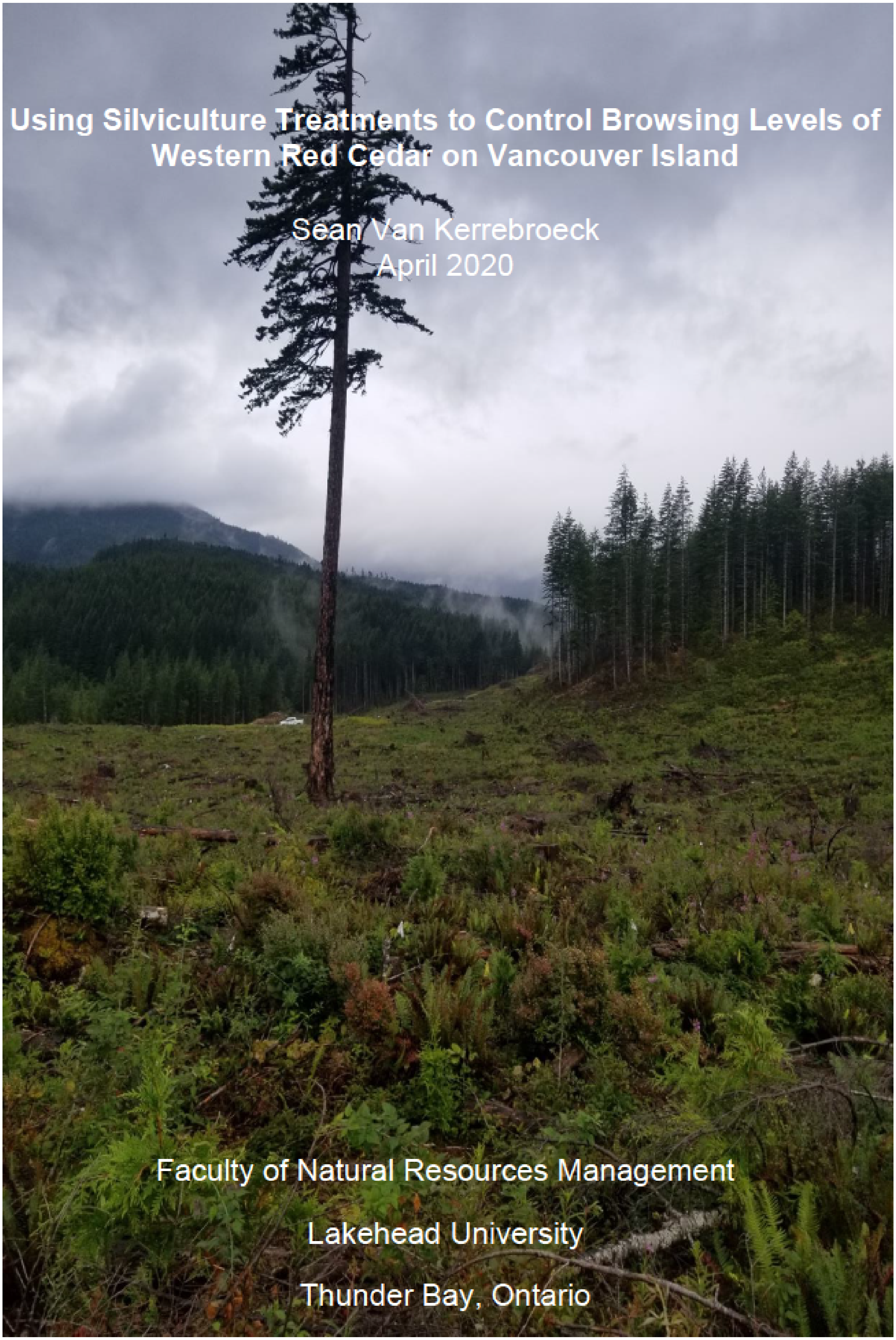

Using Silviculture Treatments to Control Browsing Levels of Western Red Cedar on Vancouver Island

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April 2020

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USING SILVICULTURE TREATMENTS TO CONTROL BROWSING LEVELS OF WESTERN RED CEDAR ON VANCOUVER ISLAND

by

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An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management Lakehead University

April 2, 2020

Thesis Supervisor

Second Reader

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ABSTRACT

Van Kerrebroeck, S.A. 2020. Using Silvicultural Treatments to Control Browsing Levels of Western Red Cedar on Vancouver Island (*Thuja plicata*). 37 pp.

Keywords: British Columbia, browse, free-to-grow, growth, silviculture, treatment, ungulate, Vancouver Island, western red cedar (*Thuja Plicata*)

The Forest Practices Code of British Columbia Act requires forest tree farm licence (TFL) holders and timber supply area (TSA) to have a sensible silviculture prescription that ensures licensees to replace harvested trees with the suited tree species, stocking and specified free growing requirements to create a desired stand (Government of British Columbia 2000). High amounts of ungulate browsing cause TFL and TSA holders to deploy individual tree guards which can result in large costs and stunted growth. To get seedlings to free to grow status, the Ministry of Forests, Lands & Natural Resource Operations Cowichan Lake Research Station have established a study on browse resistant western red cedar. This thesis studies the height growth and browse levels on newly planted, browse resistant western red cedar in the north region of Vancouver Island. Data collected was analyzed using a two-sample T-test assuming equal variances to compare the height and browse levels between non-resistant and resistant treatments. All browse resistant treatments except for one concluded to be significant. Findings from this study highlight how new browse resistant species can eliminate the high costs and need for individual tree guards.

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I would like to acknowledge my thesis advisor Dr. Qing-Lai Dang for his helpful input in shaping my thesis. I would also like to thank my second reader Dr. Don Henne, for his edits and help in creating an experimental design to produce my results. I would also like to thank the Ministry of Forests, Lands & Natural Resource Operations Cowichan Lake Research Station for allowing me to use their data for this study. Also, I would like to thank my supervisors at Interfor Coastal Woodlands Division for allowing me to collect the data used in this thesis during my 2019 summer student contract. Finally, I would like to thank my close friends for helping in the editing process of this thesis.

INTRODUCTION

Protecting newly planted artificially regenerated western redc edar (*Thuja plicata)* seedlings from deer and elk browse in the coastal region of British Columbia can be costly. Without protection, regeneration can be delayed or result in complete failure. In order to bring seedlings to free-to-grow status, protection of the trees require individual tree guards which can result in large deployment and cleanup costs. Recent studies associating deer and elk browse to needle monoterpenes has caused the initiation of a breeding program for deer/elk-resistant western red-cedar on Vancouver Island. This study is currently taking place at various locations on Vancouver Island. This study will focus on the North Island region located in Elk Bay, within block BLKRB2. My null hypothesis states: Increased levels of monoterpenes will not reduce browsing levels on western red cedar.

LITERATURE REVIEW

WESTERN RED CEDAR

Western red cedar (*Thuja plicata*) is a common coniferous tree species found in the geographic region of Western North American mainly in the Pacific and less so in the Cordilleran range. In British Columbia it is found at low to mid elevations along the coastal region and in the wet belt of the interior, preferring a cool, moist climate (Government of British Columbia 2019).

Figure 1 Western red cedar range in B.C. (Government of British Columbia 2019)

Western red cedar most commonly grows in mixed species, uneven-aged stands and less frequently in pure even-aged stands. A medium to large sized tree, growing up to 60 m tall, up to 8 m in width, can be over 1000 years old. It has scale-leaves, drooping fern-like branches and thin brown bark. Its heartwood is reddish brown in colour and very light in weight. It is typically found in the biogeoclimatic (BEC) zones of IDF, ICH, CDF, and CWH holding a major component in old-growth stands (Government of British Columbia 2019). These zones are highly associated with species such as douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga hetero*). Species with a medium associated occurrence class are red alder (*Alnus rubra*), western larch (*Larix occidentalis*), sitka spruce (*Picea sitchensis*) and black cottonwood (*Populus trichocarpa)* (Government of British Columbia 2019).

