oak grassland more common in the south. Composite soil samples for biological communities were stored in coolers while in the field and refrigerated upon return to the lab.

Methods- Lab work

The 16 composite samples collected from the subplots were used for the soil biological community analysis. Nematodes were extracted from the soil samples using the centrifugal-flotation extraction method. The centrifugal-flotation extraction method suspends the sample in an extraction fluid with a higher specific gravity (sucrose solution) compared to the nematodes, allowing the nematodes to be separated out of the sample and identified (Van Bezooijen 2006). This method is a quick and effective extracting method (Forge & Kimpinksi 2006). Two samples were taken from each composite sample. The extracted nematodes were heat killed and stored in preservative until they were counted and identified with microscopy.

Results

Nematode abundance per sample was calculated by counting nematodes in ~15ml of sample poured into a gridded counting microscope slide. All nematodes within two rows were counted and then multiplied by 3 to account for the entire sample.

The abundance of nematodes per sample varied greatly between plots and treatments. Burned plots had the greatest variation both within the plot (two samples for both the north section and south section) and between other burned plots. Burned plots varied from 65 nematodes per sample to 474 nematodes per sample. Unburned plots ranged from 45 nematodes per sample to 348 nematodes per sample.

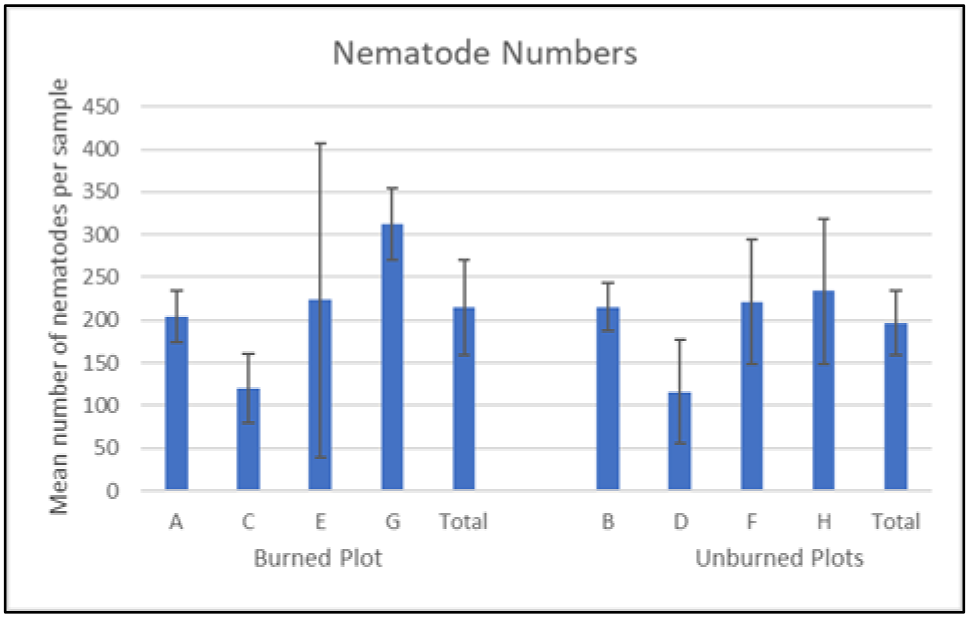

Figure 22. Mean nematode numbers per plot

Difficulties

Unfortunately, nematode identification was not successful for this project. The nematode extraction process was undertaken at the Agriculture Canada Research Station in Summerland, BC under the guidance of Dr. Tom Forge (nematologist) and Paige Munroe (lab technician). Working under direct supervision with Dr. Forge, 26 different nematode genera were identified, and broken into phylogenetic identification categories based on their mouth shapes. The identification information of known genera in the samples are summarized in the table 10 below.

Table 10. List of nematode genera identified in Tumbo island samples.

Genera List	Feeding Role
STYLET & MEDIAN BULB	
Anguinidae- group	Fungivore
Aphelenchoides- Aphelenchoides	Fungivore
Aphelenchoides- Aphelenchus	Fungivore
Tylenchidae- Tylenchus	Bacterivore/Fungivore
Tylenchidae-Boleodorus	Bacterivore/Fungivore
Tylenchidae-Malenchus	Bacterivore/Fungivore
Tylenchidae-Filenchus	Bacterivore/Fungivore
Tylenchidae-Psilenchus	Bacterivore/Fungivore
Criconematidae	Predator
Dolichodoridae-Tylenchorynchus	Predator
Paratylenchidae-Paratylenchus	Predator
Cyst Nematode	Predator
SPEAR W/O MEDIAN BULB	
Aporcelamidae- Aporrcelaimellus	Predator
Eudorylamius- group	Predator
Longidoridae- Xiphinema	Predator
Leptonchidae-Tylencholamius	Fungivore
MOUTH CAVITY CLOSED	
Cephalobidae-Acrobeles	Bacterivore
Cephalobidae-Acrobeloides	Bacterivore
Teratocephalidae- Teratocephalus	Bacterivore
LIP REGION WITHOUT OUTGROWTH	
Tripylidae-Tripyla	Bacterivore
MOUTH CAVITY CLEARLY WIDE	
Rhabditidae- Rhabditis	Bacterivore
Plectidae-Wilsonema	Bacterivore
Plectidae- Anaplectus	Bacterivore
Plectidae-Plectus	Bacterivore
NO OBVIOUS MOUTH	
Alaimidae-Alaimus	Bacterivore
MOUTH CAVITY BARREL SHAPED	
Monochidae-Clarkus	Predator

However, once the identification process of the nematodes began away from the Agriculture Canada lab, there were many difficulties. Difficulties included: lack of confidence in identification, lack of experience in microbiology/microscopy, poor identification resources and damage to nematodes from heat preserving. The researcher went into this project with minimal microscopy experience and minimal background in microbiology and nematodes. The main phylogenetic key for nematode identification is a

1989 translation by Jan van de Haar of Dr. Bonger's 1988 'De nematode van Nederland'. This resource is useful for those with more technical training in nematology and nematode reproductive systems. Some resources exist with a focus on North America, or specific ecosystems, but none included all of the genera initially identified at the Tumbo Island site. Furthermore, the preservation process used resulted in the nematodes disintegrating slightly and thus increasing the difficulty to identify specific mouth part traits.

Implications

Nematodes are gaining acceptance as environmental indicators and use outside of the agricultural realm. This project aimed to support the growing body of literature on using nematodes in restoration projects to create a snapshot of the belowground biological community health. However, due to limitations in the researcher's ability this goal was not able to be met. There are currently laboratories, predominantly agricultural, that can accept samples for nematode identification.

For researchers with a background in microbiology or significant experience using microscope, and access to very generous mentors, such as Dr. Forge, self-study and identification of nematodes in research samples is doable. The diversity of nematodes is also highly site specific which directly impacts identification difficulty. For example, during the initial identification process for the Tumbo Island site, 26 genera were identified, but in a similar M.Sc. research project conducted in Kenna Cartwright Park in Kamloops BC by Oliver Denny, only 12 species were identified (Denny 2019).

