Re-Establishing the Historic Fire Regime to Restore the Chittenden Meadow, Skagit Valley Provincial Park, British Columbia, Canada

by

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Abstract

Prescribed burning is being used by BC Parks as a restoration tool to maintain the ecologically unique Chittenden Meadow in Skagit Valley Provincial Park. Forest encroachment of conifers in the meadow, due to the absence of fire, has been an ongoing issue since the 1970s. BC Parks in partnership with the BC Wildfire Branch conducted prescribed burns in April 2003 and April 2021 to reduce forest encroachment into the meadow. In 2017, BCIT students re-established a series of plots to compare vegetation community changes with the 2003-2004 prescribed burn data. This data was compared to our 2021 findings. Continued long-term monitoring of the meadow will help to enhance our understanding of vegetation community changes following prescribed fires and will build upon a decade of existing data. The historical extent of the meadow remains unclear; therefore, we conducted a broad fire history study across ~275-ha of forest surrounding the Chittenden Meadow to better understand the area's past fire frequency and severity.

Keywords: Prescribed burning; Forest encroachment; Vegetation community change; Fire history study

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Land Acknowledgement

I respectfully acknowledge that this paper, as well as where I live and learn, was completed on the traditional, ancestral, and unceded territories of the Coast Salish peoples, including the səl̓ilw̓ətaʔɬ (Tsleil-Waututh), kʷikʷəƛ̓əm (Kwikwetlem), Sḵwx̱wú7mesh Úxwumixw (Squamish), and xʷməθkʷəy̓əm (Musqueam) Nations. The field work for this project took place in the Skagit River Drainage. This area is considered part of the traditional territory of the Nlaka'pamux (formerly called Thompson), Sto:lo, and Upper Skagit people. The area was also visited by the Similkameen (Okanagan) and Nooksack groups.

Statement of Positionality

I am of settler descent and my knowledge is mainly derived from formal university-based training and related experience.

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Glossary

Duff	The layer of partially and fully decomposed organic materials lying on the forest floor below the litter and immediately above the mineral soil (BC Wildfire Service 2022).
Escaped fire	A wildfire that has breached a control line and remains out of control following initial attack. This term is also used to describe a prescribed fire that has burned beyond its intended area (BC Wildfire Service 2022).
Fire season	The period(s) of the year during which fires are likely to start, spread, and damage values-at-risk sufficient to warrant organized fire suppression (BC Wildfire Service 2022).
Fuel	Any organic matter, living or dead, in the ground, on the ground, or in the air that can ignite and burn (BC Wildfire Service 2022).
Available fuel	The quantity of fuel (in a particular fuel type) that would be consumed under specified burning conditions.
Ground fuels	All combustible materials below the litter layer of the forest floor that normally support smouldering or glowing combustion associated with ground fires.
Ladder fuels	Fuel that provides vertical continuity between the surface fuels and crown fuels in a forest stand, thus contributing to the ease of torching and crowning.
Surface fuels	All combustible materials lying above the duff layer between the ground and ladder fuels that are responsible for propagating surface fires.
Fuel management	Fuel management is the modification of forest structure to reduce forest fuel accumulations available to burn in a wildfire. This may include treatments such as thinning, spacing, and pruning trees, and removal of needles and woody debris from the forest floor (BC Wildfire Service 2022).
Fuel type	An identifiable association of fuel elements of distinctive species, form, size, arrangement, and continuity that will exhibit characteristic fire behaviour under defined burning conditions (BC Wildfire Service 2022).
Litter	The uppermost part of the forest floor consisting of freshly fallen or slightly decomposed organic materials (BC Wildfire Service 2022).
Ignition	The beginning of flame production or smouldering combustion; the starting of a fire (BC Wildfire Service 2022).
Prescribed fire	The knowledgeable and controlled application of fire to a specific area to accomplish planned resource management objectives (BC Wildfire Service 2022).
Mineral soil	The layer of the soil profile immediately below the litter and duff (BC Wildfire Service 2022).
Mop-up	The act of extinguishing a fire after it has been brought under control (BC Wildfire Service 2022).
Smoke management	Scheduling and conducting a prescribed burning program under conditions that will minimize the adverse impacts of the resulting smoke production in smoke sensitive areas (BC Wildfire Service 2022).
Wildfire	An unplanned fire occurring on forest or range lands, burning forest vegetation, grass, brush, scrub, peat lands, or a prescribed fire set under regulation which spreads beyond the area authorized for burning (BC Wildfire Service 2022).

1.0. Introduction

BC Parks designated parts of the upper Skagit Valley, including the Chittenden Meadow, as a Recreation Area in 1973 and as a Provincial Park in 1997 (Lepofsky et al. 2003). The meadow is host to unique vegetation, including the culturally important tiger lily (*Lilium columbianum*). Park Managers are concerned with the recent encroachment of interior Douglas-fir (*Pseudotsuga douglasii*) and grand fir (*Abies grandis*) trees into the meadow and are considering options for restoring the meadow to its historical extent (Lepofsky et al. 2003). A prescribed burn was conducted in 2003 to restore the natural size and composition of the meadow and to reflect the historical practice of Indigenous burning in the area (Armstrong 2007; Witt 2006). However, the burn was too mild to have significant effects on reducing conifer encroachment while supporting native meadow species (Witt 2006). In 2017, students from the British Columbia Institute of Technology (BCIT), led by Hélène Marcoux, re-established a series of 41 plots to compare vegetation community changes from pre- and post-prescribed burn data. To increase understanding of the Chittenden Meadow's dynamics, and to build on more than a decade of existing data, we partnered with BC Parks in 2021 to monitor the current conditions of the meadow and the effects of a new application of fire treatment on the plant community.

The study site is located in the Chittenden Meadow (approx. 5 ha) in Skagit Valley Provincial Park, southwestern British Columbia (BC), Canada (Figure 1). The upper Skagit Valley is located within the Cascade Range, a mountainous region bordered by the Fraser Lowland to the west and the Okanagan Plateau to the east (Armstrong 2007). Skagit Valley Provincial Park is located approximately 150 km east of Vancouver, BC, on the north side of the USA-Canada border. The park encompasses 27,948 ha of land and is influenced by both the moist coastal and the semi-arid interior weather systems (BC Parks n.d.). The study area is in the rain shadow of the Pickett Range and receives less precipitation than other areas at similar elevations in the western Cascade Range (Lepofsky et al. 2003). In the upper Skagit Valley, mesic coastal forests are juxtaposed with dry interior forests (Agee & Kertis 1987; Lepofsky et al. 2003). The meadow is in the Interior Douglas-fir zone (IDF), wet warm subzone (ww), of British Columbia's Biogeoclimatic Classification system (BEC). The BEC system is based on the traditional view of succession where stand-replacing disturbances, such as fire, initiate even-aged stands. In the absence of disturbance, succession will proceed until a climax forest develops (Marcoux et al. 2013). Although ponderosa pine (*Pinus ponderosa*) is generally uncommon west of the Cascade crest, it occurs in the meadow and some nearby forests (Lepofsky et al. 2003). Common herb, forb, shrub, and grass species in the meadow include yarrow (*Achillea millefolium*), wild strawberry (*Fragaria virginiana*), silky lupine (*Lupinus sericeus*), common timothy (*Phleum pratense*), common snowberry (*Symphoricarpos albus*), and common dandelion (*Taraxacum officinale*). In addition, the meadow is host to a unique grass and forb plant community, including tiger lilies, a species that produces bulbs which are an important food source to Indigenous people in the region (Turner & Turner 2007). In the Skagit Valley, tiger lilies are abundant in the Chittenden Meadow, and archeological evidence of 'roasting pits" also suggests some occasional usage of the meadow by Indigenous people (Lepofsky et al. 2003).

Prior to 1880, the Chittenden Meadow was believed to be an open ponderosa pine parkland maintained by frequent surface fires (Lepofsky et al. 2003; Witt 2006). During this period, fires prevented the encroachment and establishment of interior Douglas-fir and grand fir into the meadow (Witt 2006; Lepofsky et al. 2003). Approximately 100 years ago, an open meadow with scattered pines was created by fire or felled by homesteaders (Witt 2006; Lepofsky et al. 2003). Climatic changes in the 1970s (high spring temperatures and low spring snowpacks) permitted the successful establishment of interior Douglas-fir and grand fir seedlings (Witt 2006; Lepofsky et al. 2003). In addition, fire suppression and park management prevented the natural removal of the trees from the meadow, potentially altering the composition and structure of the meadow's vegetation community and significantly decreasing the historical extent of the meadow (Witt 2006; Lepofsky et al. 2003). The Chittenden Meadow ecosystem likely transitioned from open ponderosa pine parkland to meadow over time (Lepofsky et al. 2003). However, the historical extent of the meadow remains unclear (300+ years). Our current understanding of the extent of the meadow comes from historic aerial photographs (dating from 1946; Figure 2) and a multidisciplinary study by Lepofsky et al. (2003). However, their study did not extend far beyond the immediate meadow boundary. Therefore, in this study we conducted a broader fire history study across ~275-ha of forest surrounding the Chittenden Meadow using tree rings and fire scars to better understand past fire frequency and severity.

This project's goal was to help evaluate the effectiveness of prescribed burning as a management technique to maintain native vegetation. Therefore, we reviewed studies conducted in the Chittenden Meadow since 2000 (Table 1). In addition, the study aimed to increase the understanding of the historic role of fire in the forest surrounding the meadow and to inform future decisions around fuel management and restoration. Without proper intervention by management, tree encroachment is expected to continue over time (Lepofsky et al. 2003).

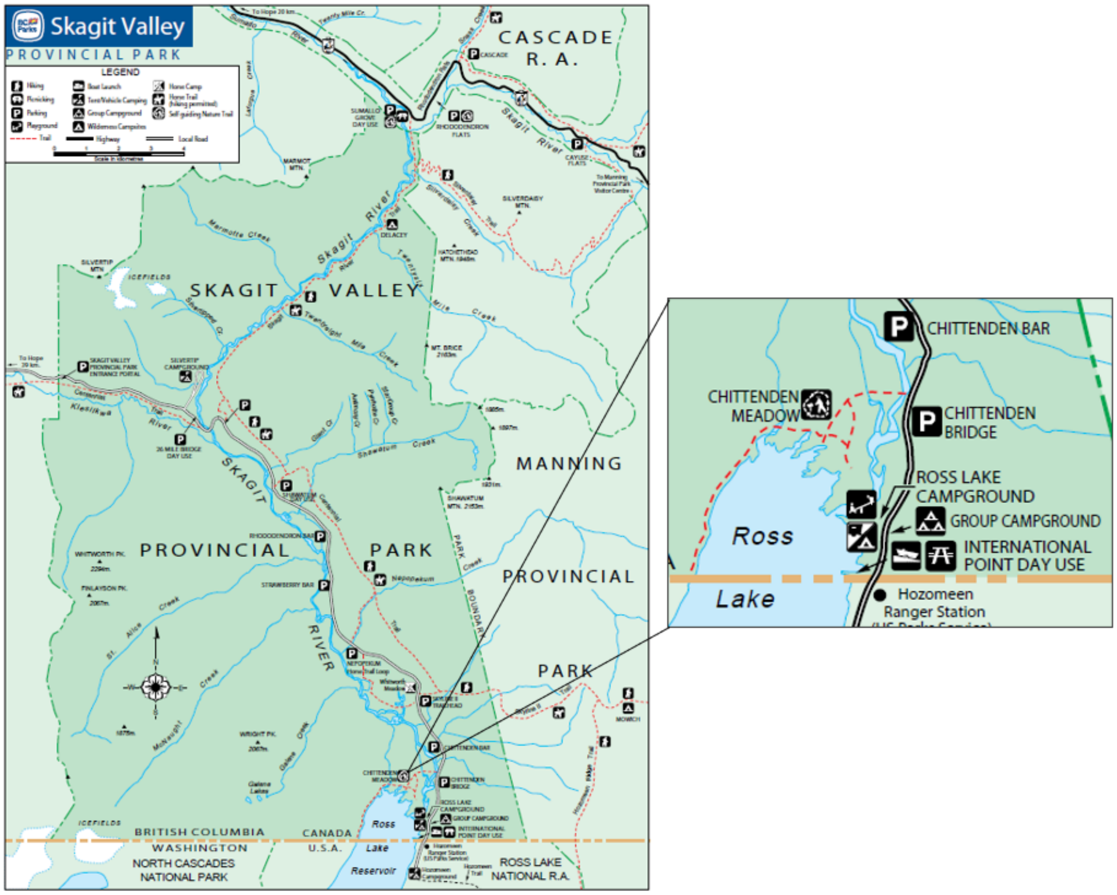


Figure 1. **BC Parks map of Skagit Valley Provincial Park with inset map of the Chittenden Meadow (BC Parks n.d.).**

1.1. Human History

The Skagit River Drainage and surrounding Cascade Mountains were used by a number of Indigenous peoples and are considered part of the traditional territory of the Nlaka'pamux (formerly called Thompson), Sto:lo, and Upper Skagit people. The area was also visited by the Similkameen (Okanagan) and Nooksack groups (Fraser-Cascade Mountain School 2008).