Table 1 Tolerances of western red cedar (Government of British Columbia 2019)

Tolerance:	**Frost**	**Shade**	**Heat**	**Water deficit**	**Water surplus**	**Nutrient**
Tolerance Class:	Low-Medium	High	Medium	Medium	High	High

Western red cedar has strong mechanical properties and unique physical features making it a high value species, holding a strong economic and ecological component of the Pacific Northwest (PNW) forests.

Up to 10 million seedlings are planted annually in British Columbia (Daniels and Russel 2007). Most commonly used in exterior wood products such as roofing, fencing and siding because of its heartwood chemicals which are made up of β-thujaplicin, γthujaplicin, and β-thujaplicinol, giving it the ability to resist fungal attack and decay. Western red cedar needles produce a- and b-thujone, oxygenated monoterpenes which promotes gastroenteritis and possibly inhibit microbial rumen activity, which are not found in either Douglas-fir or western hemlock (Burney and Jacobs 2011).

SILVICULTURE SYSTEM IN BRITISH COLUMBIA

The Forest Practices Code of British Columbia Act requires forest tree farm licence (TFL) holders and timber supply area (TSA) to have a sensible silviculture prescription that ensures licensees to replace harvested trees with the suited tree species, stocking, and specified free growing requirements in order to create a desired stand (Government of British Columbia 2000). British Columbia defines a free growing stand as "An established seedling of an acceptable commercial species that is free from growth-inhibiting brush, weed, and excessive tree competition; or young trees that are as high as or higher than competing brush, with one metre of free-growing space around their tops" (Forest Practices Board 2019). In order to determine the appropriate preferred and acceptable species, the prescriber is to review the recommended species options for the site displayed below in Figure 2.

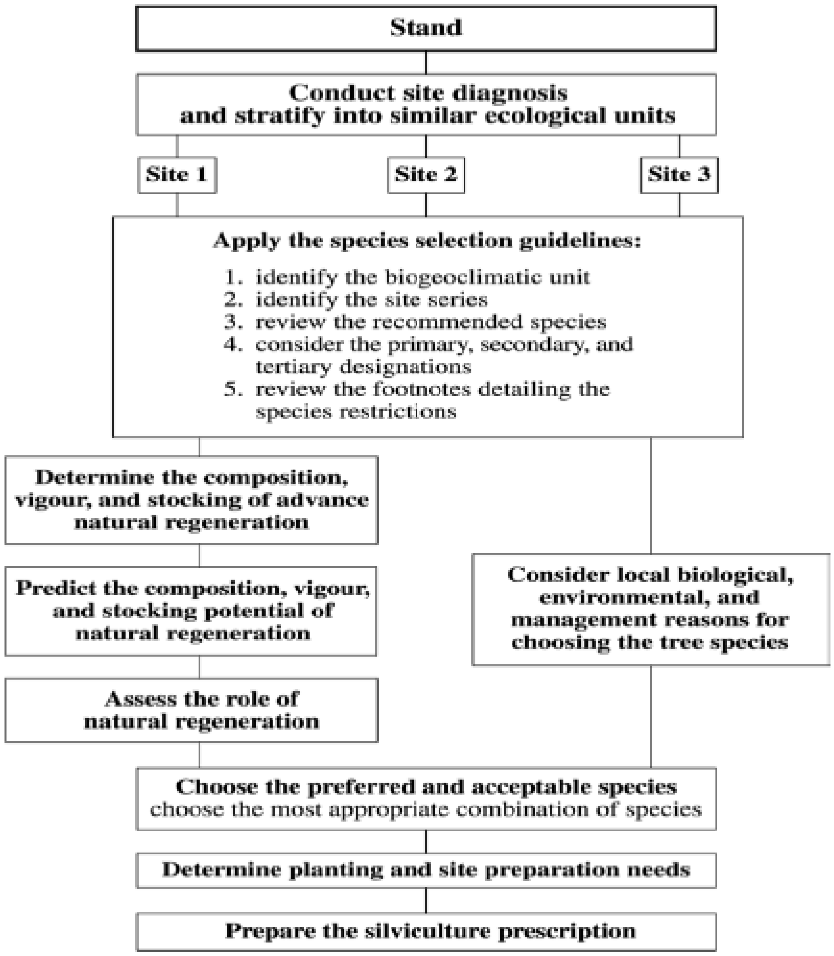

Figure 2 Decision making process to determine appropriate, preferred and acceptable species for forest regeneration sites in BC (Government of British Columbia 2000).

BIOGEOCLIMATIC ECOSYSTEM CLASSIFICATION PROGRAM

The BEC program is a classification system used by the BC Ministry of forests for forest, range and wildlife management. BEC is a hierarchical classification system that uses vegetation climax communities to infer climate and soil combined ecological effects. The province of BC is divided into 14 BEC zones which can be seen in Figure 3.

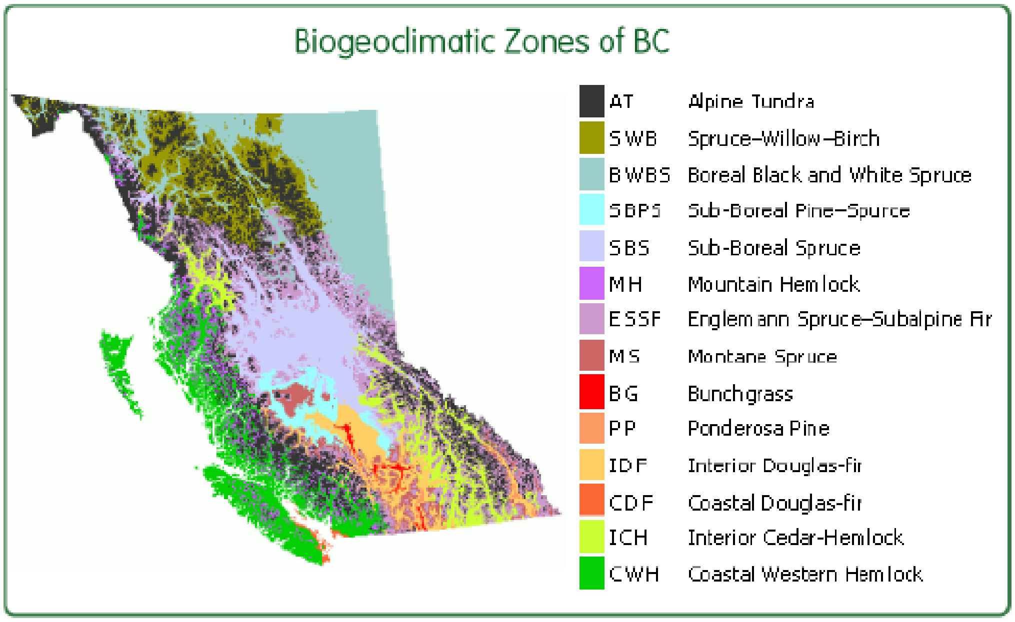

Figure 3 BEC zones of BC (CFCG 2019)

The coastal Western Hemlock (CWH) zone stretches along the entire coast of Vancouver Island at low to mid elevations. This is one of Canada's most productive forest areas and also the wettest with annual precipitation ranging from 1200 mm to 3300 mm (Meidinger 1991). The zone contains 10 subzones varying in continentality and precipitation (CFCG 2019).

<u>CWHxm Forest Description</u>

This forest is classified as a very dry maritime coastal western hemlock subzone. The subzone occurs at elevations up to 700 m along the east side of Vancouver Island. Due to a rain shadow caused by the insular mountains the CWHxm has dry, moist summers and mild winters with little snowfall. Growing seasons are long, and zonal sites suggest water shortages (BC Ministry of Forests 1999). Forests in the CWHxm are made up of douglas fir, western hemlock and small amounts of western red cedar. Understory species that are common include salal, dull Oregon-grape, red huckleberry, *Hylocomium splendens*, and *Kindbergia oregana*. Less common species include vanilla-leaf, sword fern, twinflower, and bracken (CFCG 2019).