Nematodes have great potential to positively impact restoration work, by giving, an often-neglected, insight into soil biological communities and saving costs by providing the needed guidance to start restoration work from the soil up. Nematodes are unique in that their mouthparts can be used to identify them (Bongers & Ferris 1999; Brady &Weil 2009), which in comparison to other soil species identification is relatively straightforward. Nematodes abundance and diversity are impacted by ecosystem type, management and substrate and in turn impact ecosystem processes, succession, and plant diseases (Wilson & Kakouli-Duarte 2009). Since population numbers are directly linked to the population dynamics of the organisms they consume and are impacted by the physical and chemical environment that surrounds them, by identifying the nematodes present, managers can get a holistic view of the belowground ecosystem health (Kardol & Wardle 2010). With the right training, the use of nematodes in restoration projects could be highly beneficial by understanding the disturbance history of the site, potential plant parasitic nematodes which could impact vegetation recovery and plant succession (Bongers & Ferris 1999) and without relying on costly soil chemistry and phospholipid fatty acid (PLFA) tests.

Appendix B: Soil Data Analysis

Prior to conducting the Wilcoxon rank sum test for non-parametric data for the chemistry, the means for each plot as well as the mean of the treatment (burn total includes plots A,C,E,G and unburned total includes B,D,F,H) were analyzed by comparing the means to the standard error of the mean with 95% confidence intervals. The following graphs visually show the variation between treatments and between plots within the same treatment. Through this analysis, the confidence intervals suggested a significant difference between treatments for mean percent total carbon, mean ammonium and the mean pH. These differences were present in the 0-5 cm soil layer and carried over to affect the 0-10 cm soil profile but were not present in just the 5-10 cm portion of the soil.

Percent total carbon

The mean total carbon at 0-5 cm soil depth has a clear pattern of higher percent carbon in all unburned plots than burned plots (Figure 23). There is a clear difference between the total burned (4.6%) and unburned (7.8%) plots.

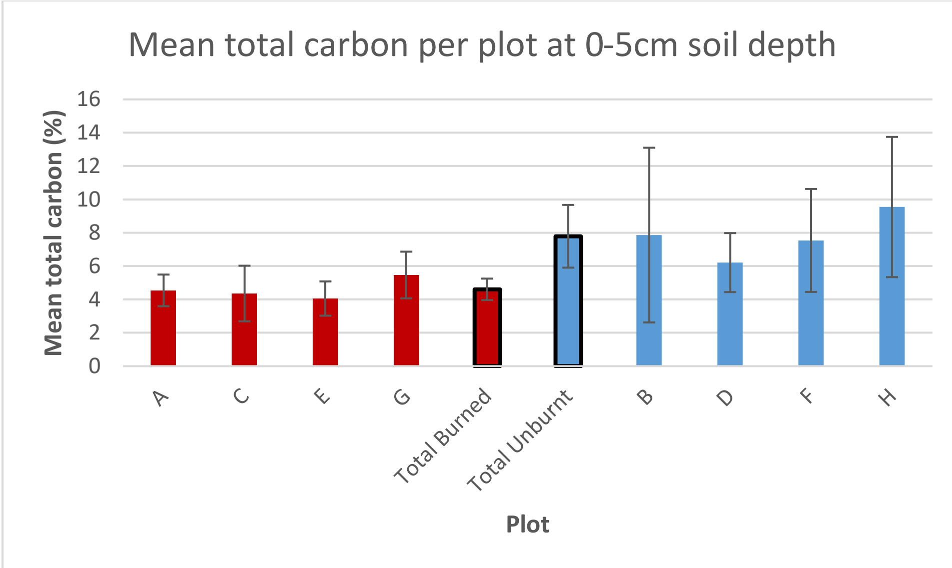

Figure 23. Mean total carbon measured in percentage at 0-5 cm soil depth. Black outlines indicate difference in values for total burned and total unburned through 95% confidence intervals

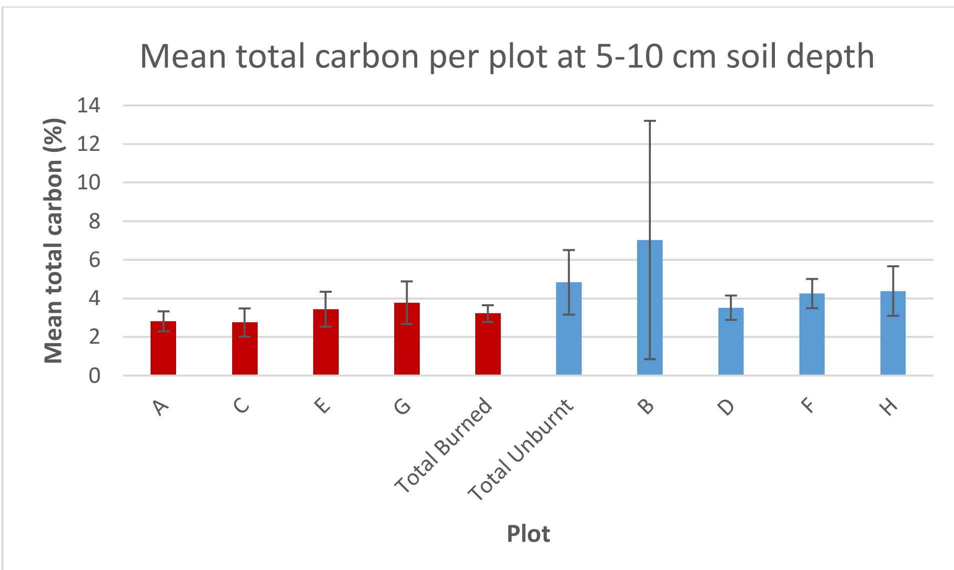

Figure 24. Mean total carbon in 5-10 cm soil depth measured as percentage. Calculated as standard error of the mean with 95% confidence intervals

The mean total carbon present at the study site was relatively similar at the 5-10cm depth. Plot B was the highest at ~7%, with all other plots averaging around 3-4%.

Percent total nitrogen

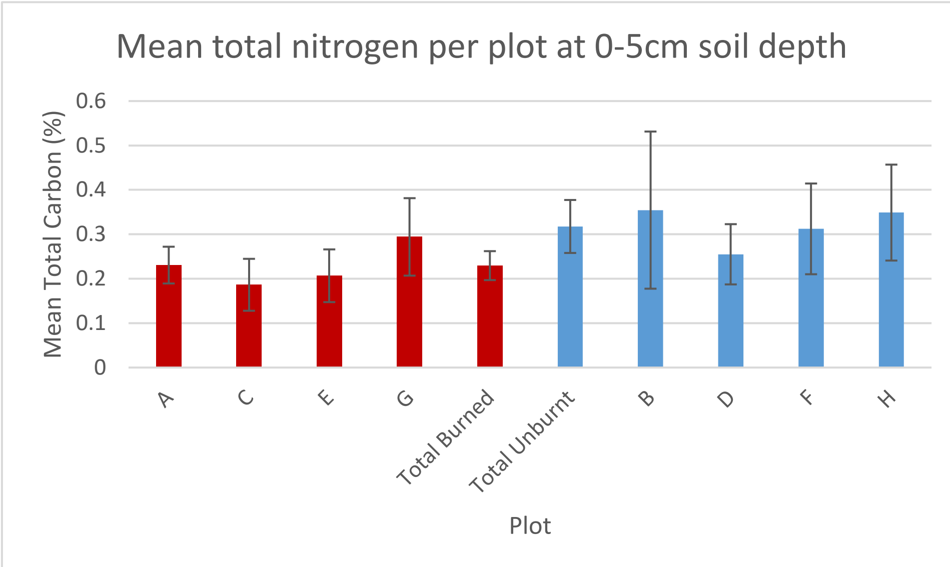

Figure 25. Mean total nitrogen in 0-5 cm soil depth measured as percentage. Calculated as standard error of the mean with 95% confidence intervals

In general, there was a trend of total nitrogen being higher in unburned than burned plots. However, there was no pattern in the difference in the amounts between the treatments.