Dramatic changes came to the Skagit in 1946 when the first logging road brought vehicle access into the main valley. The Silver-Skagit Logging Road was constructed from the Trans-Canada Highway near Hope, up Silver-Hope Creek, past Silver Lake, and down the Klesilkwa River into the Skagit’s lower valley. This road remains the only vehicle access to Skagit Valley Provincial Park (Fraser-Cascade Mountain School 2008).

Curley Chittenden was a Canadian logger employed by Seattle City Light (SCL) in 1953 to supervise the clearing of the lower part of the Skagit Valley in preparation for flooding by the Ross Lake Reservoir. When that work was completed, SCL asked Chittenden to continue logging the valley upstream of the reservoir in preparation for more flooding from the proposed High Ross Dam. Chittenden noticed the unusual mix of coastal and interior ecosystems in the Skagit, such as ponderosa pines growing far west of the BC Interior. He refused to cut down the pines. Chittenden was among the first people to begin publicly opposing the High Ross Dam. His memory is honoured by Chittenden Meadow and Chittenden Bridge due to his dedication to protect the upper Skagit forests from flooding (Fraser-Cascade Mountain School 2008).

1.2. Prescribed Fire

The use of prescribed fire is well documented for the Stó:lō Nation, the Nlaka'pamux Nation, and the Upper Skagit Tribe, and may have been used as a land management tool in the Chittenden Meadow (Lepofsky et al. 2003). In the upper Skagit Area (now Manning Park), it is documented that Indigenous hunting groups deliberately set fire to the forest to clear underbrush and improve travel (Turner 1999). There are many historical records of prescribed fire throughout BC, including dendrochronological studies, charcoal in soil profiles, and eyewitness accounts. Reasons for intentional burning include repelling mosquitos and other insect pests, promoting ungulate grazing, clearing land, and protecting forests from crown fires (Turner 1999).

There is renewed interest by wildfire management agencies in Canada to use prescribed burning. Prescribed burning is distinct from cultural burning, primarily in the burn objectives, techniques used to burn, and who is conducting the burning (Hoffman et al. 2022). Throughout Canada, Indigenous peoples have specific times for burning, the majority of which takes place when fire risk is low. Indigenous peoples in BC often burned in the early spring or late fall (Hoffman et al. 2022).

Several plant species were reported by Indigenous peoples to be enhanced by periodic burning. Many of the species which benefit from burning are early successional species and require clearings or open canopy for optimal growth (Turner 1999). For example, testimonies from elders indicate that bulbs of the tiger lily were greater in size from areas that had been previously burned (Turner 1999). Increased growth could be attributed to an increased supply of available nutrients following burning. Fire increases the pH of the soil through release of alkaline ions such as phosphorus, potassium, calcium, and magnesium. The amount of nutrients released varies with the type of soil and the intensity of the burn. Burning also reduces competition from fire-intolerant species (Turner 1999).

The use of prescribed fire is most common in fire-suppressed ecosystems that have historically experienced high frequency, low-severity fire regimes (Witt 2006). The timing of a prescribed fire can influence the success of a restoration project. For example, burning outside of the historic fire season – for smoke management or to minimize the threat of an escaped fire – can result in a patchy, less severe burn that favours invasive species (Witt 2006). In addition, burning early or late in the growing season may correspond with different phenological timing of plant species than timing of natural or unaltered fire regimes. This has potential implications of favoring certain species over others (Knapp et al. 2009).

1.3. Altered Fire Regime

Understanding variation within and among forest types is critical for identifying fire regimes that have been altered by fire exclusion and suppression. Knowledge of fire regime variability is also important for determining where forest resilience is compromised and if ecological restoration is justified (Marcoux et al. 2015). A fire regime describes the spatial and temporal dimensions of fires for a defined area and time period. Low-severity fire regimes involve frequent, low-intensity surface-fires that burn at short intervals and consume surface fuels and understory vegetation as well as killing a few overstory trees (Agee 1998; Marcoux et al. 2015).Thick-barked trees usually survive surface fires, forming fire scars. The result is an open-canopy stand with few subcanopy trees. High-severity fire regimes involve infrequent, high-intensity active or passive crown fires that kill understory vegetation and the majority of overstory trees. This can initiate a new even-aged cohort that is dominated by early-successional and shade intolerant species. Mixed-severity fire regimes are complex and vary at multiple scales (Agee 1998; Marcoux et al. 2015). In this study, we are testing the hypothesis that the forest surrounding the Chittenden Meadow likely had a mixed-severity fire regime.

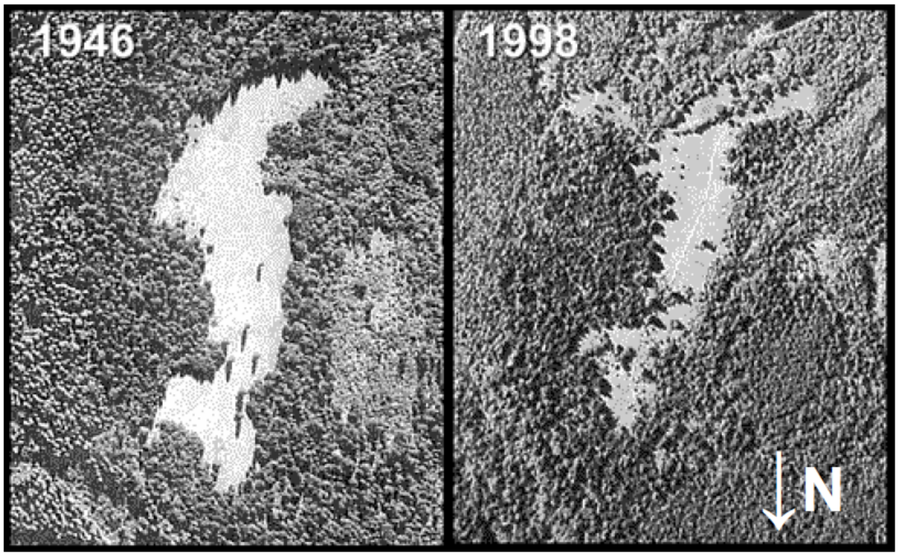


Figure 2. Aerial photos of Chittenden Meadow showing tree encroachment in 1946 and 1998 (Lepofsky et al. 2003).

Table 1. Overview of Chittenden Meadow studies since 2000.

Year*	Study / Author(s)	Objectives
2003	Lepofsky et al.	Determine the human, ecological, and physical factors resulting in the historical dynamics and encroachment of woody vegetation in the Chittenden Meadow. Multidisciplinary collaboration to examine the processes responsible for the historical and current state of the Chittenden Meadow.
2006	SFU / Witt	Describe the immediate effects of a prescribed burn that occurred in the Chittenden Meadow. Use prescribed fire to reduce tree and shrub cover and re-establish the historic, fire-dependent, vegetation community.
2018	BCIT / Davis et al.	Establish a permanent sampling plan for long-term monitoring of plant communities within the Chittenden Meadow and document the effects of prescribed burning on conifer encroachment. Develop a long-term plan to manage forest encroachment and promote ungulate habitat in the Chittenden Meadow.

*Year Published/Completed

1.4. Research Questions

(1) How can prescribed burning remediate the effects of past fire suppression and the encroachment of fire intolerant species in the Chittenden Meadow? Will restoration activities help to re-establish culturally important species, such as tiger lilies, in the meadow?

(2) How can restoration of the historic fire regime benefit the ecological integrity of the park? Do restoration interventions have the potential to re-establish the ecology reflected in the historic fire regime?

1.5. Project Objectives

(1) Assess the diversity and composition of the plant community in the Chittenden Meadow pre- and post-prescribed burn over time (2003-2021).

(2) Investigate the historical fire regime and area extent of the Chittenden Meadow using tree-ring science (fire scars and tree ages) to inform decisions regarding fuel treatment and the use of prescribed burns in the restoration of the Chittenden Meadow and surrounding forests.

2.0. Methods

Objective 1.0. Assess the diversity and composition of the plant community in the Chittenden Meadow pre- and post-prescribed burn over time (2003-2021; Appendix A).

> **Action 1.1.** Conduct a prescribed burn in the Chittenden Meadow in partnership with BC Parks and the BC Wildfire Branch (April 2021).
>
> **Action 1.2.** Measure vegetation parameters over two time periods: (1) June 2021 following a planned prescribed burn, and (2) August 2021.

The study site is in the IDFww Biogeoclimatic subzone. It has an even slope (<5%) and the aspect is a flat meadow, with an elevation of 460 m (Table 2). Fuel types consist of scattered C7 and abundant 01-b fuels within the prescription area, surrounded by dense, mature C7 stands. It is anticipated that the fuel type will shift from C7 and O1-b to S3, once pre-burn treatments have occurred, which will add immature Douglas-fir to the surface fuels. Fuels within the prescription area consist of low shrubs (*Mahonia spp.* and *Rosa spp.*), patchy meadow grasses, and regenerated Douglas-fir and ponderosa pine, with a small percentage of dominant ponderosa pine, and sub-dominant Douglas-fir and ponderosa pine. Fuels surrounding the prescription area include mature Douglas-fir, ponderosa pine, western red cedar (*Thuja plicata*), and western hemlock, with a conifer understory of the same species and low shrubs (*Symphoricarpos spp.* and *Rosa spp.*).

Prescribed Burn. A prescribed burn was conducted in the Chittenden Meadow in partnership with BC Parks and the BC Wildfire Branch on April 15, 2021. The prescribed burn was contained to the meadow and prevented from escaping into standing timber. Preparations for the burn included clearing a perimeter around the prescription area by removing ladder fuels up to 2 m and creating a fuel-reduced strip by mechanically brushing down to the mineral soil to a width of 2 m. In addition, veteran ponderosa pine was protected by being flagged or otherwise identified prior to pre-burn treatment. Crews conducting burn operations were notified of their importance prior to initiating any burning activities. Post-operation monitoring, including mop-up techniques such as cold-trailing (Appendix C), occurred for three days after ignition.

Vegetation Assessment. We contracted Frontera Forest Solutions Inc. to capture drone orthoimagery of the meadow on April 27, 2021, 12 days after the prescribed burn (Figure 3). From June 15-18, 2021, we completed the vegetation assessments in the Chittenden Meadow with 38 new plots. We returned in August 29-30, 2021 and sampled every second plot established in the meadow. Sampling methods and plot locations from the papers published in 2006 and 2018 were used to inform our 2021 research design and methods (Figure 4; Table 4). Sample plot locations were selected using a random-systematic sampling approach, using a 40 m x 40 m grid established at random in ArcMap (Figure 5). At each plot we captured plant community composition in two nested subplots:

(1) 1 m² square plot – to target species richness, abundance, and diversity of forb, grass, and moss composition.

(2) 50 m² (3.99 m radius) circular plot – to capture shrub and tree percent cover and densities by size class.