Moisture Regime

Under the BEC zone, the area of study can be classified by a moisture regime represented by a code (0-8) 0 meaning very xeric and 8 being hydric. This code is assigned based on environmental factors, soil properties and indicator plants relative to other sites within same BEC unit (B.C. Ministry of Forests 1998). B.C. moisture regime table can be found in appendix I.

Nutrient Regime

Under the BEC zone, the area of study can be classified by a nutrient regime represented by a code (A-F) A meaning oligotrophic and F being hypereutrophic. This code indicates the available nutrient supply relative to other sites within the same BEC unit. This assessment is based on a combination of environmental factors, soil properties, and indicator plants. Strongly expressed features may compensate for other factors to create richer or poorer conditions (B.C. Ministry of Forests 1998). Nutrient regime classes and relationships between nutrient regime and site properties can be found in appendix II.

BLACK-TAILED DEER

Mule and Columbia Black-tailed deer are members of the *Odocoileus hemionus* species and are both common species in British Columbia. Mule deer is a hybrid of Black-tailed and White-tailed deer (Ministry of Environment, Lands and Parks B.C. 2000). Columbia Black-tailed deer have a plentiful population in the Vancouver Island region, displayed in figure 4. Black-tailed deer are dark reddish brown in colour, have a small rump patch and a dark brown or black tail. Adult males weigh anywhere from 48 to 90 kg and females 40 to 65 kg (Ministry of Environment, Lands and Parks B.C. 2000).

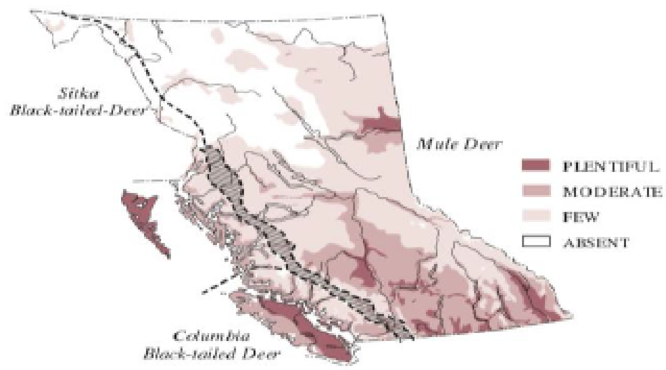

Figure 4 Deer sub-species range in British Columbia (Ministry of Environment, Lands and Parks B.C. 2000).

ROOSEVELT ELK

Roosevelt elk can be found on areas of Vancouver Island and coastal regions of the mainland, displayed in figure 5. Elk can be identified by their brownish fur, dark mane and white rump patch. Bulls have large forked antlers, both male and female have large rounder upper canines. Adult bulls are commonly 140 cm tall at the shoulder, weighing 265 – 410 kg. Adult cows are 130 cm high and weigh 190 - 270 kg. Out of the four subspecies present in North America, the Roosevelt Elk (C. e. roosevelti) is the species found in the Pacific northwest coast (Ministry of Environment, Lands and Parks B.C. 2000).

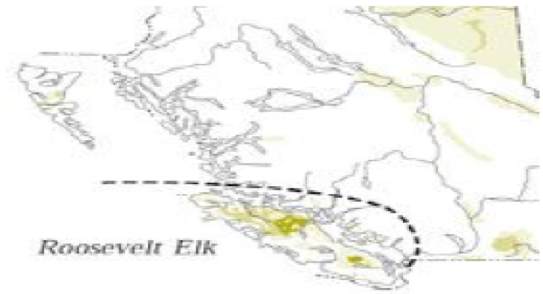

Figure 5 Roosevelt Elk Range in Coastal B.C. (Ministry of Environment, Lands and Parks B.C. 2000).

UNGULATE BROWSE

Deer and elk browse creates a problem during the growing process of western red cedar. After a forest disturbance, changes in vegetation can influence ungulate behaviour. They typically prefer grass and forbs, but will due to plant availability, there diet can change (Hansen and Clark 1977). Ungulates diet can vary depending on season, weather conditions, plant phenology, forage availability, and plant chemical composition (Burney and Jacobs 2011). Over winter months, ungulates must adapt and change their diet to conifers buds and needles. In the PNW of North America, ungulate damage on conifer seedlings is a recurring issue.

According to Weisberg and Bugmann, "Ungulate and vegetation relationships are dynamic, with potential for each to significantly alter processes and functions of the other at various spatial and temporal scales". Ungulate browse can present a costly issue for TFL and TSA holders. Individual plastic tree guards are the current and most common method of protection for western red cedar seedlings. Guards are wrapped around the seedling, protecting it from environmental hazards. This method is effective in the reduction of deer and elk browse but unproductive for the growth of the seedlings due to the continuous suffocation and shortage of sunlight. Areas where western red cedar typically grow can be quite rugged and remote, making the deployment and clean-up a timely and expensive process. As a result, CAN$ 20 to 25 million are spent annually in British Columbia to bring a plantation to free-to-grow status using individual tree guards (Russel 2008). Licensees who avoid planting western red cedar encounter additional indirect costs, including maladapted or inappropriate species selection, and reduced manufacturing opportunities (Russell 2008).

Silviculture Treatments

Recent studies have found that ungulate browse is linked to levels of monoterpenes in conifer needles, triggering a breeding program for browse-resistant western red cedar at the Cowichan Lake Research Station on Vancouver Island (Russell 2008). During a study conducted at Holt Creek on southern Vancouver Island where subsamples of individuals from a western red cedar population study with family structure found a strong correlation between heavy browse levels and low monoterpene content (Vourc'h et al. 2002). This study determined that populations sourced from northern British Columbia had greater needle monoterpene levels than southern British Columbia sources. Levels of monoterpenes in conifer needles are influenced by age, genetics and environmental factors, as well as their interactions with the environment (Baradat et al. 1972). Deer "non-preferred" selections are currently going through rapid breeding and testing cycles for enhanced needle monoterpene concentrations. However, planting stock bred for higher monoterpene levels alone may not ensure that seedlings will be adequately protected from browse (Russell 2008).

To gain a more precise understanding of the relationship between deer browse and needle monoterpenes, an enclosed deer populated area was used to study multiple copies cuttings that were rooted from 60 trees from Holt Creek that varied in monoterpene concentrations. These clone cuttings were planted at the USDA National Wildlife Center, Olympia Field Station Olympia, Washington. Results of this test are displayed in figure 6 below. The results in figure 6 depict that browse preference is correlated to total monoterpene content (Russell and Kimball 2008).