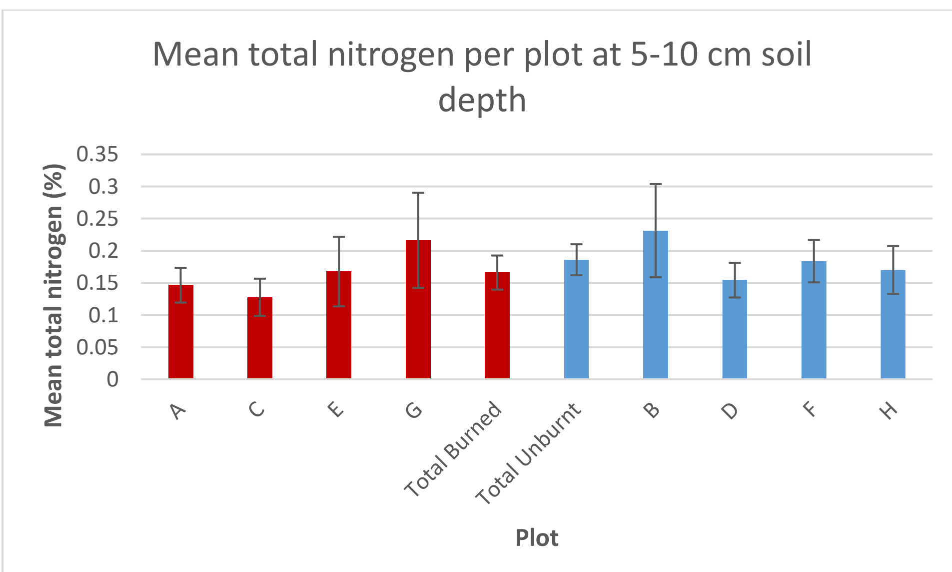

Figure 26. Mean total nitrogen in 5-10 cm soil depth measured as percentage. Calculated as standard error of the mean with 95% confidence intervals

Mean total nitrogen was relatively similar across all of the plots, ranging from 0.12-0.22%.

pH

The pH was significantly higher in burned plots than unburned plots. The mean total of burned plots was 6.00 +/- 0.0769 compared to the mean total of unburned plots of 5.76 +/- 0.0886 as measured as pH in water.

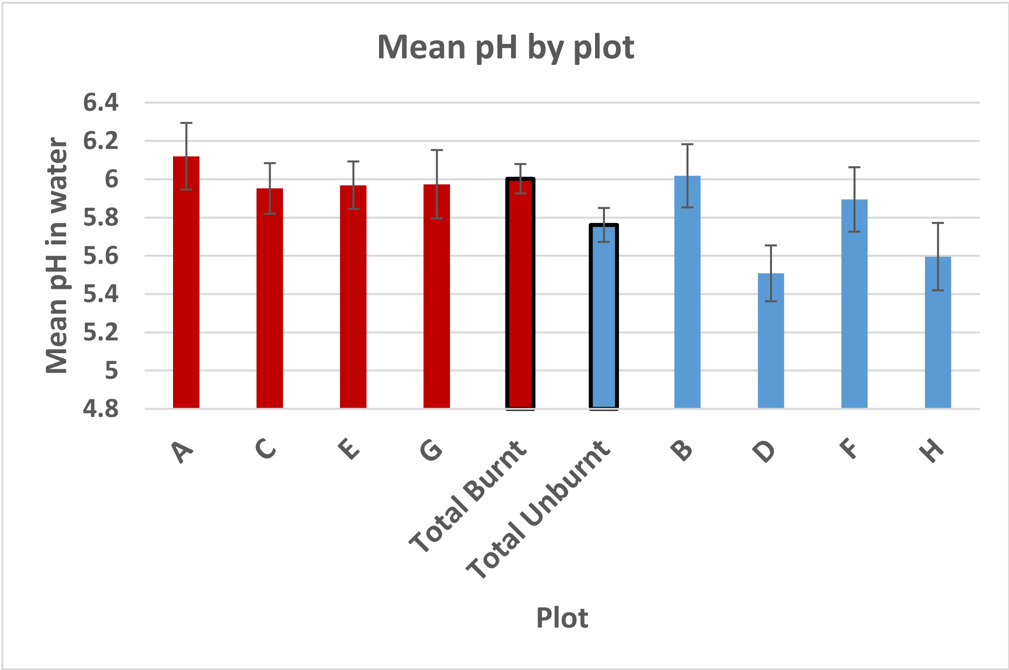

Figure 27. Mean pH in water measured in each plot. Error bars indicate 95% confidence intervals, with black outline indicating significant difference between total burned and total unburned plots pH.

Nitrate

Available nitrate varied significantly within and between plots. It ranged from <0.1 mg/kg to 43 mg/kg. There was no clear pattern between the treatment and available nitrate. There was considerable variation in nitrate concentration in the top five centimeters of the soil across the site.

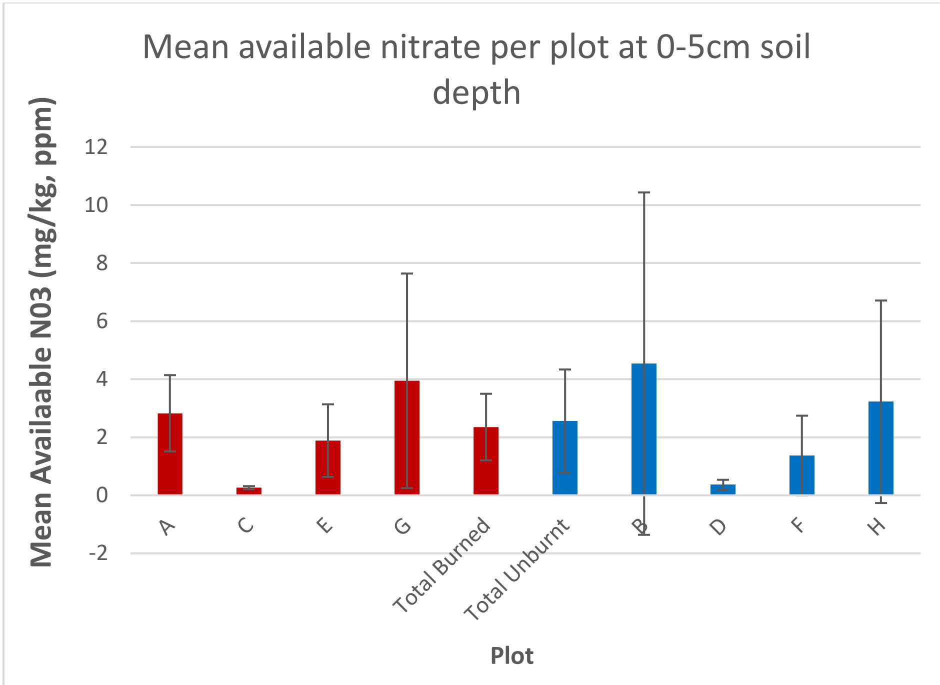

Figure 28. Mean available nitrate in 0-5 cm soil depth measured as mg/kg. Calculated as standard error of the mean with 95% confidence intervals