Plots were permanently marked with stakes that were placed at the top-right of the 1 m² plot (northeast corner). We conducted visual cover estimates, which are fast and non-destructive; however, they are subjective (Figure 6). Therefore, cover was scored in classes using a modified Braun-Blanquet system. We identified each species present or collected samples for later identification. Witt (2006) also recorded percent cover by species using a modified Braun-

Blanquet system (Table 3). The classes were assigned to each species by plot according to percent cover estimates.

The plant community percent frequency was calculated using the following formula:

% frequency spp. = (# of plots in which spp. occurs) / (total # of plots examined) x 100

Table 2. Site information for the Chittenden Meadow.

1) Biogeoclimatic Zone	IDF (Interior Douglas-fir)
2) Biogeoclimatic Subzone	ww (wet warm)
3) FBP Fuel Type	C7, O1-a/O1-b, S3*
4) Forest Cover	<5% in middle (Fd, Pp) and >40% on perimeter (Fd, Hw)**
5) Slope	Even (<5%)
6) Aspect	Flat meadow
7) Elevation	460 m
8) Slope Position	Lower to flat, grassy meadow
9) Valley Orientation	N-S and NW-SE
10) Duff Depth	3-8 cm
11) Soil texture	Moraine deposits, luvisols and/or brunisols
12) Fuel Loading	Grass, low shrubs, saplings/seedlings

*C7 – Ponderosa Pine-Douglas-Fir; O1-a/b – Grass; S3 – Mixed Conifer Slash
** Fd – Douglas-fir; Pp – Ponderosa pine; Hw – Western Hemlock

Figure 3. **Drone imagery of the Chittenden Meadow, captured April 2021 by Frontera Forest Solutions Inc.**

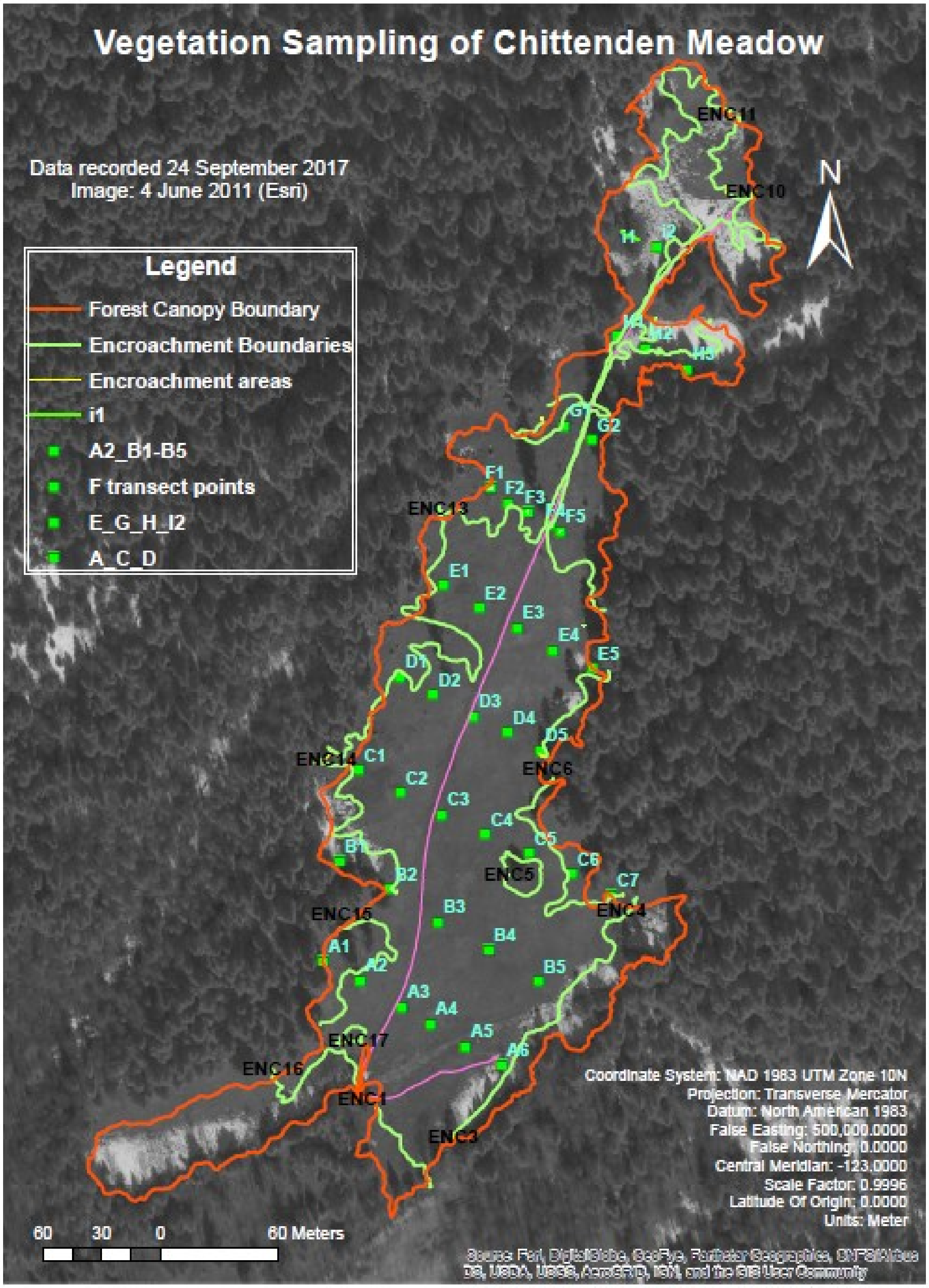


Figure 4. Chittenden Meadow sampling design, September 2017 (Davis et al. 2018).

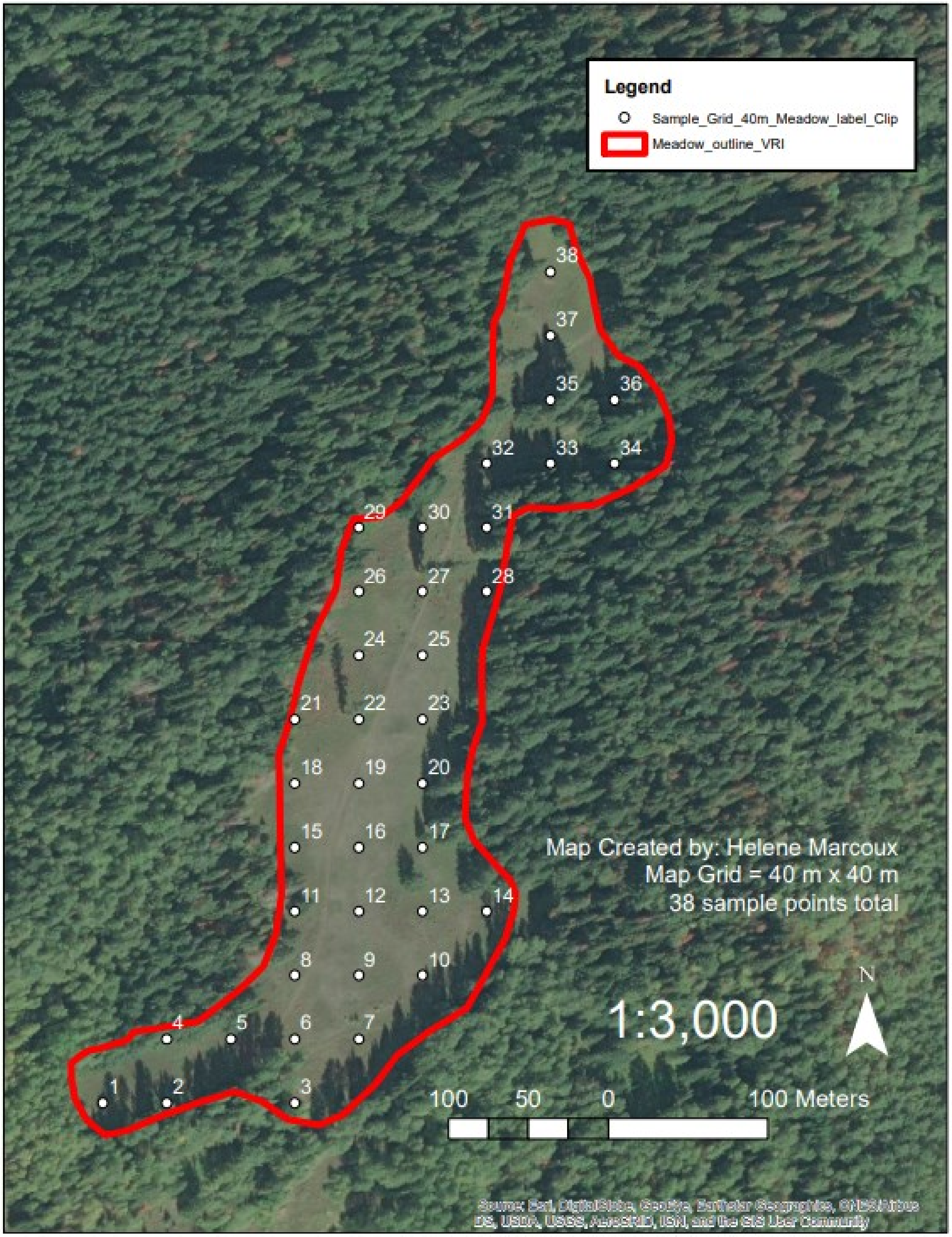


Figure 5. **Chittenden Meadow sampling design, June and August 2021. Each plot location included two subplots.**

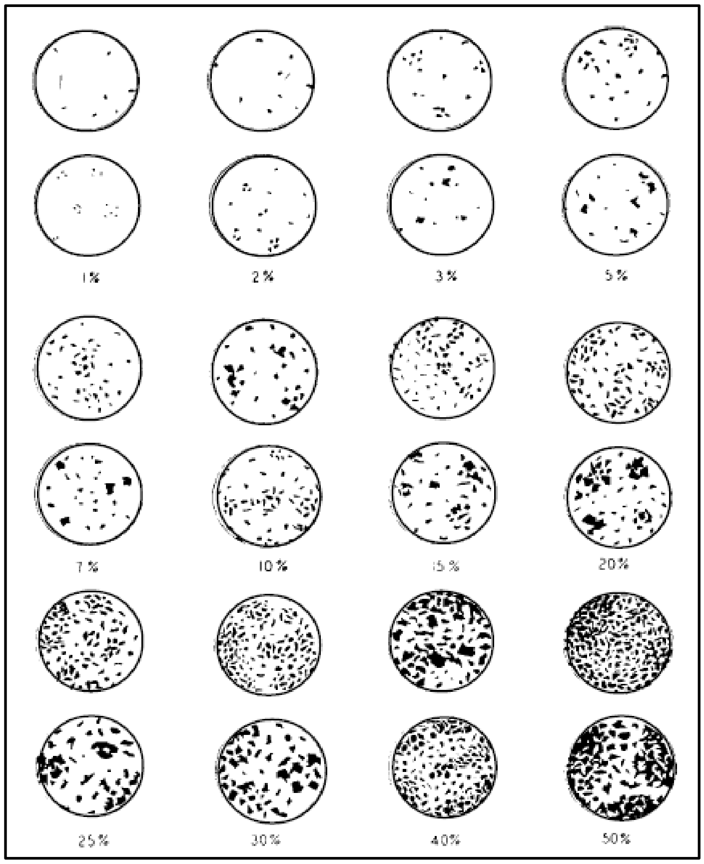


Figure 6. Visual estimation of vegetation percent cover (Luttmerding et al. 1990).

Table 3. Conversion table for vegetation percent cover to cover classes (Witt 2006).