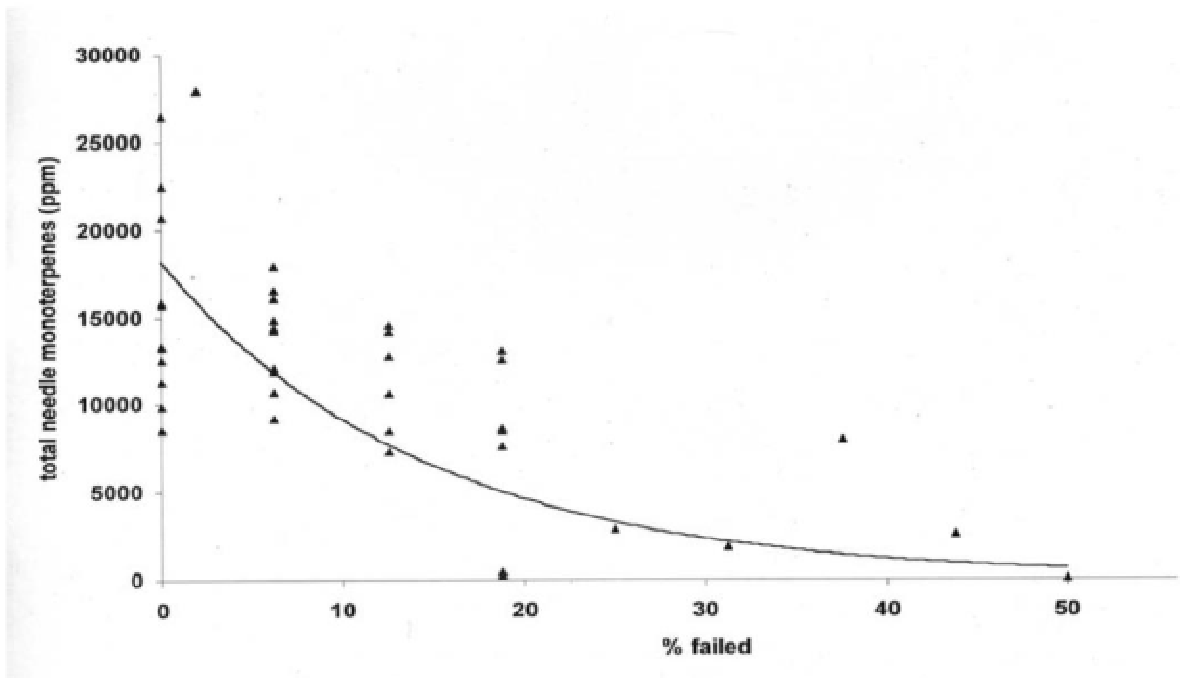

Figure 6 Relationship between level of total needle monoterpenes and percentage of mean failure by clone for western red cedar from the USDA National Wildlife Center, Olympia Field Station. (Russell 2008).

MATERIALS AND METHODS

STUDY AREA

The deployment of browse resistant Western red cedar (*Thuja plicata*) were planted in the region of Elk Bay, within Bear Lake block BLKRB2 located in the District of Campbell River north-west of the city of Campbell River, British Columbia, Canada. Data collection was undertaken in the summer of 2018 and 2019 and was analyzed during the winter of 2019-2020. The study area is located in the Coastal Forest Region displayed in figure 7. Common Coastal Forest Region tree species are western red cedar (*Thuja plicata*), western hemlock (*Tsuga hetero*), Sitka spruce (*Picea sitchensis*), and Douglas-fir (*Pseudotsuga menziesii*). All of these tree species can be found in the immediate area of the Bear Lake Blocks.

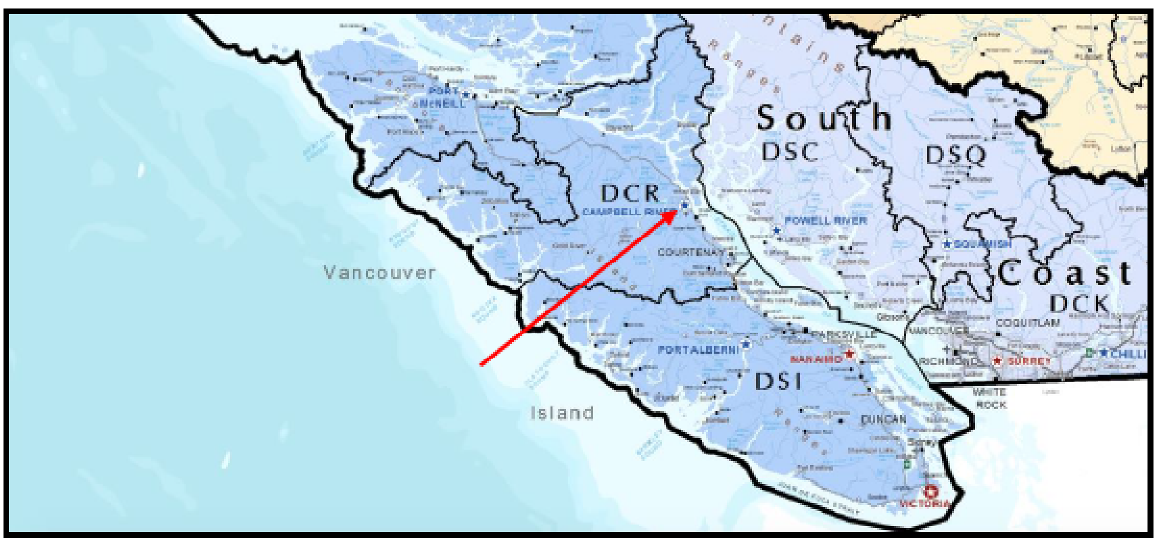

Figure 7 Coastal Forest Region in the District of Campbell River

The study area is located around 40 km north of Campbell River on the forest service road (FSR) of Rock Bay main line between the 12 and 13 km markers. Within BLKRB2, the study area is sectioned off, displayed in the red box below in figure 8.

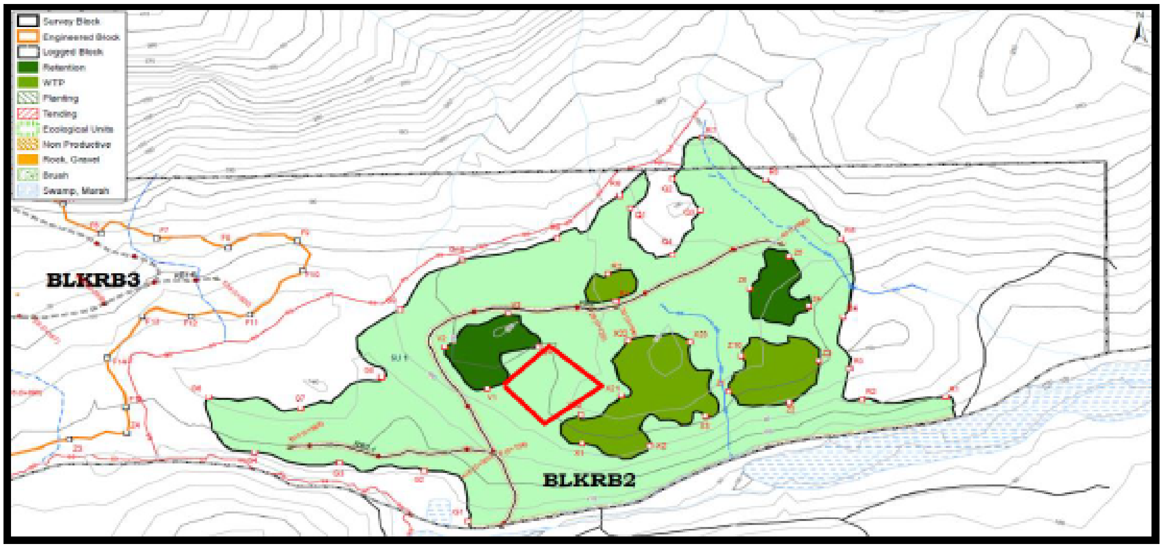

Figure 8 Area of Study within BLKRB2 (Interfor, 2019)

Figure 9 displays an image taken on a trail camera capturing a black-tailed deer browsing a western red cedar tree in the area of study within BLKRB2.

Figure 9 Black-tailed deer caught browsing in BLKRB2 (Interfor, 2020)

BLOCK HISTORY AND INFORMATION

Harvesting in BLKRB2 began in February 2016, ending in June 2016. In 2017 the site was prepped with a hoe chuck and planted with Douglas fir at 900 stems per hectare. The study area within the block was left without being site prepped and planted only with western red cedar. BLKRB2 is located in the BEC zone of coastal western hemlock (CWH), subzone xm1. The soil is in the submesotrophic/mesotrophic (B-C) nutrient regime class and a submesic/mesic (3-4) in moisture regime (B.C. Ministry of Forests 1998). The study area within BLKRB2 can be seen below in figure 10.

MATERIALS

Materials used in this experiment were: 1 metric measuring tape, 1 write in the rain notebook, 1 pencil, 1 cell phone camera and 2 trail cameras.