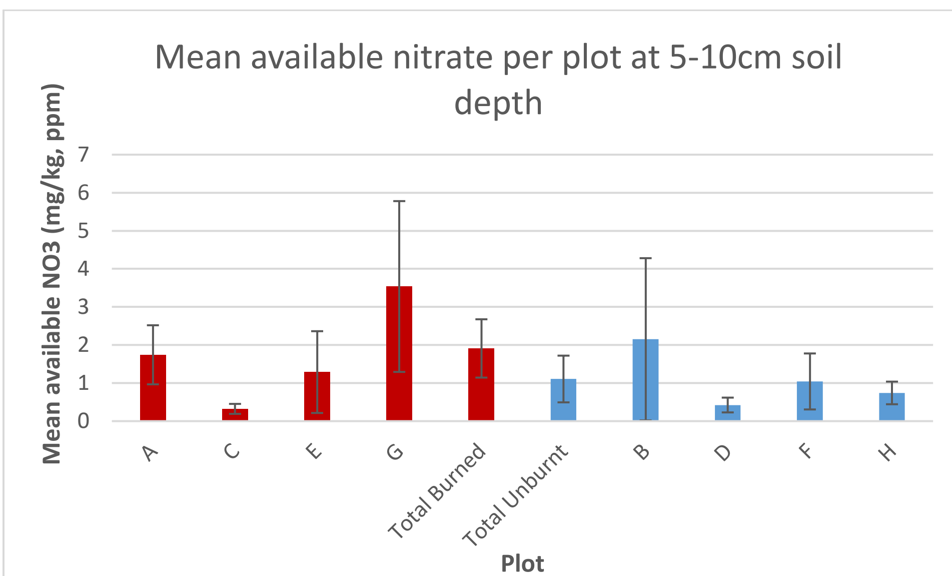

Figure 29. Mean available nitrate in 5-10 cm soil depth measured as mg/kg. Calculated as standard error of the mean with 95% confidence intervals

There was substantial variation between plots in the mean nitrate present in 5-10cm soil depth. This variation was across all plots, regardless of treatment.

Ammonium

Available ammonium was higher in unburned than burned plots. There was less variation in available ammonium than available nitrate. Ammonium ranged from <0.1 mg/kg to 9.5 mg/kg through the study site. This pattern was seen in both the 0-5 cm (Figure 30) and 5-10 cm (Figure 31) soil depths but was more strongly differentiated in the 0-5 cm portion on the soil layer.

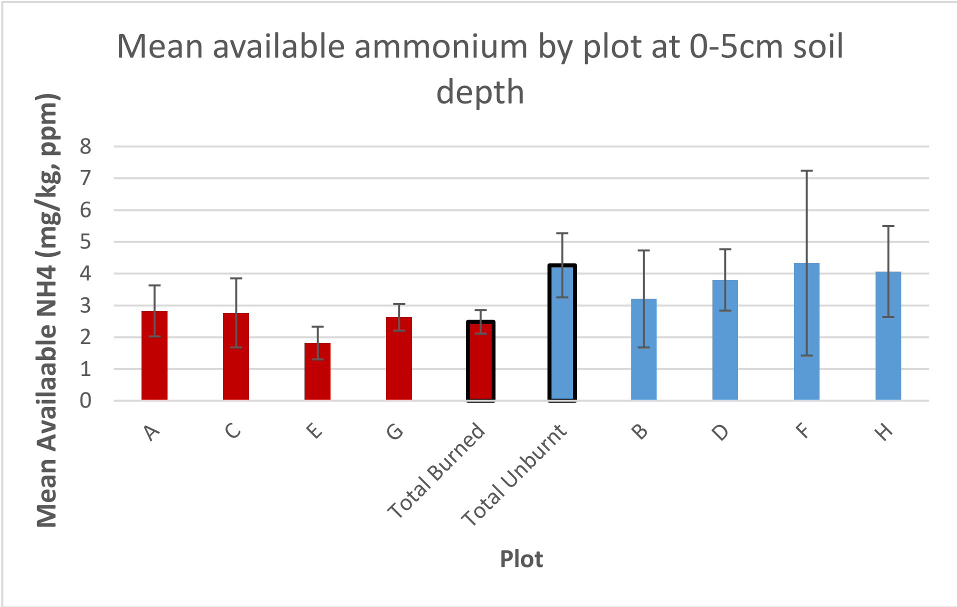

Figure 30. Mean available ammonium in 0-5 cm soil depth measured in milligrams per kilogram or parts per million in each plot. Black outlines indicate difference in values for total burned and total unburned through 95% confidence intervals.

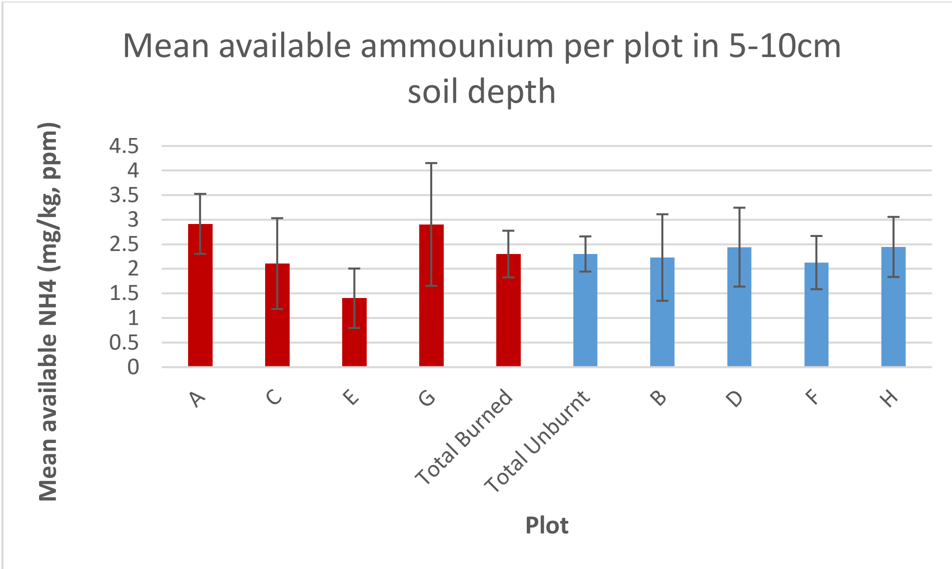

Figure 31. Mean available ammonium in 5-10 cm soil depth measured as mg/kg. Calculated as standard error of the mean with 95% confidence intervals

There was no clear trend in mean ammonium at the plots at 5-10cm depth. Burned plots have a greater variation between them in terms of the amount of ammonium present than the unburned plots.

