Plant Facilitation Effects as a Potential Restoration Tool in Riparian Ecosystems in Southwestern British Columbia

by

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Abstract

This study began to investigate potential facilitative effects among shrub species in riparian ecosystems in southwestern British Columbia. I ran two concurrent studies. Six plots for each of four treatments were established at the Coquitlam River Wildlife Management Area. The first two treatments compared the survival, growth, flowering, and herbivory rates of planted twinberry seedlings in plots where the shrub layer was removed to plots where it was not. The other two treatments compared the survival, growth, leaf loss, flowering and herbivory rates of snowberry plants in plots where the salmonberry upper shrub layer was removed to those where it was not. No significant differences between the measured parameters in any of the treatments were found. These results are discussed in the context of the riparian forest ecosystem and current facilitation theory. The results are then used to inform an ecological restoration plan for the Suwa'lkh School Forest.

Keywords: ecological restoration; facilitation; riparian forests; native vegetation; *Symphoricarpos albus*; *Lonicera involucrate, Rubus spectabilis*

Dedication

I would like to dedicate this document to Jadav Payeng, the Forest Man of India. Anyone can practice ecological restoration. Don’t make excuses - get it done.

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List of Acronyms

SFU	Simon Fraser University
BCIT	British Columbia Institute of Technology
LAC	Library and Archives Canada
CRWMA	Coquitlam River Wildlife Management Area
SGH	Stress Gradient Hypothesis
MWW	Mann-Whitney-Wilcoxon test for significance
BEC	Biogeoclimatic Ecosystem Classification system
CWHdm08-10	Biogeoclimatic Ecosystem Classification system designation representing the Coastal Western Hemlock Dry Maritime riparian bench site series

Glossary

Ecological Restoration	The process of aiding the recovery of an ecosystem that has been degraded, damaged, or destroyed.
Facilitation	The process whereby the presence of one organism or species in an ecosystem increases the survival, growth or reproduction of another organism or species.
Relative Stress-Gradient Hypothesis	A species is more likely to benefit from facilitation when under conditions that are stressful relative to its adaptation to that stress.
Riparian Forest	Forest ecosystems adjacent to water bodies (generally rivers) that are subject to periodic flooding.

Chapter 1. Introduction

Facilitation is the process by which the presence of a species increases the growth, survival, or reproduction of another species in its immediate physical environment. Facilitative interactions have been observed in a wide variety of ecosystems and can have important effects on the post-disturbance trajectory of these ecosystems (Bellingham et al. 2001; Brooker 2008). Understanding this process may lead to increased success in restoration projects by informing appropriate management decisions. My study focuses on the potential facilitative effects between common plants in riparian ecosystems in southwestern British Columbia.

Riparian ecosystems are important for their role in shading and supporting rivers, serving as wildlife corridors, and filtering excess nutrients and pollutants from entering waterbodies (Randhir & Ekness 2013). These ecosystems are often degraded by past logging and ongoing disturbances associated with urbanization and development. Because of this, as well as their general accessibility in the landscape, they are also often the target of ecological restoration activities (Poulin et al. 2000), including revegetation with native plants.

Salmonberry (*Rubus spectabilis*), snowberry (*Symphoricarpos albus*), and twinberry (*Lonicera involucrata*) were chosen for this study. They are all common woody species in these ecosystems, are frequently used in restoration, and are traditional sources of food and medicine. It is common practice to start with woody shrubs, that often provide structural protection, when assessing facilitative effects in previously unstudied ecosystems because they often provide more noticeable facilitative effects (Padilla & Pugnaire 2009; Pueyo et al. 2009; Liu et al. 2013). If the facilitative interactions between these plants are better understood, it could lead to greater survival, growth, and reproductive output of these species in a restoration context.

Facilitation in temperate ecosystems is an understudied field. However, there is some evidence that facilitative shading may be an important effect in the re-establishment of stable state temperate plant communities immediately post-disturbance (Galindo et al. 2017).

This chapter will provide further details on the concept of facilitation, common mechanisms of plant-plant facilitation, and its potential as a restoration tool in riparian ecosystems in southwestern British Columbia.

1.1. Facilitation

1.1.1. What is Facilitation?

Facilitation occurs when the benefactor (or 'nurse') species changes the biotic and/or abiotic conditions of the ecosystem in a way that improves the quality of life for the beneficiary species (McIntire & Fajardo 2014). It is often defined to only include commensalistic interactions, although mutualistic and parasitic interactions are occasionally included (Callaway 2007; Pugnaire & Haase 1996). It is generally measured by comparing changes in survival, growth or reproductive rates (Callaway 2007).