EXPERMENTAL DESIGN

Data collection for this study begun in the summer of 2018 after the BLKRB2 was harvested and planted in 2017. Data that was gathered for this study was collected for the Ministry of Forests, Lands and Natural Resources in the South Island Natural Resources District in British Columbia. Interfor Coastal Woodlands Division was contracted for collection of this data.

Over 60 "not preferred" selections (minimal deer browse and enhanced needle monoterpenes) from a base population of approximately 2500 range-wide western red cedar trees have been selected to be planted on this site as part of the breeding program. Furthermore, a number of "deer preferred" selections (high browse and low monoterpene concentrations) have also been included (Russell J. 2008).

Figure 10 BLKRB2 (Van Kerrebroeck 2019)

The design for this experiment is similar to a matched-pairs design, a special case of a randomized complete block design. Each treatment is paired with a reference, or in this situation, a control. Matched pairs, similar to a completely randomized design by using randomization to control for confounding effects (Stat Trek, 2020). In order to perform further analysis, treatments were organized into nine blocks. Four treatments and four paired controls within each block. Within each treatment block, a subsample was created by obtaining a single average measurement for each treatment block. Variability from block-block was low, so each block yielded a single measurement, gathering nine observations for each treatment. The treatment is the non-preferred selections and the control is the preferred. Non preferred and preferred selections were planted in straight rows approximately 2 meters apart in distance, length and width. Each preferred selection tree was planted in rows with a white flag next to it. Non preferred trees were planted in rows of orange, pink, yellow or blue flags along with an ID number attached to the tree, each colour is considered a treatment. ID numbers were not used in this experiment due to the lack of information on what they represent.

Orange flags represent a 2+0 cutting (2 year old cutting when planted), pink flags represent 1+0 seedling (1 year old seedling when planted), yellow flags represent 1+0 cutting (1 year old cutting when planted), blue flags represent 2+0 seedling (2 year old seedling when planted) and white flags represent class A (preferred control) . As an example, the area of study began with a row of white flagged preferred seedlings, followed by a row of blue flagged non preferred seedlings, followed by a row of white flagged preferred seedlings, followed by a row of orange flagged non preferred seedlings, etc. Design layout is displayed below, in figure 11.

Figure 11 Randomized ungulate browse trial design (Interfor 2019)

Data collection consisted of measuring the height of each tree in centimeters using a measuring tape, recording the colour of the flag beside the seedling, locating and recording the ID number for non-preferred species and determining the browse level of the seedling from 1-4. One meaning little to none and four meaning heavily browsed or dead. Collection of data was performed with two people, one measuring the height and determining the browse level and one recording the information. Data was recorded using a pencil and paper and was later entered and organized into Microsoft Excel.

Figure 12 Western red cedar seedling (Van Kerrebroeck 2019)

Variability in Data

During data collection, there are a few environmental factors that cause variability in the data which affect the growth of seedlings and probability of browse. Block effect creates variability within the study area. Trees located closer to residual tree stands were noted to typically have higher browse levels due to ungulates preferring to stick to the edge of the stand rather than the middle Moisture content throughout the study area varied from well drained dry areas to very wet areas. Slope changes throughout the study area varied, resulting in different levels in fertility of the soil. High levels of brush species including red alder were more common in some sections of the study area, which affects seedlings ability to meet free to grow standards. Measurements were only taken in 2018 and 2019, allowing one year of comparison data. Weather patterns between 2018 and 2019 have a large influence between the year of growth that was measured.

During collection of data, errors did occur due to the nature of the study. Many trees were missing ID tags due to the tags being made out of paper, easily damaged by weather, or tree growth. The second issue that was faced was missing trees in spots where there should be trees, these were marked off as N/A if the stem was not able to be located. The third issue was unplantable areas. Some areas had permanent water or high levels of slash, making the area unplantable, resulting in recording the tree as N/A. Height and browse data can be skewed due to error during measurement. Different surveyors have different rounding techniques and have different ideas for browse level assessment. Errors of misreading height during measurement or even completely skipping a seedling can also be considered as a common error.

STATISTICAL ANALYSIS

Pooled Data Analysis

Data analysis was performed to understand the effects of applied treatments when compared to the pooled deer preferred selections (control). Analysis was first performed on Microsoft Excel with 2018 and 2019 data to compare the number of samples, mean height, maximum height, minimum height, standard deviation of height, mean browse level, standard deviation of browse level and mortality of samples between 2018 and 2019. This data was analysed by looking at the study area as a whole, without pairing each treatment with a control and having no regard for blocks.

Two-Sample T-test

To further analyze these results, data was organized into a matched pairs design to perform a two-sample T-test assuming equal variances to compare the significance of the treatments and corresponding control using SPSS. After comparing the standard deviations between the treatments and corresponding control, equal variance was assumed. Separate analysis of 2018 browse, 2018 height, 2019 browse and 2019 height between the four treatments and the control associated with the treatment was performed. In order to input this data into SPSS, it was first organized on Microsoft Excel.

RESULTS

Treatment identification used in the statistical analysis can be shown in table 2 below. Each treatment that was used in this experiment was labeled 1 to 4 for the purpose of SPSS data analysis setup requirements.

Table 2 Treatment identification represented by flag colour and number

Treatment	**Treatment Represented by Flag Colour**	**Treatment Represented by Number**
2+0 Cutting	Orange	Treatment 1
1+0 Seedling	Pink	Treatment 2
1+0 Cutting	Yellow	Treatment 3
2+0 Seedling	Blue	Treatment 4
Class A – Deer Preferred	White	Control (1,2,3 & 4)

Figure 14 compares the separate height growth data that was collected during 2018 and 2019. It compares mean height, maximum height and minimum height of treatments and control between the years of 2018 and 2019. Values of this figure can be found in appendix III.