Appendix C: Long Term Vegetation Changes

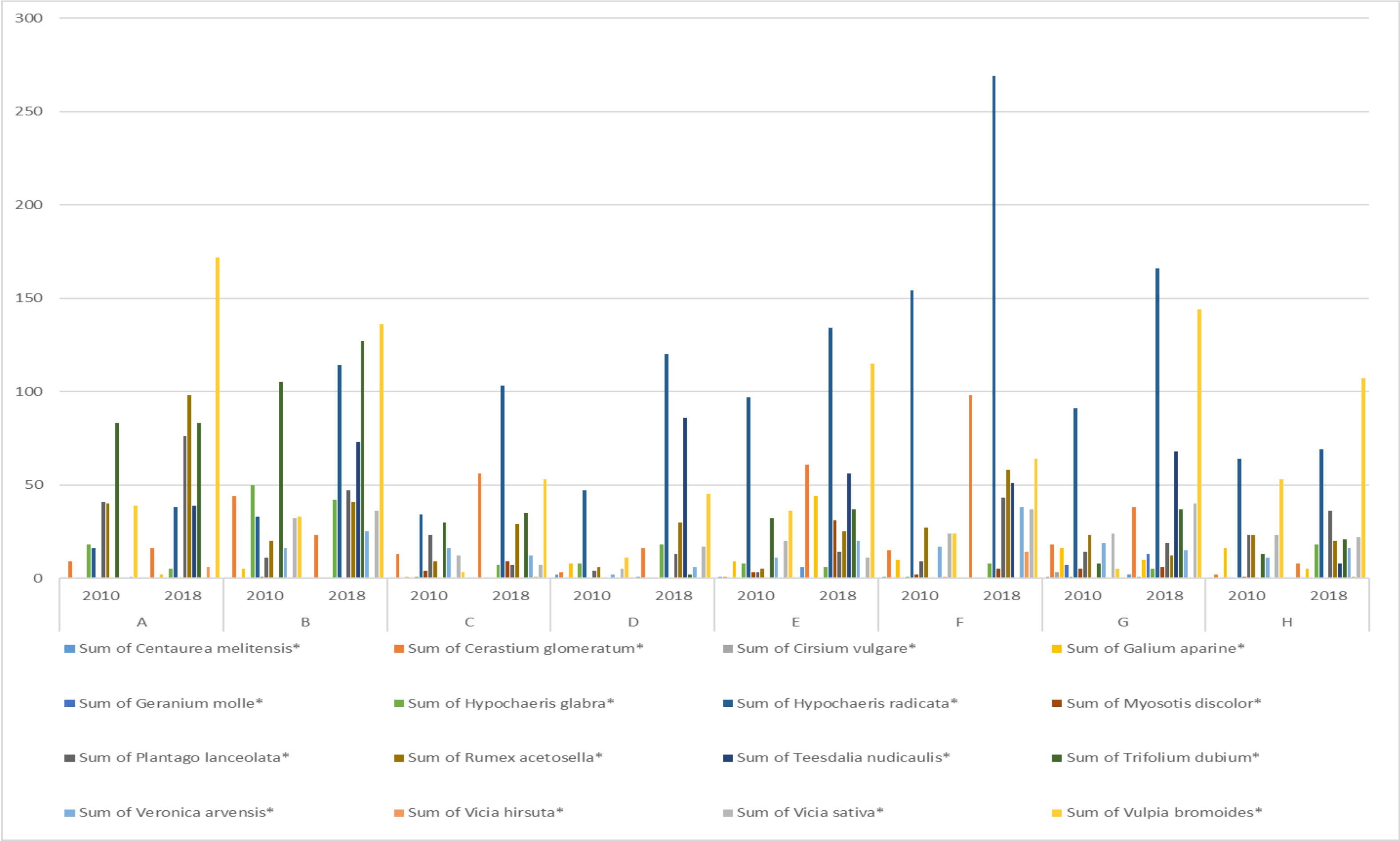

Figure 32. Invasive forbs occurences across all plots in 2010 and 2018.

Overall there was an increase in every plot in the number of occurences and the diversity of invasive forbs from 2010 to 2018.

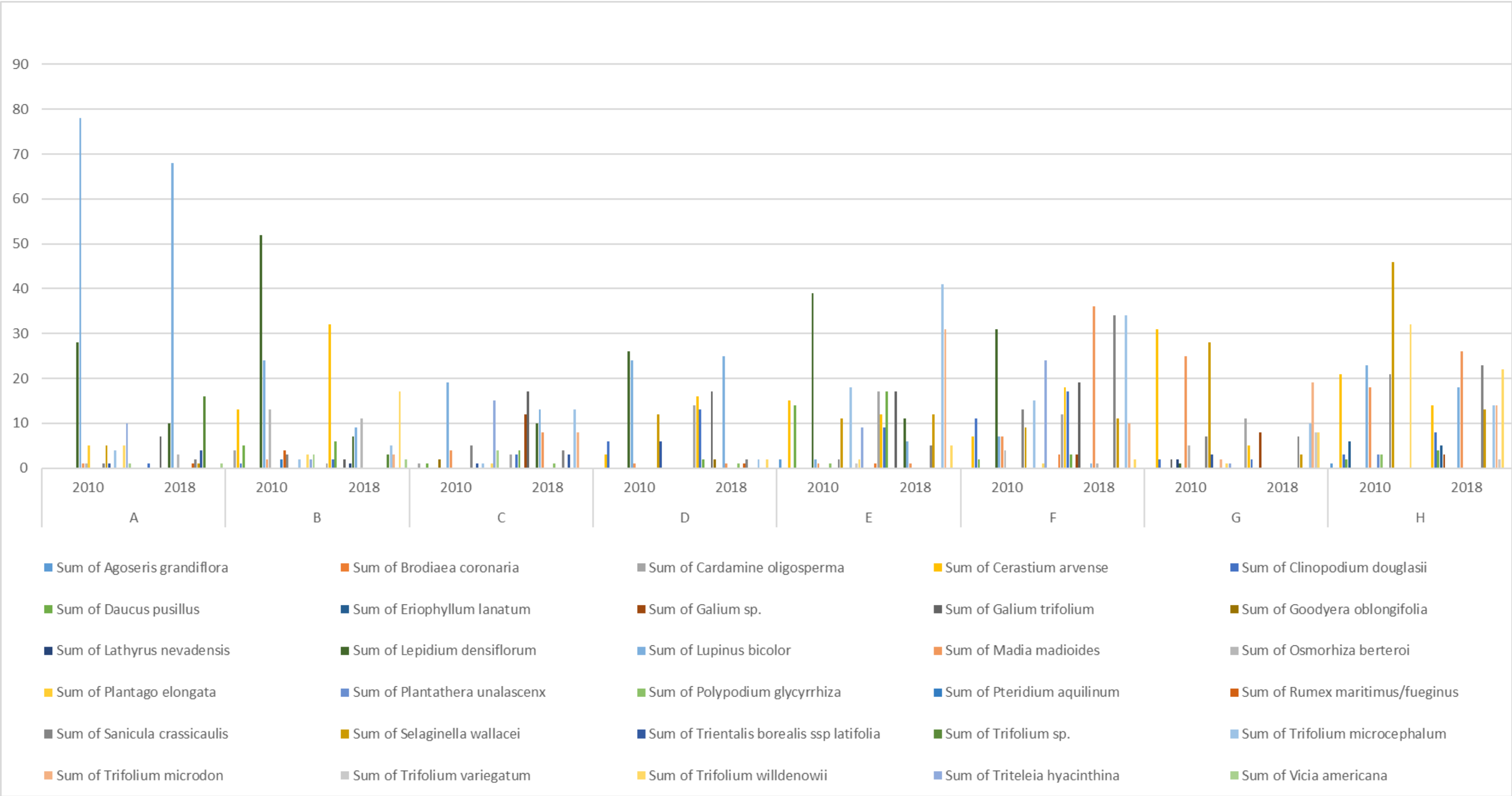

Figure 33. Native forb occurrences across all plots in 2010 and 2018. Only native forbs with more than one occurrence total per plot are shown in the figure.

No clear patterns in the number of occurrences or diversity of native forbs between treatments in 2010 to 2018.