The concept of facilitation was first described by Clements. Clementsian succession, where ecosystems deterministically proceed through temporarily stable stages on a fixed and inevitable pathway back to their climax stage, was theorized to be possible because of the changes to the abiotic environment caused by each successive biotic stage (Clements 1916). This process of successive facilitation was the mechanism by which ecosystems returned to their climax stage.

Facilitation has not always been incorporated in the dominant paradigms of plant community assembly. Gleason, for example, took an opposing view. He argued that plant communities exist purely as a reflection of their physical conditions and their ability to immigrate and establish at a given site (Gleason 1926). Plant-plant interactions were deemed a minor effect in the creation of plant communities, which is an idea that has continued to dominate plant ecology. This undervaluation of facilitation, however, is based largely on correlative studies of plant communities along environmental continua – studies that rarely, if ever, delve into the processes and mechanisms that cause these patterns (Callaway 1997).

This view as challenged in the 1990s, first by Odum, and then by Callaway and Bertness. Odum introduced important concepts such as: mutually beneficial interactions becoming more likely as resources become scarce, that indirect effects between species may be as important as direct ones and that species affect their ecosystems in ways that benefit other forms of life (Odum 1992). Two years later, Bertness and Callaway published a seminal paper that introduced facilitation as a critical ecosystem process that can contribute significantly to the formation of communities. It also introduced the stress-gradient hypothesis (SGH) – the idea that positive species interactions are more common in physically stressful environments (Bertness & Callaway 1994). Since then, research into facilitation and its inclusion into general ecological theory has become increasingly important (Bruno et al. 2003).

Initially, the stress-gradient hypothesis (SGH) specifically theorized that facilitation was more likely to occur where environments were ‘extreme’ (Callaway 2002; Castro et al. 2004; Schöb et al. 2012). The term ‘extreme’ was rarely defined and often included ecosystems as diverse as alpine, semi-arid shrublands and saltwater marshes. Because of this, the stress-gradient hypothesis has been brought under criticism and redefined with increased appreciation of the adaptation of plants to their local conditions (Holmgren & Scheffer 2010; McIntire & Fajardo 2011). It has been suggested that the original interpretation of the SGH is largely the result of experimental design – which relied heavily on observing pair-wise interactions in lieu of any measure of the actual frequency of facilitative interactions at the level communities or ecosystems (Maestre et al. 2005, Soliveres & Maestre 2014). The most recent interpretation of the SGH is that, since the experience of stressful conditions is relative to a species’ resilience to that stress, facilitation is more likely to be important to species near the edge of the range of their tolerances – whatever those tolerances are – and not necessarily any more likely in some ecosystems than others (Holmgren & Scheffer 2010; Schöb et al. 2012; McIntire & Fajardo 2014). This is corroborated by the finding that locally rare species (i.e. those that are likely at the edge of their geographic – and therefore tolerance – ranges) likely benefit from facilitation more because it allows them to live more outside of their normal biophysical conditions (Pugnaire & Lazaro 2000; Soliveres et al. 2015). The debate remains unresolved but it highlights the need to study facilitation in all ecosystems (Brooker 2008).

Despite its contentious history, facilitation continues to be an important research focus. Facilitative effects have been observed in a wide variety of ecosystems (Brooker 2008). Only by continuing experimentation into specific conditions and mechanisms can facilitative effects be properly assessed as a tool for effective ecological restoration (see "Facilitation as a Restoration Tool').

1.1.2. The Multiplicity and Variability of Facilitative Effects

As these rapidly evolving and often contradictory views suggest, facilitation is not an easy effect to study. Facilitation is as likely to be an indirect or inconsistent effect, such as protection from herbivory or competition, than a direct one such as the improvement of physical conditions (Callaway 2007). This leads to the underestimation of its frequency and importance. Since direct effects (e.g. shading) are easier to observe and test, they are also more likely to be studied – leading to a bias in facilitation research (Stachowicz 2001; Van der Putten 2009; McIntire & Fajardo 2014). Direct effects may be even more obvious in environments with low plant biomass and species diversity, even though they are not necessarily more important in these environments (Bonanomi et al. 2011). In addition to this imbalance, the very nature of facilitation makes it difficult to study in a traditional manner. Facilitation is not always likely to be apparent in laboratory studies where abiotic conditions are often held constant and the presence of the rest of the natural plant community is eliminated. Even when the interactions between two species in lab conditions are competitive, facilitative effects can be observed between the same species in the field (Callaway 2007; McIntire & Fajardo 2014).