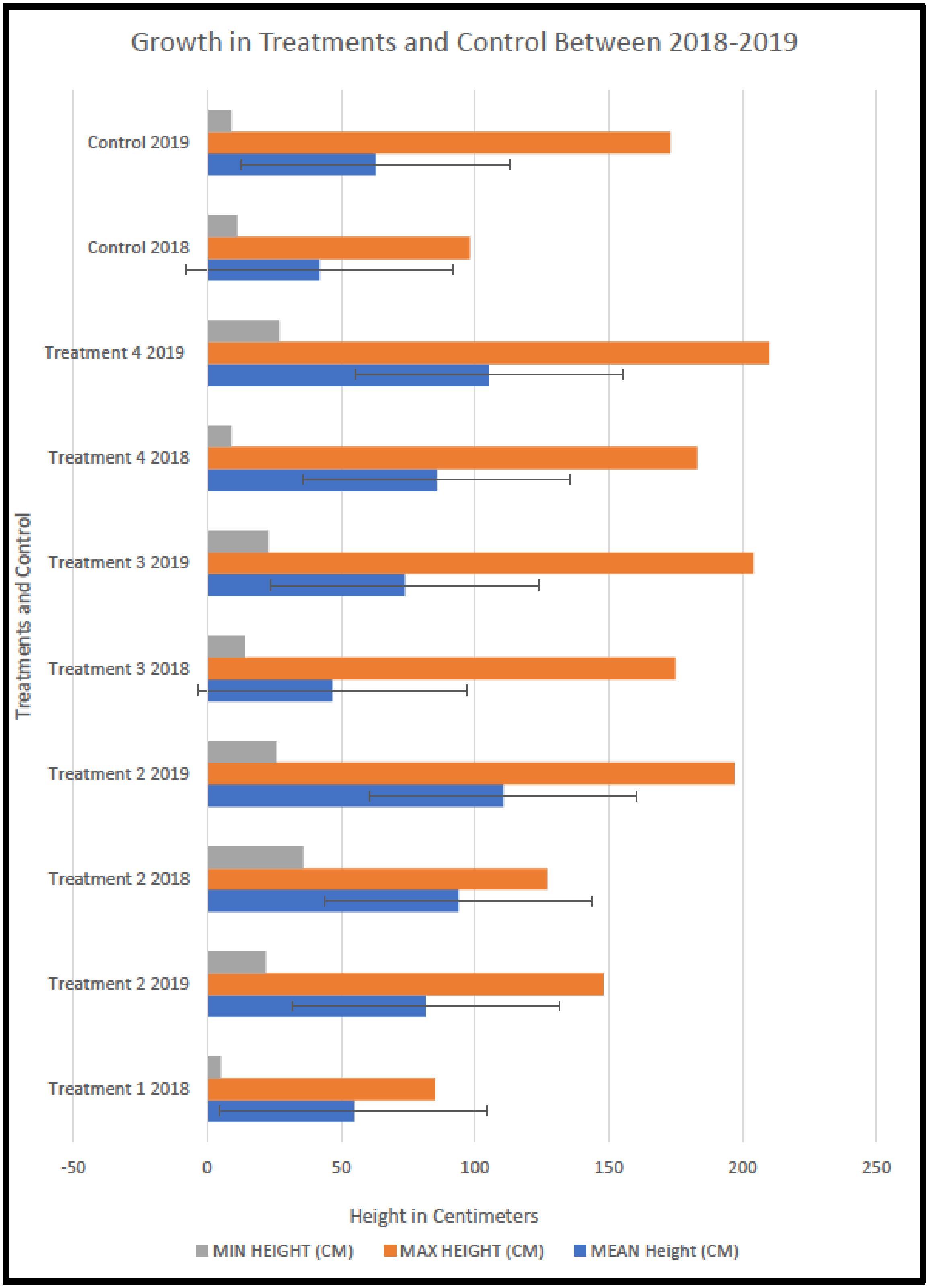

Figure 13 Growth comparison (cm) of treatments and pooled controls between 2018 and 2019

Figure 15 compares the mean browse level recorded in 2018 and 2019 between the treatments and control. All browse levels recorded for each sample within each treatment and control was averaged separately for 2018 and 2019. Values of this figure can be found in appendix III.

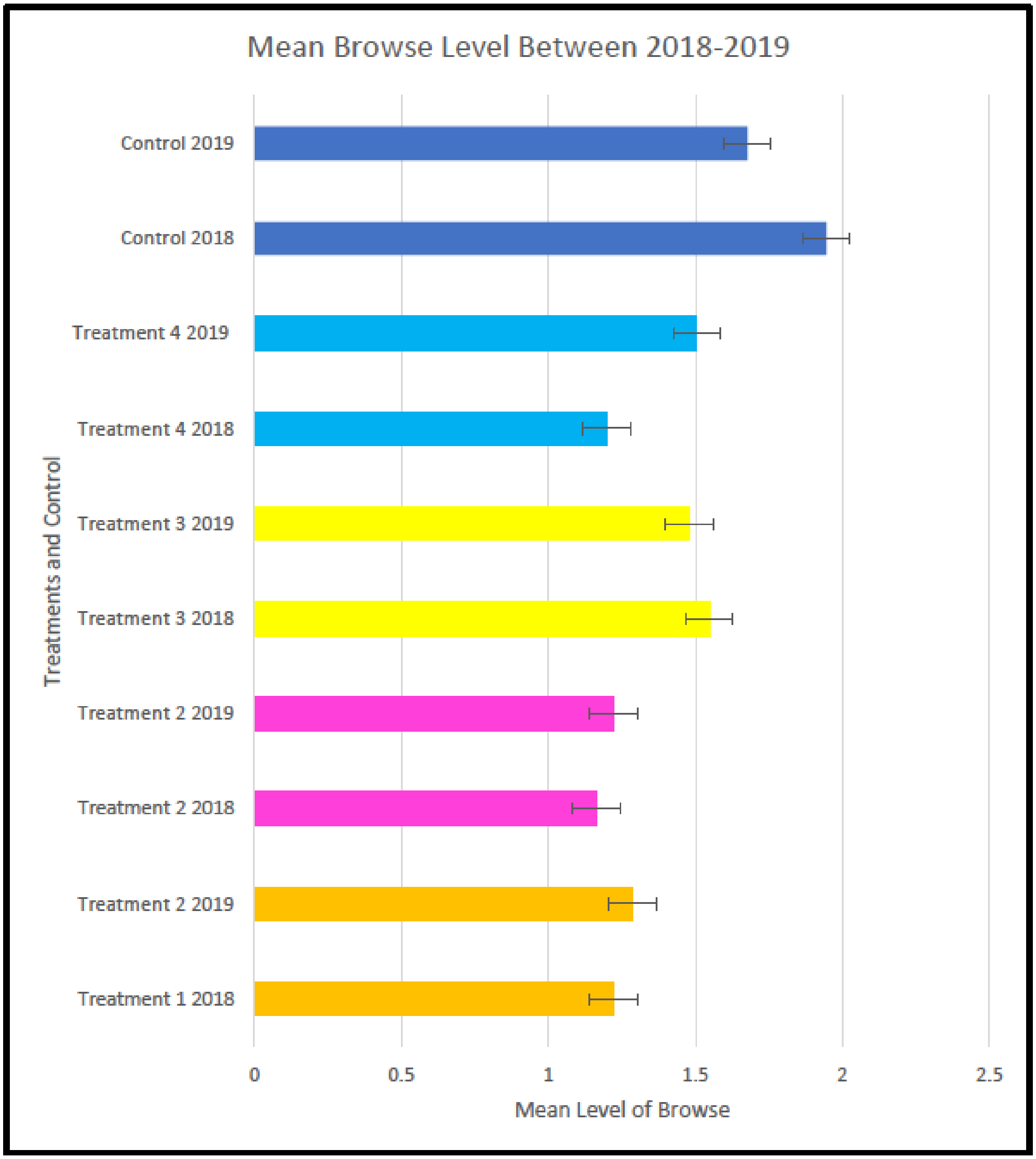

Figure 14 Comparison of mean browse levels (levels 1-4) of treatments and pooled controls between 2018 and 2019

Figure 16 compares the mortality of seedlings measured bewteen 2018-2019. This data was calculated by subtracting the number of samples measured in 2018 by the number of samples measured in 2019. Values of this figure can be found in appendix III.