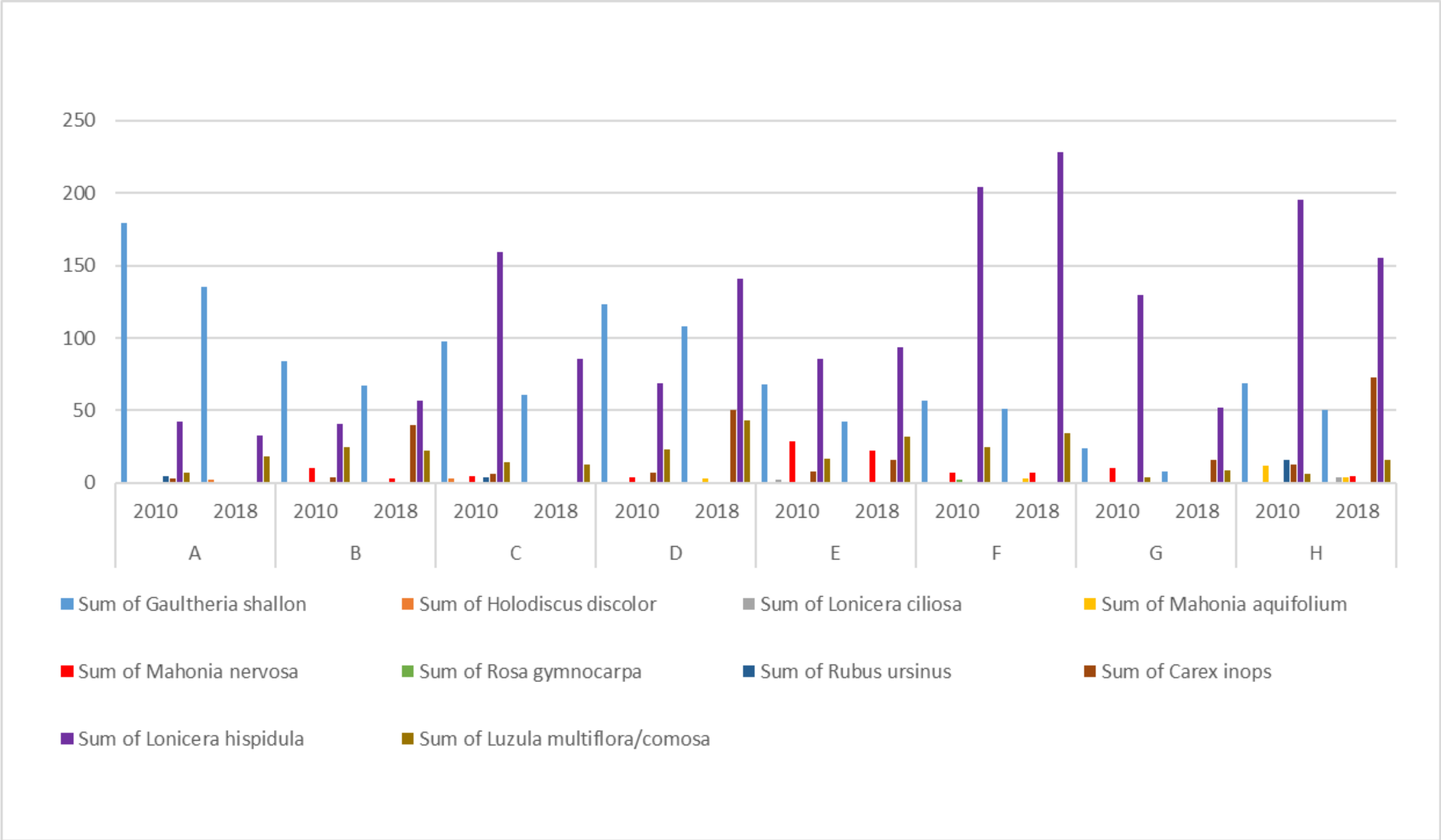

Figure 34. Shrub and miscellaneous plants in 2010 and 2018 compared across all plots.

Both 2010 and 2018 were dominated by *Lonicera hispidula* and *Gaultheria shallon.*

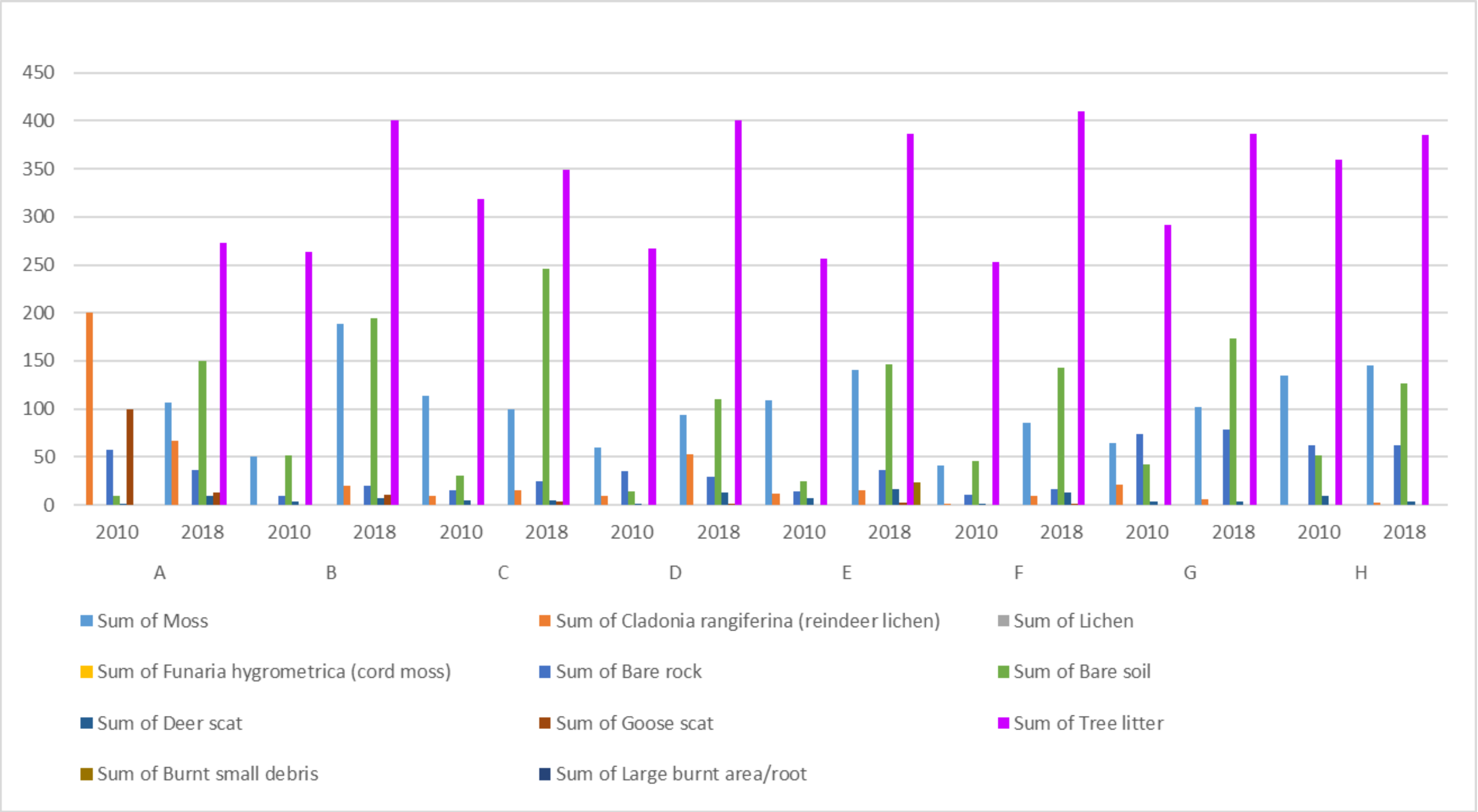

Figure 35. Ground cover and non-vascular plant occurrence numbers in 2010 and 2018 on all plots.