Percent Cover Estimates	**Average Value**	**Braun Blanquet Scores**	**Chart of Conversions**	
0	0	0	Cover Classes	Median Values
<1 (T = trace)	1	1	1	0.5
1-4	3	2	2	3
5-14	10	3	3	15
15-24	20	3	-	-
25-34	30	4	4	40
35-44	40	4	-	-
45-54	50	4	-	-
55-64	60	5	5	65
65-74	70	5	-	-
75-84	80	6	6	88
85-94	90	6	-	-
95-100	98	6	-	-

Objective 2.0. Investigate the historical fire regime and area extent of the Chittenden Meadow using tree-ring science (fire scars and tree ages) to inform decisions regarding fuel treatment and the use of prescribed burns in the restoration of the Chittenden Meadow and surrounding forests.

Action 2.1. Establish 10 plots using a grid across the study area to target stands with interior Douglas-fir that are greater than 120 years of age, as identified in the VRI data.

Action 2.2. At each plot, we extracted tree cores using increment bores from the ten largest diameter trees from plot center using the *n*-tree sampling method.

Action 2.3. In the lab, tree cores were mounted and sanded using standard dendrochronology techniques. Tree-ages were determined at an annual resolution, and cross-dating was used to improve accuracy of dating.

Action 2.4. At the 10 plots, we conducted a 1-ha fire scar search around the plot center for signs of fire scarred trees, logs, and snags. Any scarred trees or snags were cored. We used a chainsaw to sample any logs or stumps with signs of fire scars. All samples were mounted, sanded, and measured in the lab using CooRecorder dendrochronology software.

From June 18-25, 2021, we sampled 10 fire history plots in stands with interior Douglas-fir as either leading or secondary species and age classes 7 or 8 (representing stands with tree ages greater than 121 years). We used Vegetation Resource Inventory (VRI) data to identify stands that met our species composition and age criteria. This amounted to approximately 145-ha of the 275-ha study area (Figure 7). We targeted these stands because Douglas-fir is well adapted to fire (thick barked) and commonly forms fire scars (Agee 1993).

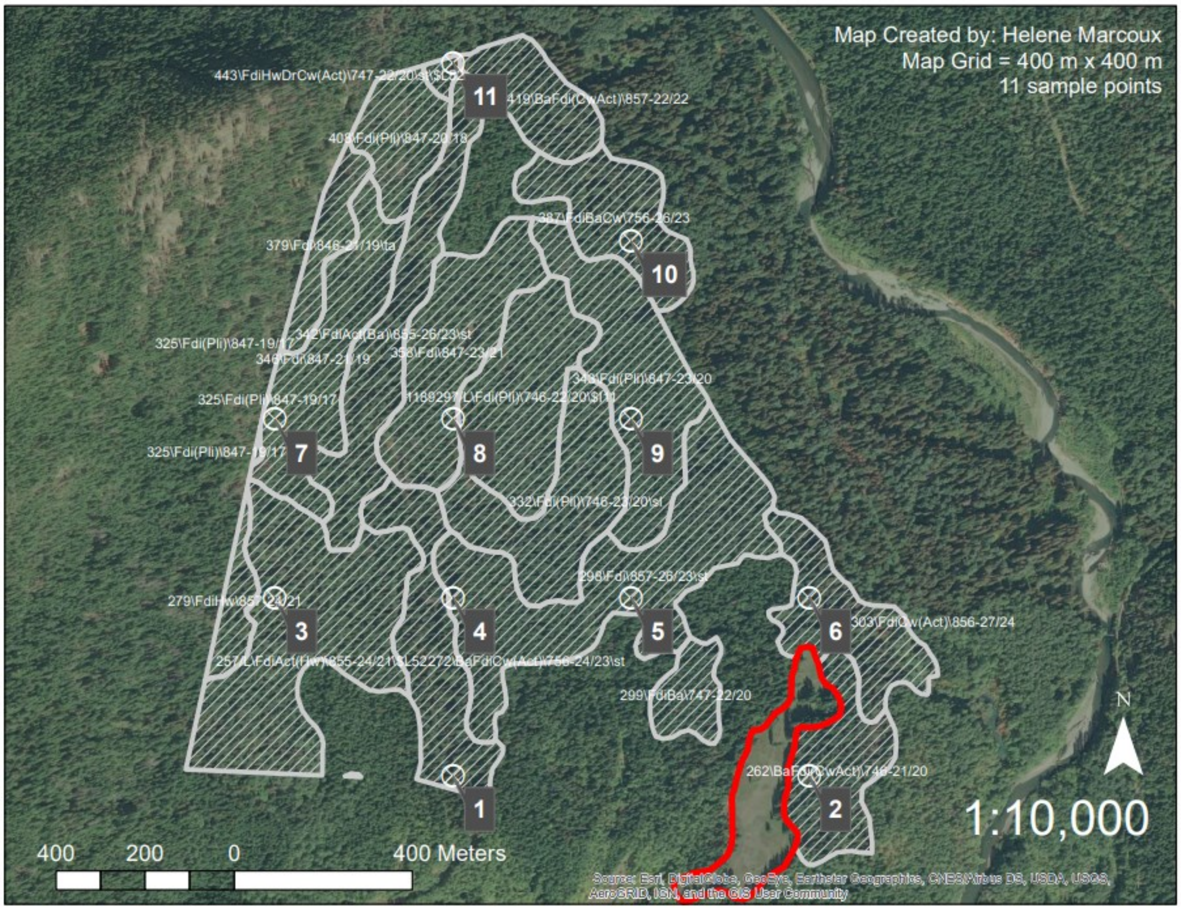


Figure 7. **Skagit Valley fire history sampling design (June 2021). The Chittenden Meadow is outline in red.**

At each fire history plot, we cored the 10 closest dominant or codominant trees to plot center to capture their ages (Figure 7). Crown classes were categorized as dominant, sub-dominant, intermediate, or suppressed (Figure 8; Luttmerding et al. 1990).

(1) Dominant – trees with crowns extending above the general level of the crown canopy.

(2) Co-dominant – trees with crowns forming the general level of the crown canopy.

(3) Intermediate – trees with crowns below, but still extending into, the general level of the canopy.

(4) Suppressed – trees with crowns entirely below the level of the canopy.

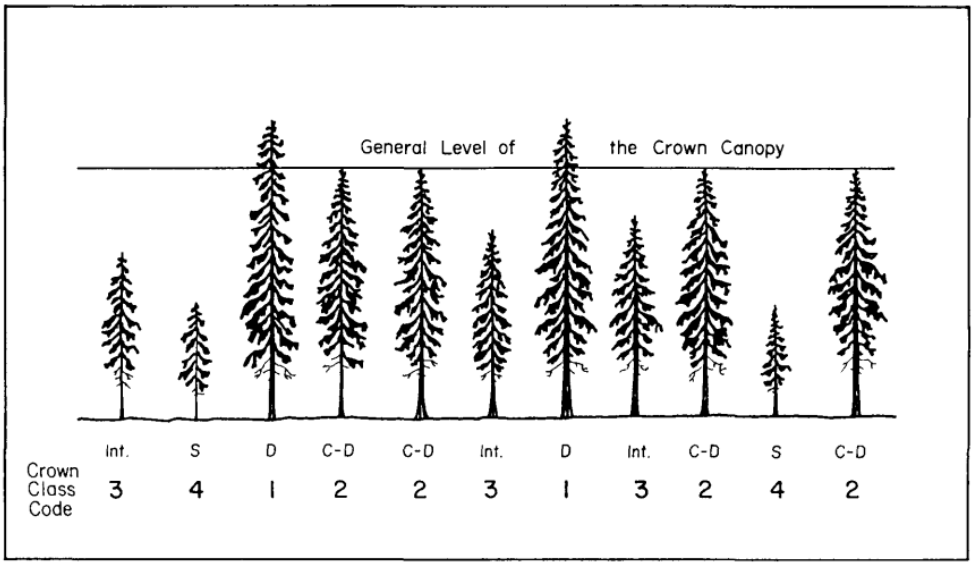


Figure 8. Explanatory diagram of crown classes (Luttmerding et al. 1990).

The *n*-tree sampling method was used. This method uses the distance of the *n*th tree from the plot center as the plot radius, from which the plot multiplier is derived (Lessard et al. 2002). For this study, *n* was ten. This technique is used when the spatial pattern of a stand is clumped or random to eliminate bias (Lessard et al. 2002; Van Vliet et al. 2022). We measured the distance from plot center to each tree near DBH (diameter at breast height; 1.3 m high), and removed increment cores near the ground (the average core height was 65.6 cm above the ground) to determine the establishment date. Cores were visually assessed in the field to ensure they either intercepted or were close to pith (Marcoux et al. 2013). We also conducted a 1-ha fire scar search around the plot, looking for logs, stumps, snags, or trees with signs of fire scars. Partial sections were removed from stumps and logs if they were sound enough to cross-date (Marcoux et al. 2013).

Nine fire scar cookies (Figure 13) and 180 tree ring samples were collected in total. Samples were taken from 10 of the 11 plots that were established using VRI data. The 11th plot was not sampled, due to time and budget constraints. At least 10 samples were taken at each plot; however, several trees were sampled multiple times due to missing rings (proximity to pith) or heart rot. Increment cores and partial sections were prepared by mounting cores on wooden supports, gluing decayed partial sections, and sanding all samples. The samples were then measured in the lab using CooRecorder dendrochronology software. For cores that did not intercept the pith, the number of missing rings to pith were estimated using a geometric correction (Duncan 1989; Marcoux et al. 2013).

2.1. Differences Between Sampling Protocols

Table 4. Overview of sampling methods used in the Chittenden Meadow since 2000.

Year*	Study / Author(s)	Sampling Period	Time**	# Plots	Sampling Design
2006	SFU / Witt	July 2003 and July 2004	Pre- (2003) and post-burn (2004)	276 (2003) and 280 (2004)	Clustered sampling design. Collected data from 1 m² quadrats along transects. To describe pre-treatment conditions, sampled the meadow in July 2003 (the summer prior to the burn). Sampled 28 transects and 276 quadrats. The prescribed burn occurred on April 22, 2004. Post-burn vegetation monitoring took place in July 2004. Sampled 33 transects and 280 quadrats.
2018	BCIT / Davis et al.	End of September 2017	Pre-2021 burn	41	Established 41 plots using a random-systematic design along 9 transects. These plots were marked permanently in the field using fire-resistant tags and nails and mapped using survey grade GPS/GNSS receivers (+/- 0.5 m accuracy).
2023	SFU and BCIT / Morris	Mid-June and August 2021	Post-2021 burn	38	We were unable to relocate the 2017 plots post-fire (April 2021). Established 38 new plots using a 40 m grid created in GIS and overlaid on an orthoimage of the meadow. Navigated to each plot using Avenza PDF maps.

*Year Published/Completed
**Pre- or Post-Prescribed Burn

2.2. Sampling Design 2003-2004

The first prescribed burn occurred on April 22, 2004 (Table 4). The weather was cool and the vegetation damp. The resulting burn was low in severity. On May 1, 2004 an unplanned burn of unknown origin burned an additional region of the meadow which provided supplemental treatment data (Witt 2006). Post-burn vegetation monitoring took place in July 2004. Each transect and quadrat that was established in 2003 was resampled; however, a few transects were not accessible. In the pre-burn season (July 2003), 28 transects and 276 quadrats were sampled. In the post-burn season (July 2004), 33 transects and 280 quadrats were sampled. The culturally significant plant species selected by BC Parks for monitoring in Witt's (2006) study included

Nootka rose (*Rosa nutkana*), Saskatoon (*Amelanchier alnifolia*), and tall Oregon grape (*Mahonia aquifolium*).

The severity of the burn was low and there was no measurable consumption of the fermentation layer (the layer below the litter). The fire burned only the litter layer, which produced a superficial burn with limited effects on vegetation cover. In addition, the weather was very different for the two field seasons. Pre-treatment data was collected in July 2003. It was a very hot and dry month compared to July 2004, when the post-burn data was collected, which was considerably cooler and more damp. The differences in weather may have obscured the effects of the burn (Witt 2006).

2.3. Sampling Design 2017

Site Selection. Each sampling site was represented by a transect letter (A-I) and site number (1-8). Therefore, each site was named A_1, A_2, A_3, B_1, etc.