The numerous ways in which facilitation may occur in the field also increases the difficulty of its study. Even though the nature of an interaction may be consistent, facilitative effects can differ strongly in importance along abiotic gradients such as topography and elevation (Callaway 1994; Holmgren et al. 2000; Choler et al. 2001; Kikvidze 2005). The rate of change in importance is itself inconsistent across the same environmental gradients in different ecosystems. For example, Spanish and Australian semi-arid ecosystems have different patterns of facilitation importance across the same rainfall gradient (Soliveres et al. 2011).

Facilitation can also be temporally variable. Wright et al. found that the facilitation effects can change over the course of a single day. They found that on cool/humid days, juvenile bur oaks (*Quercus macrocarpus*) grew less when surrounded by more established plants but that the opposite was true on hot/dry days as a result of the microclimatic influence of those same neighbouring plants (Wright et al. 2015). This variability in the effect of facilitation can also be seen in interannual climatic patterns (Tielborger & Kadmon 2000).

This variability can be even less predictable, responding to stochastic weather events (Mulder et al. 2001). Kitzberger et al. found that *Austrocedrus* trees will recruit successfully under protective nurse shrubs especially when exposed to drought events (Kitzberger et al. 2000). This pattern was also found to be true for similar plants in Mediterranean environments (Gomez-Aparicio et al. 2004).

The variability in facilitative effects can be additionally complicated by other pressures, such as herbivory, leading to even more complex facilitative patterns. Ibanez and Schupp found that plants that are competitive when herbivory is excluded can protect each other under herbivory pressure, leading to a net positive interaction (Ibanez & Schupp 2001). A set of two plants can be generally competitive, except when in the presence of a third plant species, when they become facilitative (Takahashi 1997; Levine 1999). There is also some evidence that this happens more frequently among closely-related taxa (Valiente-Banuet & Verdu 2008).

Facilitation can be two-way, as in a study by Pugnaire et al. (1996) that showed that a leguminous shrub gave structural protection to an increasing diversity of herbs with age. The herbs then provided the shrub with a greater abundance and range of nutrients, increasing its growth. Facilitation can also affect life stages differently (Holmgren et al. 2000), which can lead to the facilitated establishment of a species that will eventually outcompete its nurse plant (Bertness 1991; Chapin et al. 1994; Callaway 2006). Younger life stages are often more vulnerable and, therefore, more likely to benefit from facilitation, especially when exposed to extreme climatic events (Maestre et al. 2002; Zanini et al. 2006; Ganade et al. 2008; Wright et al. 2014). This does not exclude the possibility of facilitative benefits at other life stages (Shumway 2000; McIntire & Fajardo 2011).

Facilitation can increase some measures of fitness and not others – such as increasing the survival of plants while simultaneously not affecting or even decreasing their growth or flowering rates (Casper 1995; Castro et al. 2004). A nurse plant may be facilitative in one way (such as structural protection) and competitive in another (such as resource competition) (Holmgren et al. 1997; Tielborger & Kadmon 2000; Callaway

2006). Specific facilitative effects, such as litter deposition can range from facilitative to interfering, depending on the species they are affecting. Finally, while there is some evidence that some facilitative effects are species-specific, this is not always the case (Maranon & Bartolome 1993; Franco-Pizana et al. 1996; Callaway 1998; Callaway 2006).

This extreme variability in timing, specificity, and interaction suggests that facilitation may be uncommonly difficult to detect or study simply because it may not happen to be acting at the time of the experiment, and not necessarily because it is unimportant.

1.1.3. Mechanisms of Facilitation

The variable nature of facilitation is partly the result of the extreme variety of mechanisms that produce facilitative effects. These include but are not limited to: light regulation, soil nutrient and moisture improvement, improved soil oxygenation, physical defenses, increasing local seed rain, supporting more favourable soil microflora, mycorrhizal associations, and increased attraction of pollinators (Hunter & Aarssen 1988; Pal Bais et al. 2004; Callaway 2006; Bonanomi et al. 2011; Gomez-Ruiz et al. 2013; Rodrigues-Echeverria 2013).

Investigation into facilitative effects generally starts with the regulation of light intensity. Shade can buffer plant tissues from lethal temperatures, decrease respiration costs, reduce ultraviolet irradiation, and increase soil moisture (Rigg et al. 2002; Hobbie 2006; Callaway 2006; Callaway 2007). Facilitation is more likely to benefit shade-tolerant species (Gomez-Aparicio et al. 2004). It becomes more important in riparian areas when there is less shade (Galindo et al. 2017), and can have indirect facilitative effects, such as maintaining lower soil salinities by controlling evaporation (Callaway 2006). Observing the effects of shade is often an essential first step in assessing possible facilitative interactions.