Ground cover and non-vascular plants in 2010 vs 2018 showed an increase in 2018 in the occurrences of tree litter and moss.

Appendix D: Plant Data Analysis

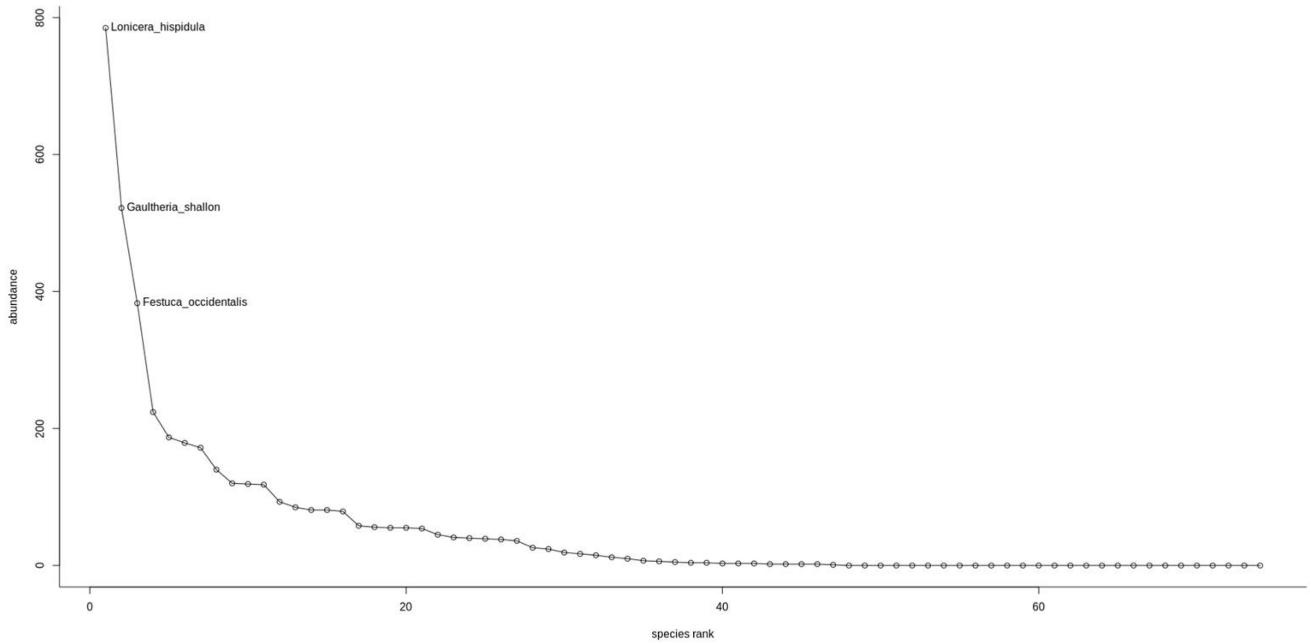

Figure 36. Rank abundance curve for native species for total site in 2018. Y-axis is 0-800 occurrences.

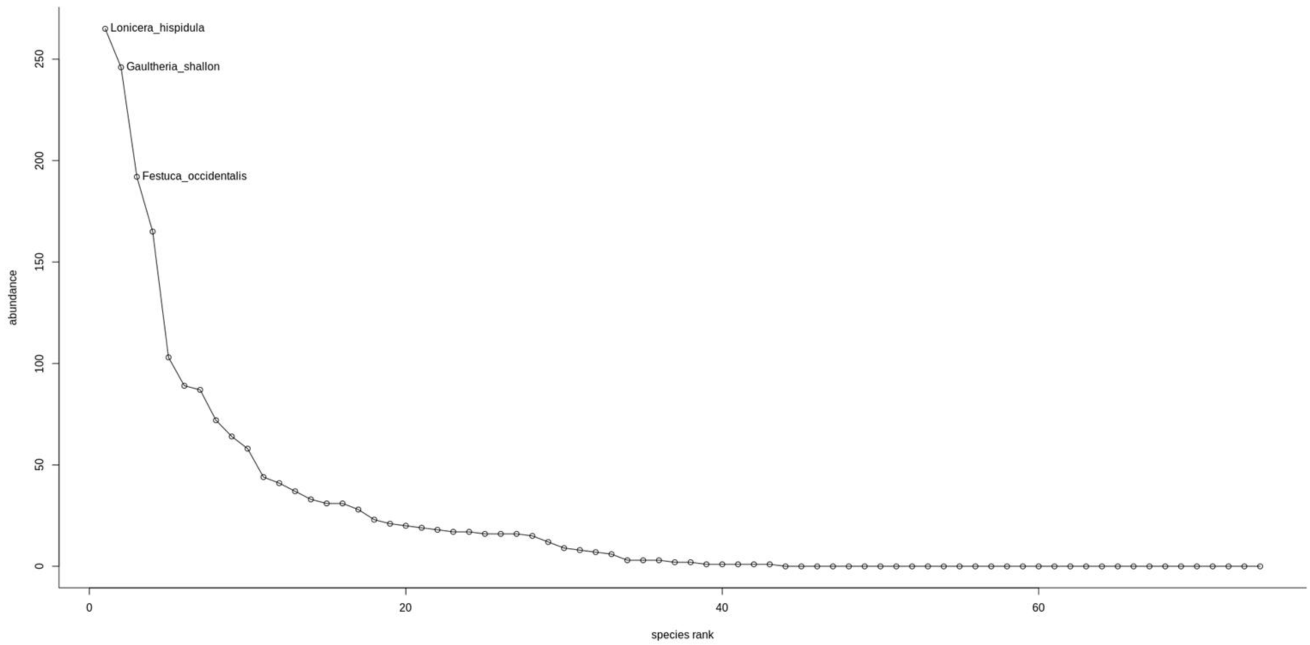

Figure 37. Rank abundance curve for native plant species in 2018 on burned plots. Y-axis is 0-300 occurrences.