Stratification. Witt (2006) stratified the area based on three community types: meadow, encroaching (tree and shrub), and mature forest. Witt (2006) suggested focusing on the center of the meadow (1st priority), followed by the north end (2nd priority), and possibly the southwest corner (3rd priority). He indicated that the bottom southeast corner should be avoided, which is predominantly a wet meadow associated with wetland complexes further south.

Baseline. A baseline was established along the center-path, which runs from northeast to southwest of the meadow. Witt (2006) used a similar approach. The transects were located off this center-line.

Transects (1 m x 1 m quadrats). Due to time constraints, 8-10 transects were established, with 6 quadrats (1 m x 1 m assessment of percent cover by species) per transect. This generated 50 quadrats, which were assessed from September 23-24, 2017. Transects were located along the baseline at randomly selected distances between 50-70 m.

Shrub and Tree Count Plots. A secondary plot was also added and assessed by BCIT students in October 12-13, 2017. Each 1 m^2 quadrat was nested within a 50 m^2 plot (radius 3.99 m). This generated stems/ha for shrubs (by species), and DBH size classes for saplings (<1.3 m height) and seedlings (>1.3 m height, <= 5 cm DBH, 5-12.5 cm DBH, >=12.5 cm DBH).

Permanent Marking of Plots. A permanent marker was placed at the top-right of each quadrat (northeast corner).

3.0. Results

Objective 1.0. Assess the diversity and composition of the plant community in the Chittenden Meadow pre- and post-prescribed burn over time (2003-2021).

Plant community change over time was compared for three time periods (July 2004, September 2017, and June 2021). Notable changes in forb percent frequency (Table 5) involved yarrow (*Achillea millefolium*) which was 34% in July 2004, 76% in September 2017, and 58% in June 2021. Field chickweed (*Cerastium arvense*) also differed among years with 23% in July 2004, 56% in September 2017, and 37% in June 2021. Tiger lily which is a culturally significant species, had 0% frequency in 2004 and 2017, with 13% in 2021. Silky lupine (*Lupinus sericeus*) percent frequency was 23% in 2004, 17% in 2017, and 50% in 2021.

Notable changes in graminoid percent frequency involved blue wild rye (*Elymus glaucus*) which was 0% in 2004, 2% in 2017, and 24% in 2021 (Table 6). In addition, common timothy – which was the only graminoid species identified over all three time periods – was estimated to have 26% frequency in July 2004, 68% in September 2017, and 61% in June 2021. Significant non-native and invasive plant species change (Table 7; Figure 9) in the meadow involved common St. John's wort (*Hypericum perforatum*). It increased from 3% in 2004, 7% in 2017, and 32% in 2021. Another non-native species, sheep sorel (*Rumex acetosella*) increased from 1% in 2004, 7% in 2017, and 18% in 2021.

The culturally significant shrub species selected by BC Parks for monitoring in Witt's (2006) study included Nootka rose, Saskatoon, and tall Oregon grape. Nootka rose changed from 58% in 2004, 83% in 2017, and 79% in 2021 (Table 8; Figure 10). Saskatoon changed from 17% in 2004, 20% in 2017, and 8% in 2021. Tall Oregon-grape remained relatively stable with 60% frequency in 2004, 61% in 2017, and 61% in 2021.

The two types of trees encroaching in the meadow were interior Douglas-fir and grand fir. After the prescribed burn and mechanical removal in July 2004, total percent cover for encroaching Douglas-fir and grand fir was 6% and 3%, respectively (Figure 11). In 2017, percent cover increased to 15% and 20% respectively. Cover then decreased to 3% and 11% in 2021, after the Spring 2021 prescribed burn and mechanical removal.

Table 5. Chittenden Meadow forb percent frequency 2004-2021.

Scientific Name	Common Name	Frequency (%)		
		July 2004 (n = 280)	Sept 2017 (n = 41)	June 2021 (n = 38)
Achillea millefolium	Yarrow	34	76	58
Adenocaulon bicolor	Pathfinder	0	5	0
Agoseris aurantiaca	Orange agoseris	5	0	8
Anaphalis margaritacea	Pearly everlasting	1	0	0
Antennaria neglecta	Field pussytoes	1	10	3
Aster conspicuous	Showy aster	1	5	0
Castilleja miniata	Common red paintbrush	2	0	11
Cerastium arvense	Field chickweed	23	56	37
Collomia linearis	Narrow-leaved collomia	4	0	0
Cornus canadensis	Bunchberry	0	0	3
Disporum hookeri	Hooker’s fairybells	0	0	0
Epilobium angustifolium	Fireweed	2	0	0
Equisetum arvense & Equisetum hyemale	Common horsetail & scouring-rush	4	2	5
Erigeron speciosus	Showy daisy	8	22	5
Fragaria spp. /F. vesca/ F. virginiana	Wood & wild strawberry	34	34	45
Galium triflorum	Sweet scented bedstraw	10	5	18
Geum macrophyllum	Large-leaved avens	1	2	0
Lactuca muralis	Wall lettuce	1	0	3
Lathyrus nevadensis	Purple peavine	1	0	13
Lilium columbianum	Tiger lily	0	0	13
Lilium spp.	Unknown lily	1	0	3
Lupinus sericeus	Silky lupine	23	17	50
Microsteris gracilis	Pink twink	5	0	5
Moehringia lateriflora	Blunt-leaved sandwort	3	7	13
Moehringia macrophylla	Large leaved sandwort	0	0	21
Osmorhiza chilensis	Mountain sweet cicely	18	0	18
Potentilla glandulosa	Sticky cinquefoil	11	7	26
Potentilla gracilis	Graceful cinquefoil	5	15	13
Potentilla spp.	Unknown cinquefoil	0	2	0
Pteridium aquilinum	Bracken fern	3	5	5
Pyrola asarifolia	Pink wintergreen	1	0	5
Senecio sylvaticus	Wood groundsel	0	0	0
Silene menziesii	Menzies’ catchfly	24	0	0
Smilacina stellata/ Maianthemum stellatum	Star-flowered false Solomon’s-seal	12	2	3
Soladego canadensis	Canada goldenrod	0	7	37
Spiranthes romanzoffiana	Hooded ladies’ tresses	4	0	0
Tragopogon dubius	Yellow salsify	5	17	37
Trientalis latifolia	Broad-leaved starflower	11	5	0
Vicia americana	American vetch	17	2	58
Viola adunca	Early blue violet	20	17	34

Table 6. Chittenden Meadow graminoid percent frequency 2004-2021.

Scientific Name	Common Name	Frequency (%)		
		July 2004 (n = 280)	Sept 2017 (n = 41)	June 2021 (n = 38)
Agrostis capillaris	Colonial bentgrass	0	7	0
Bromus sitchensis	Alaska brome	0	0	16
Carex spp.	Unknown sedge	0	54	79
Danthonia intermedia	Timber oatgrass	0	5	5
Elymus glaucus	Blue wild rye	0	2	24
Festuca sp. / Festuca saximontana	Unknown fescue / sheep fescue	0	22	8
Phleum pratense	Common timothy	26	68	61
Poa palustris	Fowl bluegrass	0	34	47
Stipa columbiana	Columbia needle grass	0	0	13

Table 7. Chittenden Meadow invasive species percent frequency 2004-2021.

Scientific Name	Common Name	*Growth Form	Frequency (%)		
			July 2004 (n = 280)	Sept 2017 (n = 41)	June 2021 (n = 38)
Cirsium spp.	Unknown thistle	F	1	0	0
Hypericum perforatum	Common St. John's wort	F	3	7	32
Leucanthemum vulgrave	Ox-eye daisy	F	2	15	13
Rumex acetosella	Sheep sorrel	F	1	7	18
Trifolium pratense	Red clover	F	1	5	5

*F (Forb),

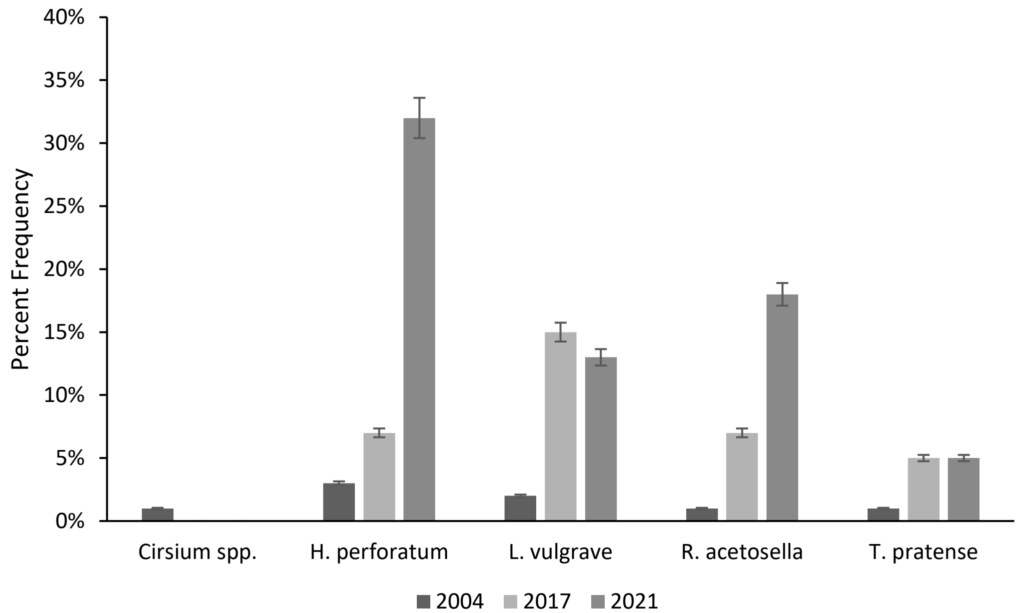


Figure 9. Chittenden Meadow invasive species percent frequency 2004-2021.

Table 8. Chittenden Meadow shrub percent frequency 2004-2021.

Scientific Name	**Common Name**	**Frequency (%)**		
		July 2004 (n = 280)	**Sept 2017 (n = 41)**	**June 2021 (n = 38)**
Amelanchier alnifolia	Saskatoon	17	20	8
Arctostaphylos uva-ursi	Kinnikinnick	1	2	8
Chimaphila menziesii	Menzies' pipissewa	0	5	3
Cornus stolonifera	Red-oiser dogwood	1	0	0
Holodiscus discolor	Oceanspray	0	0	0
Lonicera ciliosa	Orange honeysuckle	6	0	0
Lonicera involucrata	Black twinberry	0	2	0
Lonicera utahensis	Utah honeysuckle	0	0	3
Mahonia aquifolium	Tall Oregon-grape	60	61	61
Mahonia nervosa	Dull Oregon-grape	10	2	3
Paxistima myrsinites	Falsebox	5	2	0
Rosa nutkana	Nootka rose	58	83	79
Rubus leucodermis	Black raspberry	0	5	0
Rubus parviflorus	Thimbleberry	10	2	3
Rubus spectabilis	Salmonberry	4	0	0
Rubus spp.	Unknown Rubus	0	0	3
Rubus ursinus	Trailing Blackberry	0	0	3
Sambucus racemosa	Red elderberry	0	0	5
Spirea betulifolia	Birch-leaved spirea	15	20	18
Spirea douglasii	Hardhack	0	5	21
Symphoricarpos albus	Snowberry	58	49	61