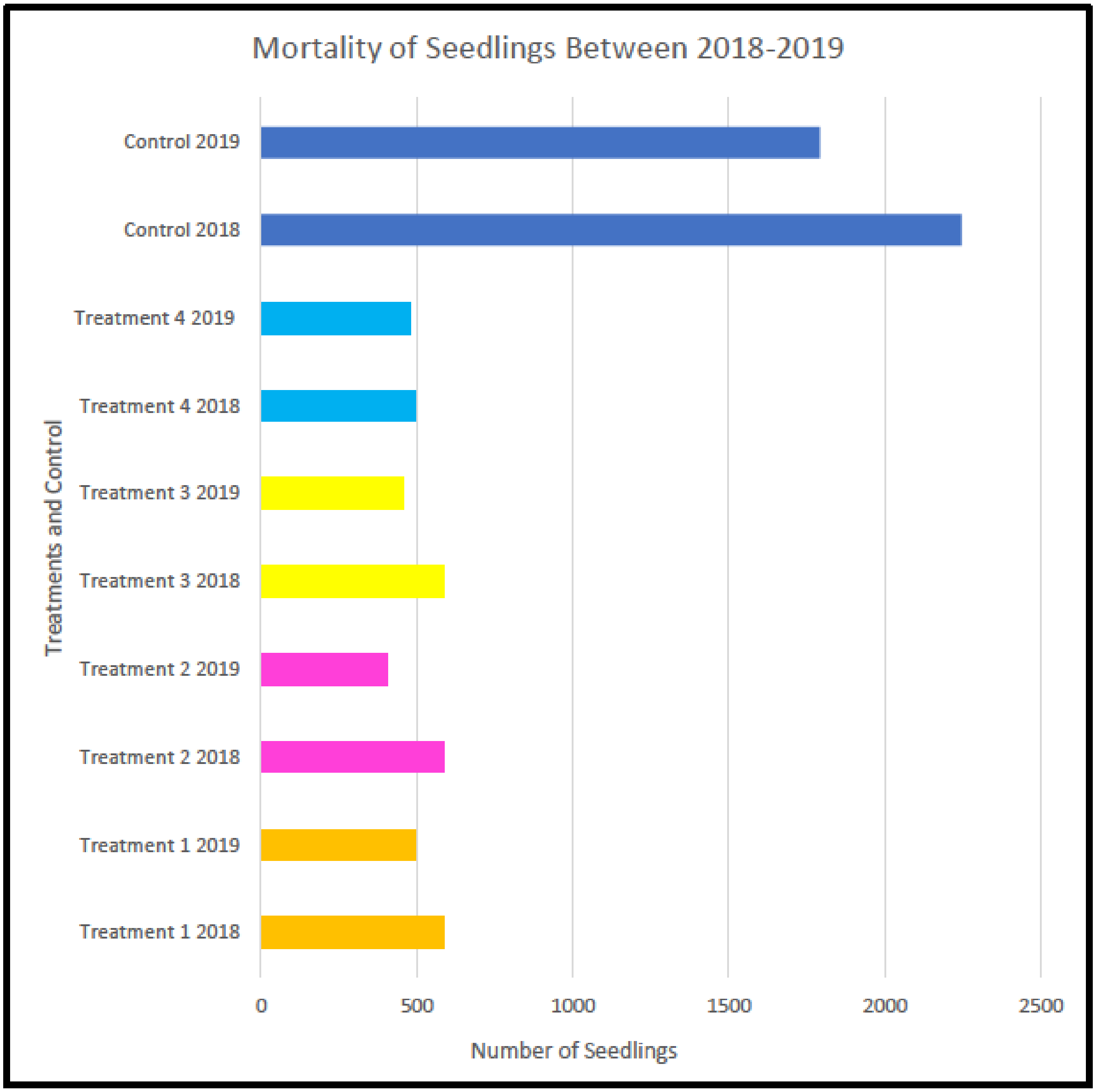

Figure 15 Number of mortalities in treatments and pooled controls between 2018 and 2019

Table 3 displays the number values and percentages of change in of analysis tests between 2018 and 2019. 2019 data was subtracted from the 2018 data in to analyse the change between the years. All controls were pooled and not associated to any treatment.

Comparison between 2018 and 2019 data, looking at the study area as a whole, display that each treatment and control show decline of samples. Deer preferred selection (control) experienced the largest amount of change in numbers, 455 seedlings, losing 20% of its population (Table 3). Treatment 2 experienced the highest percentage seedling loss, losing 31% of its population, 180 seedlings (Table 3). Treatment 4 had the lowest change in seedling loss, losing 4%, 18 seedlings (Table 3). Control selection had the highest mean browse level in 2018 and 2019. Treatment 3 experienced 58% change in mean height, the largest amount of growth between the treatments (Table 3). Control showed the largest maximum height change at 77% (Table 3). Treatment 1 displayed 340% change in its minimum height growth, the largest change out of the treatments (Table 3). Treatment 4 showed a 26% increase in its mean browse level, and control showed a decline of -14% in mean browse level (Table 3).

Table 3 Change in values of treatments and control between 2018 and 2019

Measurement	Treatment 1		Treatment 2		Treatment 3		Treatment 4		Control	
	Change +/-	Percentage	Change +/-	Percentage	Change +/-	Percentage	Change +/-	Percentage	Change +/-	Percentage
NO OF SAMPLES	-93.000	-16%	-180.000	-31%	-133.000	-23%	-18.000	-4%	-455.000	-20%
MEAN Height (CM)	26.923	49%	16.770	18%	27.095	58%	19.522	23%	21.024	50%
MAX HEIGHT (CM)	63.000	74%	70.000	55%	29.000	17%	27.000	15%	75.000	77%
MIN HEIGHT (CM)	17.000	340%	-10.000	-28%	9.000	64%	18.000	200%	-2.000	-18%
MEAN BROWSE LVL	0.062	5%	0.058	5%	-0.068	-4%	0.307	26%	-0.269	-14%

Table 4 depicts the significance between the 2018 height measurements (cm) of the four treatments and the corresponding controls using a two-sample t-Test with equal variances. T-test findings for 2018 height data found all treatments and corresponding controls was significant. Treatment and control 1 resulted in *df*=15, *t*=13.25, *p*<0.0001 (Table 4). Treatment and control 2 resulted in *df*=13, *t*=58.79, *p*<0.0001 (Table 4). Treatment and control 3 resulted in *df*=16, *t*=3.54, *p*=0.003 (Table 4). Treatment and control 4 resulted in *df*=14 *t*=27.79, *p*<0.0001 (Table 4).

Table 4 T-Test assuming equal variance comparing the 2018 height of the treatments and corresponding control

2018 Height (cm)	Mean	Variance	df	t Stat	P(T<=t) two-tail
Treatment 1	55.06	5.17	15	13.26	0.000000001
Control 1	42.09	2.77			
Treatment 2	95.07	2.95	13	58.80	0.00
Control 2	41.74	3.21			
Treatment 3	48.30	14.54	16	3.54	0.003
Control 3	43.02	5.43			
Treatment 4	86.45	10.44	14	27.80	0.0000000000001
Control 4	43.41	8.74			

Table 5 depicts the significance between the 2018 browse level assessments of the four treatments and the corresponding controls using a two-sample T-Test with equal variances. T-test findings for 2018 browse levels found that all treatments and corresponding controls was significant. Treatment and control 1 resulted in *df*=15 *t*=-11.01, *p*<0.0001 (Table 5). Treatment and control 2 resulted in *df*=13 *t*=-10.97, *p*<0.0001 (Table 5). Treatment and control 3 resulted in *df*=16, *t*=-6.15, *p*<0.0001. (Table 5). Treatment and control 4 resulted in *df*=14 *t*=-8.46, p<0.0001 (Table 5).

Table 5 T-Test assuming equal variance comparing the 2018 browse level of the treatments and corresponding control

2018 Browse	Mean	Variance	df	t Stat	P(T<=t) two-tail
Treatment 1	1.26	0.02	15	-11.01	0.00000001
Control 1	2.05	0.02			
Treatment 2	1.21	0.02	13	-10.97	0.0000001
Control 2	1.96	0.01			
Treatment 3	1.52	0.03	16	-6.15	0.00001
Control 3	1.98	0.02			
Treatment 4	1.22	0.01	14	-8.46	0.000001
Control 4	2.00	0.06			

Table 6 depicts the significance between the 2019 height measurements (cm) of the four treatments and the corresponding controls using a two-sample T-Test with equal variances. T-test findings for 2019 height data found that all treatments and corresponding controls was significant. Treatment and control 1 resulted in $df=16$ $t=11.18$, $p<0.0001$ (Table 6). Treatment and control 2 resulted in $df=16$ $t=32.93$, $p<0.0001$ (Table 6). Treatment and control 3 resulted in $df=15$, $t=4.45$, $p=0.0005$. (Table 6). Treatment and control 4 resulted in $df=14$ $t=14.07$, $p<0.0001$ (Table 6).