Appendix E: Community Ecology Analysis

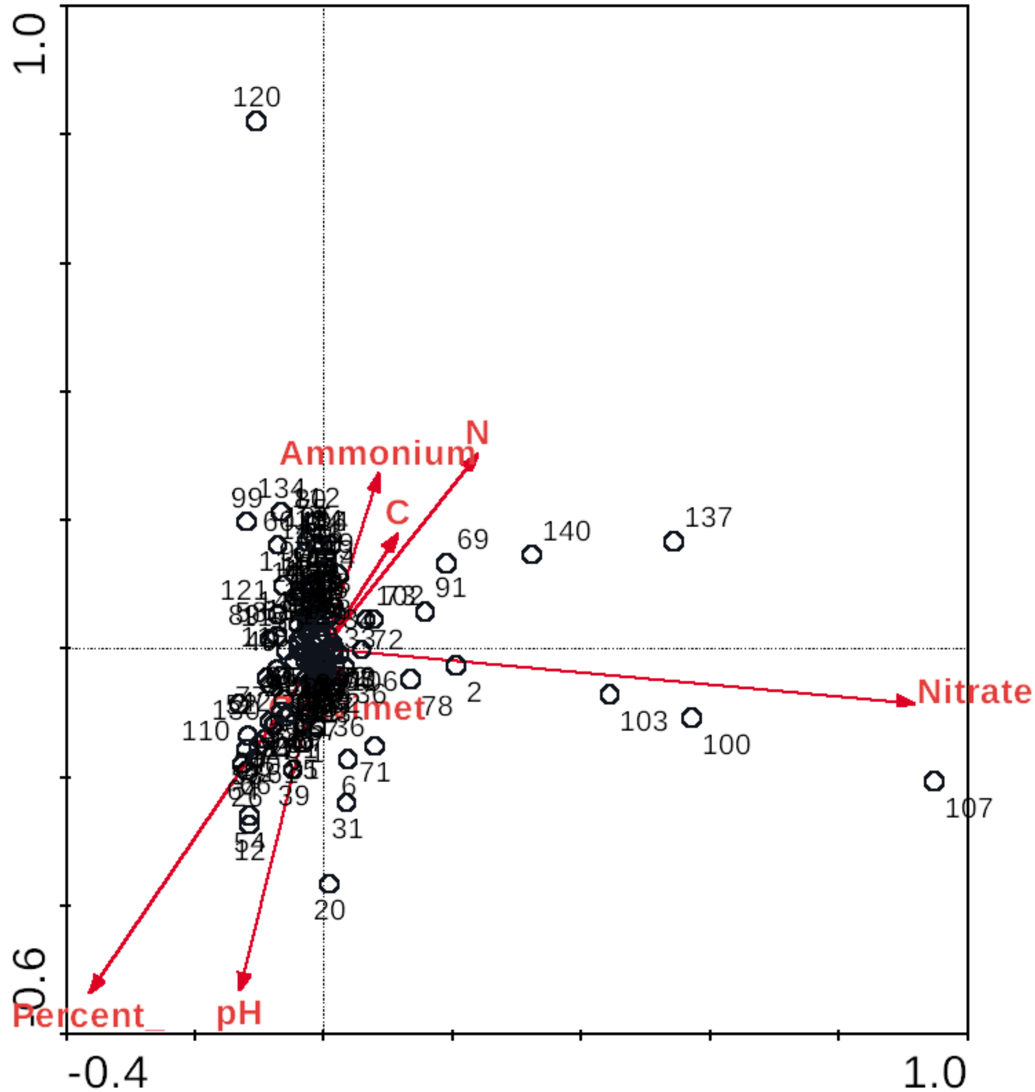

Figure 38. Biplot of sites and environmental variables separated based on LOCATION. Sites divided as 'north' if above 25m in plot and 'south' if below 25m in plot. Sites numbered such that 'north' sites are 1-71 and 'south' sites are 72-143.

Table 11. Summary of CCA of quadrat samples and environmental gradients. 0-5 cm depth environmental values used.

Axes		1	2	3	4	Total inertia
Eigenvalues	:	0.055	0.037	0.033	0.029	4.880
Species-environment correlations	:	0.628	0.525	0.507	0.519	
Cumulative percentage variance						
of species data	:	1.1	1.9	2.6	3.2	
of species-environment relation	:	26.8	44.9	61.1	75.2	
Sum of all eigenvalues						4.880
Sum of all canonical eigenvalues						0.206

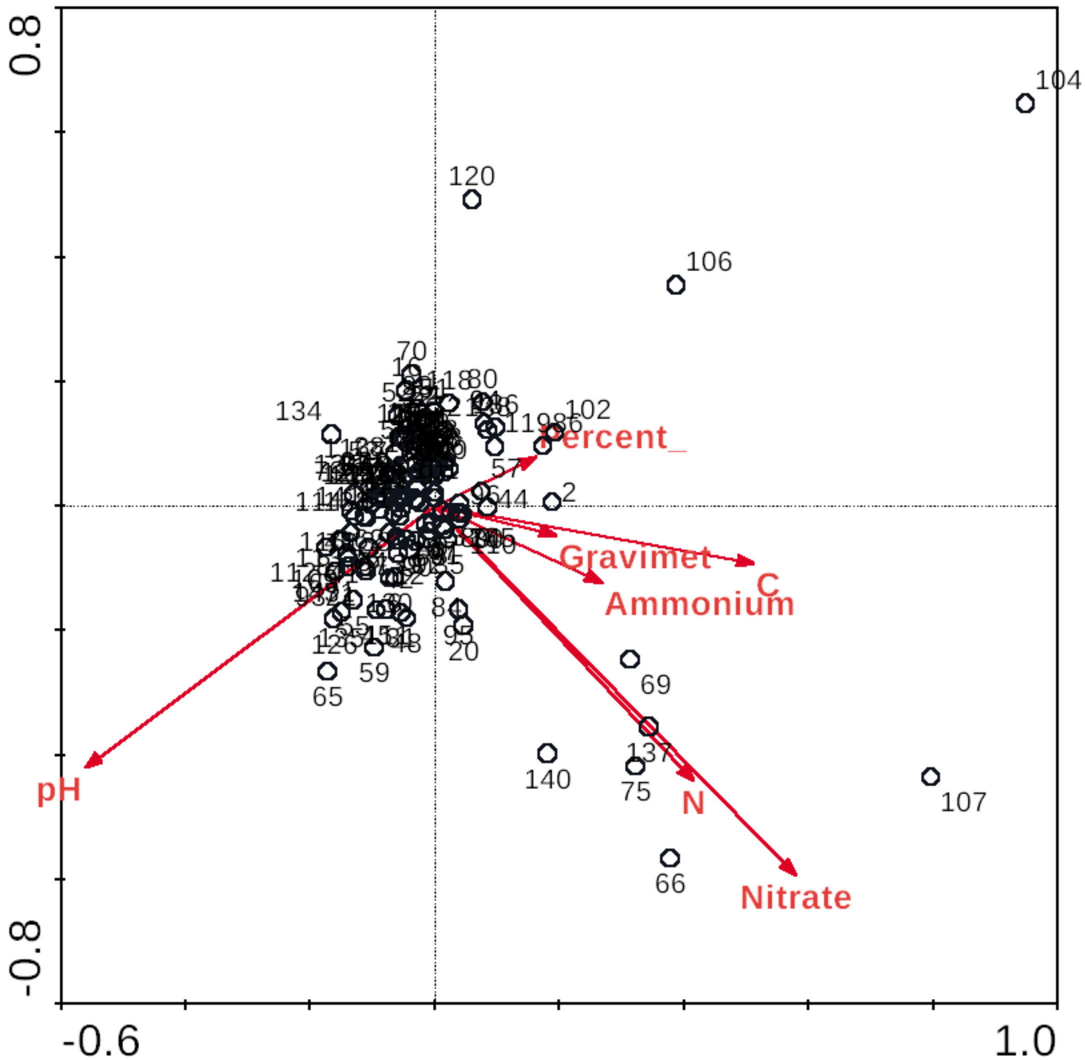

Figure 39. Biplot of sites and environmental variables separated based on TREATMENT. Sites divided as "burned" were numbered 1-72, and sites "unburned" were numbered 73-143.

Table 12. Summary of CCA of quadrat samples and environmental gradients. 0-5 cm depth environmental values used.

Axes		1	2	3	4	Total inertia
Eigenvalues	:	0.065	0.046	0.041	0.031	4.880
Species-environment correlations	:	0.597	0.617	0.522	0.544	
Cumulative percentage variance						
of species data	:	1.3	2.3	3.1	3.7	
of species-environment relation	:	26.5	45.2	62.1	74.7	
Sum of all eigenvalues						4.880
Sum of all canonical eigenvalues						0.244