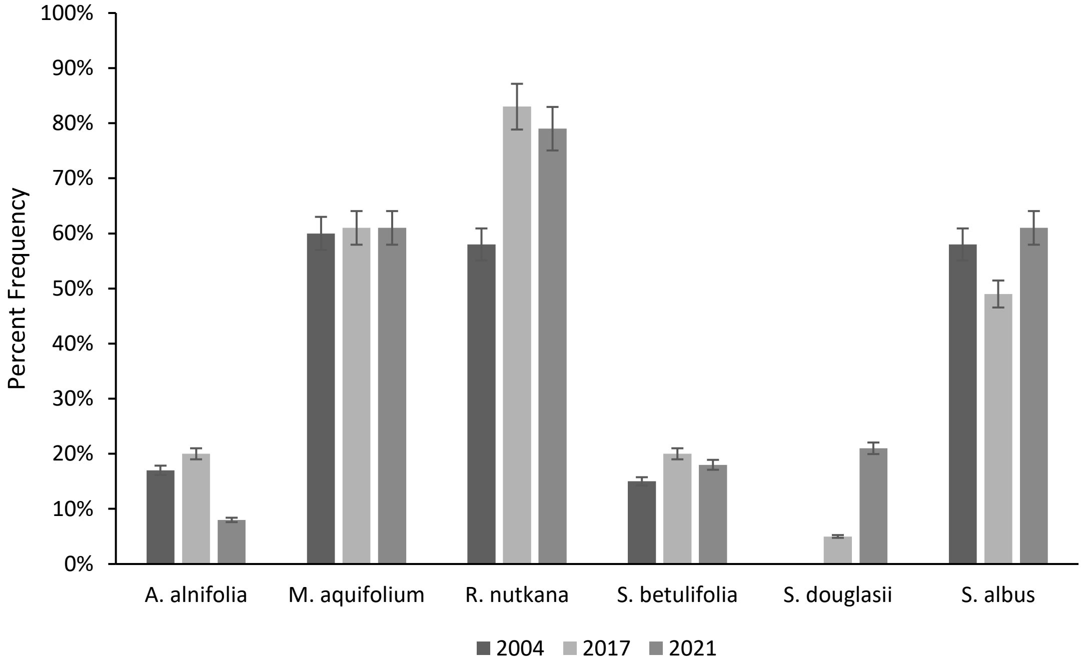


Figure 10. **Chittenden meadow shrub percent frequency 2004-2021.**

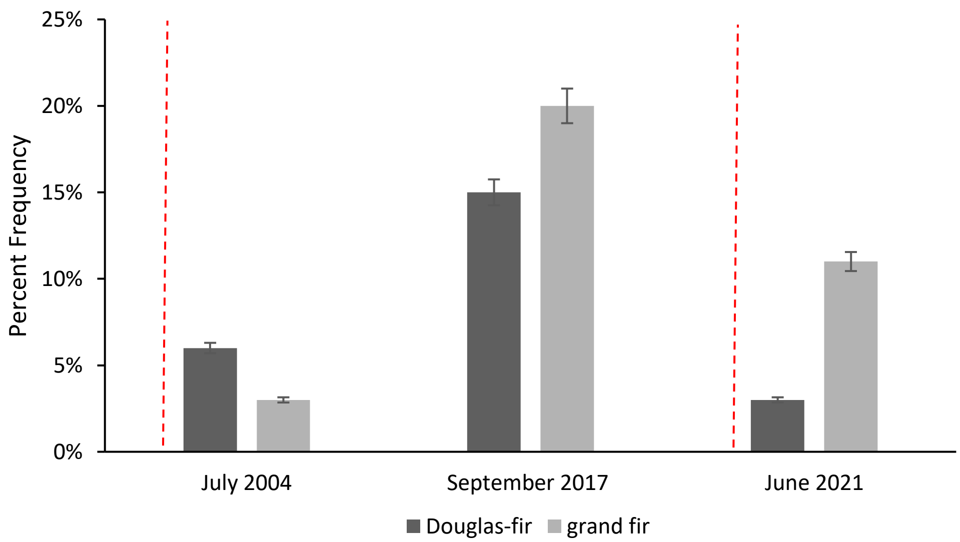


Figure 11. **Douglas-fir and grand fir percent frequency in the Chittenden Meadow from 2004 to 2021. The vertical lines indicate the prescribed fires occurring in April 2004 and April 2021.**

The number of trees per size class (stems/ha) in the Chittenden Meadow, using the 3.99 m (50 m^2) plot, was calculated with the following equation:

Area of a plot (circle): $\pi r^2 = 3.14 \times (3.99\ m)^2 = 50\ m^2$
Area of a hectare: 1 hectare = 100 m x 100 m = 10 000 m^2
Plot Multiplier: 10 000 m^2 ÷ 50 m^2 = 200

There was a reduction of Douglas-fir, grand fir, and ponderosa pine seedlings in the Chittenden Meadow between 2017 to 2021. Especially for conifers in the smaller size classes that likely established after the 2004 treatment period. Seedlings that were less than 1.3 m in height decreased from 757 stems/ha to 179 stems/ha for Douglas-fir, and from 1168 stems/ha to 505 stems/ha for grand fir. For ponderosa pine, seedlings decreased from 141 stems/ha to 0 stems/ha (Table 9; Table 10; Figure 14). These measurements only include live seedlings, since dead seedlings were not included in the 2017 data collection protocol.

Table 9. Number of trees per size class (stems/ha) in the 3.99 m plot, pre-burn treatment data collected in September 2017.

*Species	< 1.3 m height	DBH for trees > 1.3 m in height						
		0-5 cm	5-12 cm	12-20 cm	20-30 cm	30-40 cm	40-50 cm	> 50 cm
Fd	757	324	22	5	5	0	0	0
Bg	1168	497	59	5	27	5	0	5
Py	141	81	5	0	0	0	0	0

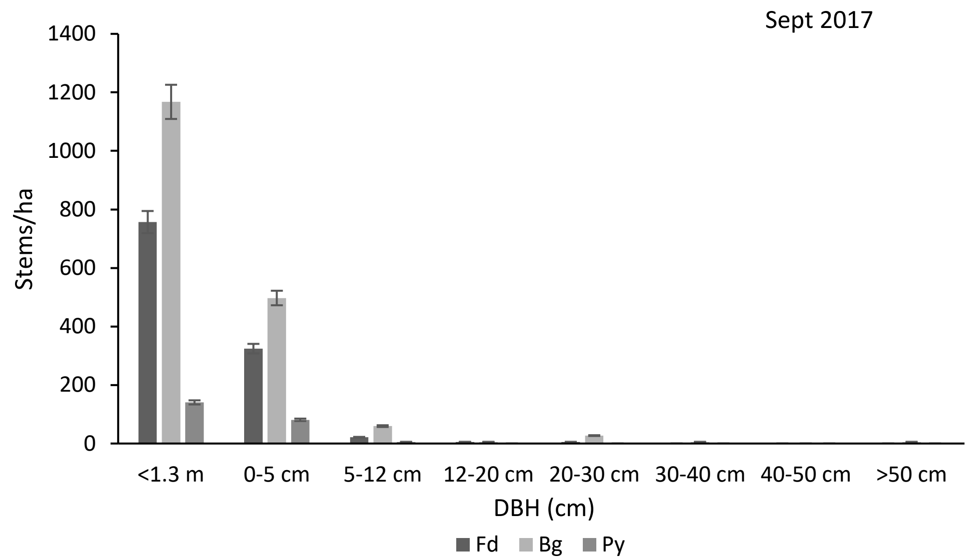
*Fd = Douglas-fir, Bg = grand fir, Py = ponderosa pine

Table 10. Number of trees per size class (stems/ha) in the 3.99 m plot, post-burn treatment data collected in June 2021.

*Species	< 1.3 m height	DBH for trees > 1.3 m in height						
		0-5 cm	5-12 cm	12-20 cm	20-30 cm	30-40 cm	40-50 cm	> 50 cm
Fd	179	0	0	5	0	0	11	0
Bg	505	5	5	5	26	5	0	11
Py	0	0	0	0	0	0	0	0

*Fd = Douglas-fir, Bg = grand fir, Py = ponderosa pine

A)



B)

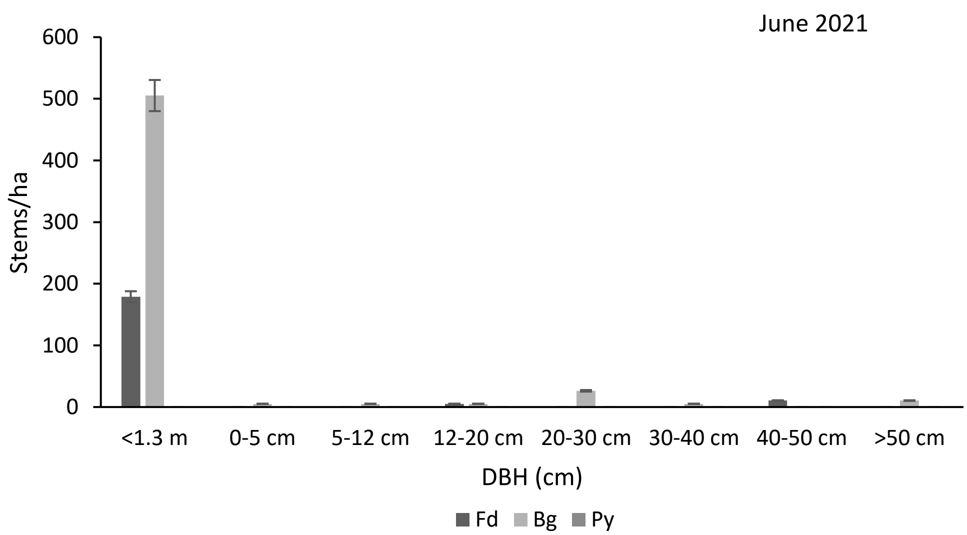


Figure 12. **Number of trees per size class (stems/ha) estimated from the 3.99 m plot. (A) pre-burn treatment data collected in September 2017, and (B) post-burn treatment data collected in June 2021. Fd = Douglas-fir, Bg = grand fir, Py = ponderosa pine.**

Objective 2.0. Investigate the historical fire regime and area extent of the Chittenden Meadow using tree-ring science (fire scars and tree ages) to inform decisions regarding fuel treatment and the use of prescribed burns in the restoration of the Chittenden Meadow and surrounding forests.

Tree core samples were taken from 10 plots; however, samples from one of the plots were not usable. Therefore, ages for samples from nine plots were able to be calculated. In total, 180 tree core samples were collected from the 10 plots. In addition, eight ponderosa pine cores were collected from the Chittenden Meadow. Of the 180 samples, 132 were analyzed in the lab. The species composition of the 132 samples was 81% interior Douglas-fir, 6.8% grand fir, 6.1% ponderosa pine, 3% western red cedar, 2.3% black cottonwood (*Populus trichocarpa*), and 0.8% lodgepole pine (*Pinus contorta*).

The minimum or estimated age was determined for 84 samples, ranging from 61-223 years. Minimum age refers to the number of rings that were counted on a sample that did not have pith or pith could not be estimated. Estimated age refers to the age of samples that had pith or pith was able to be calculated. The wide range of tree ages indicates that the study area has an uneven aged stand.

After searching each fire history plot, we found fire scars in five of the 10 plots, and more frequently on western red cedar. This result is unexpected due to the thin bark of a western red cedar, making it more vulnerable to mortality by fire. However, western red cedar was found growing in wet areas, where fire behaviour is conducive to lower fire intensity (Van Vliet et al. 2022).

Nine fire scar cookie samples were collected in the field. However, several of the samples were not usable due to rot; therefore, we were only able to gather results from four samples. With these, we were able to identify seven likely fire events, occurring in 1823, 1844, 1878, 1898, 1909, 1931, and 1952. The average return rate between these fire occurrences is approximately 20 years for the entire 145-ha area that was sampled (Van Vliet et al. 2022).

Figure 13. Tree cookie sample with fire scar, collected from one of the 10 fire history plots in June 2021 (Figure 7; Van Vliet et al. 2022).

4.0. Discussion

Objective 1.0. Assessment of the diversity and composition of the plant community in the Chittenden Meadow pre- and post-prescribed burn over time (2003-2021).

There were several challenges with the data, such as the different plot locations, different sampling intensities, and different sampling seasons. In addition, species ID was not consistent across all years. However, the senior project supervisor, Hélène Marcoux, helped to improve sampling consistency by developing both the 2017 and the 2021 data collection protocols. Nested sampling plots were added in 2017 and 2021 to capture seedling and shrub data and should be included in future data collection to compare stems/ha change over time in the Chittenden Meadow.