Table 6 T-Test assuming equal variance comparing the 2019 height of the treatments and corresponding control

2019 Height (cm)	Mean	Variance	df	t Stat	P(T<=t) two-tail
Treatment 1	81.72	7.38	16	11.18	0.00000001
Control 1	62.43	19.41			
Treatment 2	108.99	13.74	16	32.93	0.00
Control 2	62.61	4.11			
Treatment 3	73.46	21.62	15	4.45	0.0005
Control 3	65.36	5.30			
Treatment 4	107.04	53.27	14	14.07	0.000000001
Control 4	62.87	25.56			

Table 7 depicts the significance between the 2019 browse level assessment of the four treatments and the corresponding controls using a two-sample T-Test with equal variances. T-test findings for 2019 treatment and control 1 are concluded to be significant df=16 t=-5.70, p<0.0001 (Table 6). Treatment and control 2 concluded to be significant df=16 t=-6.62, p<0.0001 (Table 6). Treatment and control 3 concluded to be not significant df=15, t=-2.10, $p>0.05$ (Table 6). Treatment and control 4 concluded to be significant df=14 t=-4.73, p<0.001 (Table 6).

Table 7 T-Test assuming equal variance comparing the 2019 browse level of the treatments and corresponding control

	Mean	Variance	df	t Stat	P(T<=t) two-tail
Treatment 1	1.29	0.01	16	-5.70	0.00003
Control 1	1.68	0.03			
Treatment 2	1.23	0.01	16	-6.62	0.00001
Control 2	1.63	0.02			
Treatment 3	1.46	0.02	15	-2.10	0.05
Control 3	1.61	0.02			
Treatment 4	1.32	0.04	14	-4.73	0.0003
Control 4	1.70	0.01			

DISCUSSION

By pooling all controls together, I can conclude that there is no significant trend between treatments and control. That being said, seedling loss, mean height, maximum height, minimum height and mean browse level can call be affected by drought, lack of sunlight, poor planting site, high amounts of slash, high amounts of brush species, and surveyor error.

The null hypothesis was rejected because the t-test results show that there is a significant difference between the treatments and associated control for browse level and seedling height in all cases but one. By using the matched pairs analysis and not pooling all the controls together, the data is less susceptible to block effect variability throughout the study area.

By analysing the raw data in the area of study where treatment and control 3 were sourced, I was able to determine the absence in data in this area of study due to surveyor error, resulting in an insignificant t-test. This confirms the statement in my literature review that there is a strong correlation between heavy browse levels and low monoterpene content (Vourc'h et al. 2002). Here, I can conclude that all non-preferred selections (treatments) have lower browse levels and greater heights than preferred selections (control) in this study.

The results of this study depict a significant trend in ungulate browse levels and treatments using increased levels of monoterpenes in western red cedar seedlings in the Elk Bay region, cwhxm1 BEC zone where deer populations are significantly higher than most areas of Vancouver Island. Increasing use of non-preferred selections could save TFL and TFA holders in British Columbia up to CAN$ 20 to 25 million annually by eliminating the cost of individual tree guards (Russel 2008). Lower browse levels means western red cedar seedlings will spend less being time being suppressed, thereby allowing faster growth in stands without the need for herbicide spraying or establishment of a less valuable species such as western hemlock. This will allow western red cedar to establish itself and reach free-to-grow status quicker and force ungulates to browse less valuable species.

That being said, this experiment currently only used only two years of data from one study area. In order for more accurate results, height and browse level information must be collected until trees have been declared free-to-grow status.

I was unable to determine the different monoterpene levels in the treatments used and the official experimental design of this study due to the inability to obtain information from contacts responsible for the establishment of this study at the B.C. Ministry of Forests.

CONCLUSION

This experiment suggests that the use of increased levels of monoterpenes in western red cedar seedlings are linked to lower levels of ungulate browse in the Elk Bay region in the northeast area of Vancouver Island, British Columbia. Western red cedar's strong economic importance, ecological attributes and historical significance in the PNW makes it a high-value species, making it easy to justify this study. Deploying browse resistant western red cedar will help TFL and TFA holders in B.C. produce a stronger and more productive forest, resulting in a larger yield and lower silviculture costs. To further determine the success of this study, I recommend deployment and annual analysis of browse resistant western red cedar in various locations throughout the Pacific region of B.C.

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APPENDIX I

B.C. SOIL MOISTUE REGIME CLASSES

TABLE 1.1. Soil moisture regime classes[a]

Code	Class	Description	Primary water source
0	Very xeric	Water removed extremely rapidly in relation to supply; soil is moist for a negligible time after precipitation	precipitation
1	Xeric	Water removed very rapidly in relation to supply; soil is moist for brief periods following precipitation	precipitation
2	Subxeric	Water removed rapidly in relation to supply; soil is moist for short periods following precipitation	precipitation
3	Submesic	Water removed readily in relation to supply; water available for moderately short periods following precipitation	precipitation
4	Mesic	Water removed somewhat slowly in relation to supply; soil may remain moist for a significant, but sometimes short period of the year. Available soil moisture reflects climatic inputs	precipitation in moderate- to fine-textured soils and limited seepage in coarse-textured soils
5	Subhygric	Water removed slowly enough to keep soil wet for a significant part of growing season; some temporary seepage and possibly mottling below 20 cm	precipitation and seepage

Code	Class	Description	Primary water source
6	Hygric	Water removed slowly enough to keep soil wet for most of growing season; permanent seepage and mottling; gleyed colours common	seepage
7	Subhydric	Water removed slowly enough to keep water table at or near surface for most of year; gleyed mineral or organic soils; permanent seepage < 30 cm below surface	seepage or permanent water table
8	Hydric	Water removed so slowly that water table is at or above soil surface all year; gleyed mineral or organic soils	permanent water table

APPENDIX II

B.C. NUTRIENT REGIME CLASSES AND RELATIONSHIPS BETWEEN NUTRIENT REGIME AND SITE PROPERTIES

TABLE 1.2. Nutrient regime classes and relationships between nutrient regime and site properties

	Oligotrophic A Very poor	Submesotrophic B Poor	Mesotrophic C Medium	Permesotrophic D Rich	Eutrophic E Very rich	Hypereutrophic F Saline
Available nutrients	very low	low	average	plentiful	abundant	excess salt accum.
Humus form		Mor				
				Moder		
					Mull	
A horizon		Ae horizon present				
			A horizon absent			
					Ah horizon present	
Organic matter content		low (light coloured)				
			medium (inter. in colour)			
				high (dark coloured)		
C:N Ratio		high				
			moderate			
					low	
Soil depth	extremely shallow					
				very shallow to deep		
Soil texture		coarse textured				
				medium to fine textured		
% Coarse fragments	high					
				moderate to low		
Parent material mineralogy	base-low					
			base-medium			
					base-high	
Soil pH	extremely – mod. acid					
			moderately acid – neutral			
					slightly acid – mildly alk.	
Water pH (wetlands)	< 4–5	4.5–5.5	5.5–6.5	6.5–7.4	7.4+	
Seepage			temporary	→	permanent	

APPENDIX III

2018 AND 2019 TREATMENT AND POOLED CONTROL GRAPH DATA

2018	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Control
NO OF SAMPLES	587.000	588.000	588.000	495.000	2247.000
MEAN Height (CM)	54.709	93.887	46.744	85.761	41.870
MAX HEIGHT (CM)	85.000	127.000	175.000	183.000	98.000
MIN HEIGHT (CM)	5.000	36.000	14.000	9.000	11.000
STDEV (HEIGHT)	11.193	12.204	12.448	14.503	10.881
MEAN BROWSE LVL	1.223	1.163	1.547	1.198	1.946
STDEV (BROWSE LVL)	0.563	0.496	0.801	0.610	0.894

2019	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Control
NO OF SAMPLES	494.000	408.000	455.000	477.000	1792.000
DIEBACK FROM 2018	93.000	180.000	133.000	18.000	455.000
MEAN Height (CM)	81.632	110.657	73.840	105.283	62.894
MAX HEIGHT (CM)	148.000	197.000	204.000	210.000	173.000
MIN HEIGHT (CM)	22.000	26.000	23.000	27.000	9.000
STDEV (HEIGHT)	20.996	18.757	21.341	22.421	20.763
MEAN BROWSE LVL	1.285	1.221	1.479	1.505	1.677
STDEV (BROWSE LVL)	0.702	0.676	0.639	4.726	0.604