Plant community change over time was compared for the three time periods. These were July 2004, September 2017, and June 2021. Trends in the data for tiger lilies, with 0% frequency in 2004 and 2017 to 13% frequency in 2021, could indicate disparities in sampling techniques as well as differences in sampling periods before or after tiger lilies could be identified in the meadow (Table 5). These estimates could also be influenced by grazing of the local deer population. Tiger lilies were mapped in the Chittenden Meadow by Ayelstexw Consulting in 2021-2022; half of the meadow was mapped with ~50 tiger lilies found. It is estimated that there are approximately 20 tiger lilies per hectare in the meadow (Appendix B). Trends in silky lupine (*Lupinus sericeus*), a forb species that usually survives fires and are present in the initial stages of post-fire plant succession, was 23% in 2004, 17% in 2017, and 50% in 2021 (Table 5). Silky lupine has a deep root system and its seeds can germinate on mineral soil in full sun (Matthews 1993).

The low estimates for graminoid percent frequency in 2004 could be a result of Witt (2006) grouping many graminoid species together and not being experienced with graminoid identification. In addition, the different sampling seasons may have influenced graminoid identification. For example, 0% frequency was estimated in 2004 for all graminoid species except for common timothy. Trends in common timothy were 26% in 2004, 68% in 2017, and 61% in 2021 (Table 6). Common timothy is well adapted to fire, it has regenerative organs that are not harmed by moderately severe fires (Esser 1993). Trends in blue wild rye (*Elymus glaucus*) were 0% in 2004, 2% in 2017, and 24% in 2021 (Table 6). Blue wild rye is a short-lived perennial that does not compete well with surrounding vegetation, severity and frequency of fire greatly influence the recovery and maintenance of this species (Johnson 1999)

Changes in non-native and invasive species frequency were noticeable for common St. John's wort, which increased from 3% frequency in 2004 to 7% in 2017 and 32% in 2021 (Table 7). This increase could be attributed to sampling intensity; however, it is also commonly associated with disturbances such as fire (Zouhar 2004). Trends in sheep sorel (*Rumex acetosella*) a forb species that increased from 1% in 2004 to 7% in 2017 and 18% in 2021 (Table 7). It is known to invade disturbed areas and is commonly found on burned sites (Esser 1995). Several studies have described its establishment or increase after fire (Esser 1995). Trends for Ox-eye daisy (*Leucanthemum vulgrave*) increased from 2% in 2004 to 15% in 2017 and 13% in 2021. Ox-eye daisy was primarily located adjacent to the walking trail in the Chittenden Meadow.

The two conifers encroaching in the meadow were interior Douglas-fir and grand fir. After the prescribed burn and mechanical removal in July 2004, percent frequency for encroaching Douglas-fir and grand fir was 6% and 3%, respectively (Figure 11). In 2017, frequency increased to 15% and 20% respectively. Frequency then decreased to 3% and 11% in 2021 after the Spring 2021 prescribed burn and mechanical removal. These fluctuations in frequency indicate the importance of active management in the Chittenden Meadow to maintain the desired plant community composition and historical extent of the meadow. The project also helped to advance the cultural practice of using fire as a land management tool, which is valuable to Indigenous people in the area.

The plant community changes observed over time could be influenced by:

a) The type of ecosystem present will determine which plant species are found and which plant species can grow in an area (Feller 1993). If the ecosystem is relatively dry and warm and has been exposed to frequent fires in the past, then the plant species present will likely exhibit adaptations to fire. Prescribed fires in these ecosystems are unlikely to cause dramatic changes in vegetation (Feller 1993). In comparison, ecosystems that have burned infrequently are more likely to have changes in their plant communities after prescribed fires, both in species composition and relative dominance. Prescribed fires in frequently burned ecosystems can also cause changes in plant communities; however, there will be more pronounced changes in less frequently burned plant communities (Feller 1993). The ecosystem present can also influence fire severity. In general, fire severity will be less in moister than in drier ecosystems. In addition, regrowth of vegetation after fire is slower in drier than in moister ecosystems (Feller 1993).

b) Within a species, the response of an individual plant to fire varies depending on the local conditions at the time of the burn (Haeussler 1991). The severity of the fire is a measure of how much organic matter is consumed and how much heat penetrates the soil. This is the most important factor affecting plant response to burning, and determines the degree to which plant parts are damaged or destroyed. Fire severity is affected by fuel conditions (amount, size, arrangement, depth, moisture content); weather conditions before and during the burn (temperature, humidity, wind, precipitation); site conditions (slope, aspect, topography, soil texture, soil moisture); and ignition method and pattern (Haeussler 1991).

c) Soil and duff moisture content and duff depth are especially important. Duff is an effective insulating material, especially when wet. Temperatures hot enough to destroy roots, rhizomes, or seeds rarely occur more than a few centimeters below the surface of wet duff. The more severe the fire, the longer it takes for plants to recover and the greater the difference between pre- and post-burn plant communities (Haeussler 1991). Plants that are moderately resistant to fire may recover quickly following a low severity fire that kills or damages foliage and branches and singes the forest floor. Plants may be severely damaged by a high severity fire, where heat penetrates deep into the mineral soil, destroying roots, rhizomes, below-ground buds, and stored seeds (Haeussler 1991).

d) Fire sensitivity varies with the age of the plant. Young seedlings are typically the most vulnerable since they have not had time to develop fire-adaptive structures or mechanisms such as thick bark, an extensive root network, or seed storage (Haeussler 1991). Resistance increases with age but declines again as the plant becomes overmature and begins to lose vigour. Some plants rely on one type of fire-adaptive trait when they are young and another when they are mature (Haeussler 1991).

e) To predict how a plant species will respond to fire, the environmental conditions that the plant is adapted to must be considered. The sensitivity of a plant species to fire and the adaptations developed reflect the type and frequency of fire that it has evolved to survive (Haeussler 1991). Species found in environments where fires are frequent or recurring, such as the IDF BEC zone, generally possess a variety of adaptations that enable them to recover from fire. Even in fire prone environments, some species (typically moisture-loving, late successional plants) tend to be more sensitive to fire than early successional species found on mesic and drier sites (Haeussler 1991).

f) The response of plants to fire also depends on their morphological characteristics. In general, plants that root in the forest floor materials are more easily killed by fire than plants that root deeper in the mineral soil (Feller 1993). The greater the depth of the plant roots or rhizomes, the less easily a plant will be destroyed by fire. In addition, the healthier the plant, the less easily it will be destroyed, and the more rapidly it will recover from fire. Plants that are stressed, such as shade-intolerant plants growing in shaded forest environments, or plants experiencing moisture stress, are more easily destroyed by fire and regrow less rapidly than other plants of the same species (Feller 1993). Many plant species found in BC have evolved traits that protect them from damage, or enable them to regenerate following fire. For example, fireweed (*Epilobium angustifolium*) has prolific, wind-borne seeds that germinate well on open, burned seedbeds (Haeussler 1991). Trends in the Chittenden Meadow for fireweed were 2% in 2004, and 0% in 2017 and 2021. The low estimates may be due to the lack of a seed source nearby. In addition, ponderosa pine trees have evolutionary traits, such as protected seed buds, thick bark, prolific seed production, rapid seedling growth, long resinous needles, and highly flammable litter. All of these traits are adaptations to frequent, low-intensity surface fires (Moore et al. 1999).

g) Plants are more susceptible to fire when their moisture content is low or when their carbohydrate reserves are low, such as in late spring to early summer. In addition, the crowns of conifer trees are the most susceptible to fire during the spring bud flushing, when the moisture content of their old foliage is lowest and foliage flammability is at its highest (Haeussler 1991). Trees and other plant species are susceptible to being destroyed by fire during the bud-flushing period. However, if the surface fuels are moist and the weather is wet, such as the conditions during the 2004 burn, then mortality by fire is unlikely. In contrast, dry weather during the bud-flushing period will generally increase the likelihood of plant mortality as a result of fire (Haeussler 1991).

h) Fire is an effective tool in controlling shrubs and conifer trees in the understory of ponderosa pine meadow ecosystems. To remove undesirable shrubs, it may take two or three surface fires in succession to deplete the supply of seeds in the duff layer (Biswell 1972). Fire can keep shade-tolerant trees and shrubs out of the understory, and is able to ensure the dominance of ponderosa pine trees. Fire helped to maintain the large individual ponderosa pine trees in the Chittenden Meadow by limiting competition. Ponderosa pine-grassland habitats are highly dependent on frequent fires. Fire scar and tree-ring studies have indicated that fires were frequent in ponderosa pine-grasslands, approximately every 2-20 years on average. However, these results are likely too conservative, with natural and Indigenous set fires occurring more frequently than the data indicates (Biswell 1972; Moore et al. 1999). In ecological systems where fire has historically been a major agent of disturbance, burning is needed to maintain healthy ecosystems that provide habitat for naturally occurring plant and animal species (Haeussler 1991).

Objective 2.0. Investigate the historical fire regime and area extent of the Chittenden Meadow using tree-ring science (fire scars and tree ages) to inform decisions regarding fuel treatment and the use of prescribed burns in the restoration of the Chittenden Meadow and surrounding forests.

Fire history studies indicate that many ponderosa pine stands had mixed-severity fire regimes (Howard 2003). Historic fires in lower-elevation ponderosa pine communities were mostly low- to moderate-severity surface fires that maintained open, parkland stands, often with clusters of seedlings and saplings (Howard 2003). For as long as ponderosa pine stands have existed, they have presumably moved up and down in elevation and across latitude and longitude, following favorable environmental conditions (Moore et al. 1999). Fire scar and tree-ring studies have indicated that fires were frequent in ponderosa pine meadow ecosystems, with low-to-moderate severity fires occurring approximately every 2-20 years (Moore et al. 1999).

Ecosystems change over time and continue to evolve; however, for land management purposes, it is helpful to be able to visualize and describe what the forest structure resembled prior to fire regime disruption (Moore et al. 1999). It is important to use multiple lines of evidence to restore ecological systems, such as dendroecological reconstruction of fire regime and forest structure, along with historical photographs and vegetation community change over time (Moore et al. 1999).

Based on the dendrochronology results by Van Vliet et al. (2022), the fire return interval is approximately 20 years for the entire 145-ha area that was sampled. This return rate shows a high frequency of fire in the area. However, the presence of multiple cohorts of trees over a long-time range indicates that fire disturbance has had relatively low severity. The fire scar findings suggest that fires were localized to single plots, and were likely small, low intensity fire events. In 2019, there was a 6000-ha wildfire just north of our study area. According to our results, this type of fire should be a rare occurrence in Skagit Valley Provincial Park (Van Vliet et al. 2022).

Mature ponderosa pines with charred bark and fire scars were found in the Chittenden Meadow, but not in the immediate forest boundary, suggesting that fire was more frequent in the meadow (Lepofsky et al. 2003). Nine mature ponderosa pines were found in the meadow. Six trees established within a few years of 1800, and the remaining three trees established around 1890 (Lepofsky et al. 2003). Based on differences in soil profiles between the forest and the meadow, the boundary visible in the 1946 aerial photo has been stable for at least several hundred years (Figure 2). During this time, the area occupied by the meadow probably had a fire regime distinct from that of the surrounding forest (Lepofsky et al. 2003). Grand fir is more common on the mesic western edge of the meadow, with Douglas-fir and ponderosa pine occurring more on the drier northern and eastern edges (Lepofsky et al. 2003). Lepofsky et al. (2003) found that the age of the encroaching trees did not decrease with distance from the meadow-forest boundary. The young trees likely all established around the same time. The mature forest surrounding the meadow is relatively even-aged and dominated by Douglas-fir and grand fir, with some western red cedar and western hemlock (Lepofsky et al. 2003).

5.0. Conclusion

The best historical reference condition for the Chittenden Meadow is the open ponderosa pine parkland of the pre-1880 period. Lepofsky et al. (2003) recommended developing a management plan that returns the meadow vegetation community to that condition by reducing the encroachment of young interior Douglas-fir and grand fir and encouraging the establishment of scattered ponderosa pine. The cultural practice of using fire as a land management tool is valuable to Indigenous people in the area. It is also effective at reducing the dense seedlings and shrubs that inhibit ponderosa pine establishment. Therefore, it is recommended that the meadow is burned approximately every 2-20 years to reduce the density of young Douglas-fir, grand-fir, and shrubs, and to encourage the establishment of scattered ponderosa pine trees. The fire behaviour required to meet the desired objectives and ecological benefits is a low-to-moderate intensity fire. Lepofsky et al. (2003) recommended that the tree and shrub mortality and establishment be monitored pre- and post-prescribed burn to determine the success of burning to return the meadow to its desired state. To continue this study, it is also recommended that the site be monitored periodically by BC Parks staff to ensure that project objectives have been met. In addition, BCIT and SFU graduate students can provide annual, long-term, on-site vegetation monitoring. This will help to inform future decisions around fuel management and restoration. Without proper intervention by management, tree encroachment is expected to continue over time and the historical extent of the meadow will continue to be lost.

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Appendix A. Chittenden Meadow Vegetation 2004-2021

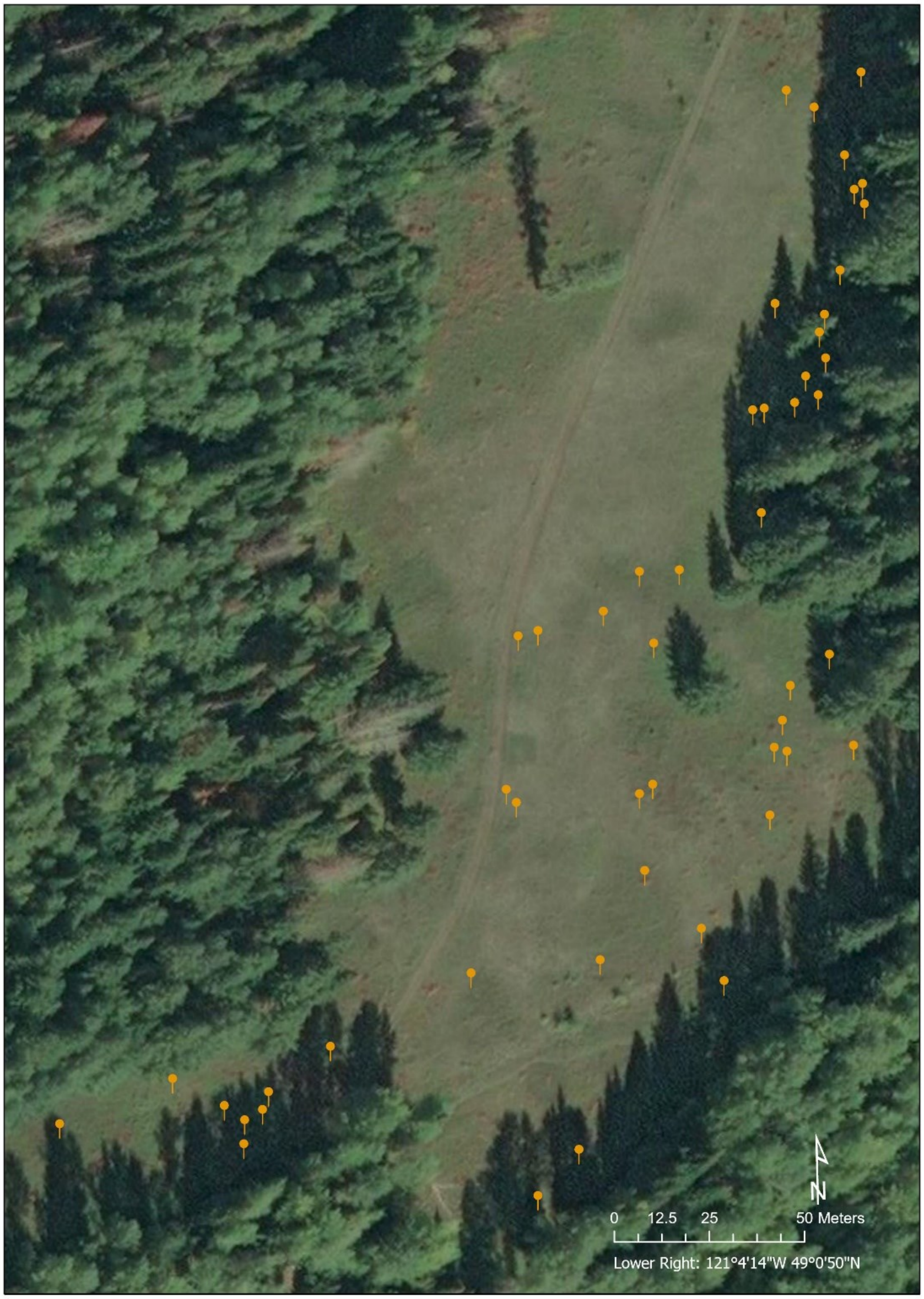
Scientific Name	Common Name	*Growth Form	Frequency (%)		
			July 2004 (n = 280)	Sept 2017 (n = 41)	June 2021 (n = 38)
Abies grandis	Grand fir	TC	3	20	11
Acer circinatum	Vine maple	TD	6	2	3
Acer glabrum	Douglas maple	TD	0	0	0
Achillea millefolium	Yarrow	F	34	76	58
Adenocaulon bicolor	Pathfinder	F	0	5	0
Agoseris aurantiaca	Orange agoseris	F	5	0	8
Agrostis capillaris	Colonial bentgrass	G	0	7	0
Amelanchier alnifolia	Saskatoon	S	17	20	8
Anaphalis margaritacea	Pearly everlasting	F	1	0	0
Antennaria microphylla	Rosy pussytoes	F	2	0	3
Antennaria neglecta	Field pussytoes	F	1	10	3
Apocynum androsaemifolium	Spreading dogbane	F	0	0	3
Arctostaphylos uva-ursi	Kinnikinnick	S	1	2	8
Aster conspicuous	Showy aster	F	1	5	0
Aster spp.	Unknown aster	F	0	0	0
Brachythecium frigidum	Golden short-capsuled moss	M	0	12	0
Bromus sitchensis	Alaska brome	G	0	0	16
Carex spp.	Unknown sedge	G	0	54	79
Castilleja miniata	Common red paintbrush	F	2	0	11
Cerastium arvense	Field chickweed	F	23	56	37
Chimaphila menziesii	Menzies' pipissewa	S	0	5	3
Cirsium spp.	Unknown thistle	I	1	0	0
Collomia linearis	Narrow-leaved collomia	F	4	0	0
Cornus canadensis	Bunchberry	F	0	0	3
Cornus stolonifera	Red-oiser dogwood	S	1	0	0
Crataegus douglasii	Black hawthorn	TD	0	0	0
Danthonia intermedia	Timber oatgrass	G	0	5	5
Disporum hookeri	Hooker's fairybells	F	0	0	0
Elymus glaucus	Blue wild rye	G	0	2	24
Epilobium angustifolium	Fireweed	F	2	0	0

Scientific Name	Common Name	*Growth Form	Frequency (%) July 2004 (n = 280)	Sept 2017 (n = 41)	June 2021 (n = 38)
Equisetum arvense & Equisetum hyemale	Common horsetail & scouring-rush	F	4	2	5
Erigeron speciosus	Showy daisy	F	8	22	5
Festuca sp. / Festuca saximontana	Unknown fescue / sheep fescue	G	0	22	8
Fragaria spp. / F. vesca / F. virginiana	Wood & wild strawberry	F	34	34	45
Galium triflorum	Sweet scented bedstraw	F	10	5	18
Geum macrophyllum	Large-leaved avens	F	1	2	0
Holodiscus discolor	Oceanspray	S	0	0	0
Hypericum perforatum	Common St. John's wort	I	3	7	32
Lactuca muralis	Wall lettuce	F	1	0	3
Lathyrus nevadensis	Purple peavine	F	1	0	13
Leucanthemum vulgrave	Ox-eye daisy	I	2	15	13
Lilium columbianum	Tiger lily	F	0	0	13
Lilium spp.	Unknown lily	F	1	0	3
Lonicera ciliosa	Orange honeysuckle	S	6	0	0
Lonicera involucrata	Black twinberry	S	0	2	0
Lonicera utahensis	Utah honeysuckle	S	0	0	3
Lupinus sericeus	Silky lupine	F	23	17	50
Mahonia aquifolium	Tall Oregon-grape	S	60	61	61
Mahonia nervosa	Dull Oregon-grape	S	10	2	3
Microsteris gracilis	Pink twink	F	5	0	5
Moehringia lateriflora	Blunt-leaved sandwort	F	3	7	13
Moehringia macrophylla	Large leaved sandwort	F	0	0	21
Osmorhiza chilensis	Mountain sweet cicely	F	18	0	18
Paxistima myrsinites	Falsebox	S	5	2	0
Phleum pratense	Common timothy	G	26	68	61
Pinus ponderosa	Ponderosa pine	TC	0	2	0
Poa palustris	Fowl bluegrass	G	0	34	47
Populus spp.	Unknown poplar	TD	3	0	0
Potentilla glandulosa	Sticky cinquefoil	F	11	7	26
Potentilla gracilis	Graceful cinquefoil	F	5	15	13

Scientific Name	Common Name	*Growth Form	Frequency (%) July 2004 (n = 280)	Sept 2017 (n = 41)	June 2021 (n = 38)
Potentilla spp.	Unknown cinquefoil	F	0	2	0
Prunus spp.	Unknown Prunus	TD	2	0	0
Pseudotsuga menziesii	Douglas-fir	TC	6	15	3
Pteridium aquilinum	Bracken fern	F	3	5	5
Pyrola asarifolia	Pink wintergreen	F	1	0	5
Rosa nutkana	Nootka rose	S	58	83	79
Rubus leucodermis	Black raspberry	S	0	5	0
Rubus parviflorus	Thimbleberry	S	10	2	3
Rubus spectabilis	Salmonberry	S	4	0	0
Rubus spp.	Unknown Rubus	S	0	0	3
Rubus ursinus	Trailing Blackberry	S	0	0	3
Rumex acetosella	Sheep sorrel	I	1	7	18
Sambucus racemosa	Red elderberry	S	0	0	5
Senecio sylvaticus	Wood groundsel	F	0	0	0
Silene menziesii	Menzies' catchfly	F	24	0	0
Smilacina stellata / Maianthemum stellatum	Star-flowered false Solomon's-seal	F	12	2	3
Soladego canadensis	Canada goldenrod	F	0	7	37
Spirea betulifolia	Birch-leaved spirea	S	15	20	18
Spirea douglasii	Hardhack	S	0	5	21
Spiranthes romanzoffiana	Hooded ladies' tresses	F	4	0	0
Stipa columbiana	Columbia needle grass	G	0	0	13
Symphoricarpos albus	Snowberry	S	58	49	61
Taraxacum officinale	Common dandelion	I	29	5	58
Timmia austriaca	False-polytrichum	M	0	2	0
Tragopogon dubius	Yellow salsify	F	5	17	37
Trientalis latifolia	Broad-leaved starflower	F	11	5	0
Trifolium pratense	Red clover	I	1	5	5
Vicia americana	American vetch	F	17	2	58
Viola adunca	Early blue violet	F	20	17	34

*F (Forb), G (Graminoid), I (Invasive/non-native), M (Moss), S (Shrub), TC (Conifer tree), TD (Deciduous tree)

Appendix B. Chittenden Meadow Tiger Lily Locations (2021-2022)



Legend

Tiger lily locations

Chittenden Meadow Tiger Lily Locations

Map Author: Jennifer Nicholls, TFT
Map Date: February 7, 2022
Map Projection: UTM Zone 10N NAD83

Appendix C. Chittenden Meadow Mop-Up (April 2021)