Another of the more easily observable facilitative effects is the improvement of soil conditions. Nitrogen fixation by plants is a classic example of the improvement of soil nutrients (Rodriguez-Echeverria et al. 2013). Soil nutrients tend to be better under the canopies of established plants than in unvegetated areas (Tielborger & Kadmon 2000;

Maestre et al. 2001; Callaway 2007). This effect does not seem to be limited to ecosystems with relatively low levels of soil nutrients (Stachowicz 2001; Callaway 2006). Improvement of soil moisture can also be important, especially in ecosystems with relatively little plant cover (Holmgren et al. 1997; Caldeira et al. 2001), or those experiencing drought events (Callaway 2007). This effect is not found only under large plants either - ground cover plants can maintain consistent surface soil moisture levels (Pugnaire & Haase 1996; Callaway 2006). This effect does not seem to be limited to arid environments either – facilitative soil moisture improvement was seen in sugar maple (*Acer saccharum*) temperate forests of eastern North America (Dawson 1993).

Nurse plants often have facilitative defenses and provide physical protection. This includes woody structures, spines, toxins, and odours (Atsatt & O'Dowd 1976). Physical defense can be as simple as minimizing damage from high winds or objects carried by the wind or flooding events (Callaway 2007). Plants with spikes have been found to be more likely to be facilitative, because of their ability to deter herbivory (Gomez-Aparicio et al. 2004). Defense can also be facilitated less directly by the association of palatable and less palatable species (Attsat & O'Dowd 1976; Stachowicz 2001), an example being the savanna grasses in east Africa (Callaway 2006).

1.1.4. Facilitation as a Restoration Tool

Strong facilitative interactions have been observed in a wide variety of ecosystems and its ubiquity makes it a likely candidate for use as a tool in ecological restoration (Brooker 2008). Facilitation has been used successfully as a tool in a wide variety of ecosystems including: Mediterranean mountains, semi-arid steppes, savannah, marshes, tropical sub-humid forest, tropical dunes, mangrove forests, arid shrubland and rangelands, and abandoned agricultural fields (Padilla & Pugnaire 2006; Padilla & Pugnaire 2009; Pueyo et al. 2009; Chen et al. 2013; Liu et al. 2013; Stahlheber & D'Antonio 2014; Teixeira et al. 2016). Facilitative effects can have serious impacts on the final state of an ecosystem, making them an important consideration when plotting an ecosystem trajectory (Bellingham et al. 2001). Research into facilitation can correct mistaken conservation and restoration practices – such as the assumption made in Mediterranean ecosystems that shrubs should be removed during restoration to prevent competition with planted species. Instead, using existing vegetation as nurse plants to support the establishment of planted species leads to more effective and economical restoration practices (Castro 2002). Since facilitation is more likely to help young plants, it can be used to increase planting survival in the first few years after restoration (Gomez-Aparicio et al. 2004). Because facilitation is more likely to aid species that are locally rare, it can also be used as a tool for the protection of endangered species like the yew (*Taxus baccata*) (Garcia et al. 2000). This is further improved by facilitation's ability to remove or buffer from extreme abiotic events that can act as selective pressures, allowing for a greater trait diversity to exist stably in a single population and making that population more resilient to future selective pressures (McIntire & Fajardo 2014).

This project is meant to further the investigation into facilitative effects by targeting an ecosystem that has been previously understudied in the context of facilitative effects. Temperate riparian ecosystems are common targets for restoration activities, making investigation into ecological dynamics in these ecosystems likely be beneficial (Poulin et al. 2000).

1.2. Site Context

Southwestern British Columbia has a long history of human interaction. The Coast Salish people (a non-traditional grouping based on language family) have occupied southwestern British Columbia for at least the last 10,000 years (Fraser Basin Council 2013). With the advent of colonialism, southwestern British Columbia began to be used heavily for resource extraction and as a transportation hub. Much of southwestern British Columbia was developed for urban, industrial, and farmland use, drastically degrading the region's ecosystems (Morgan & Lashmar 1993). Because of their importance in protecting streams and fisheries, riparian forests have been the target for many of the restoration initiatives in southwestern British Columbia (Poulin et al. 2000).

The riparian forests of the region are controlled largely by their high water tables and regular flood regimes. They are dominated by water-tolerant black cottonwood (*Populus trichocarpa*) canopies and a diversity of shrub species. These riparian forests support a large portion of the region's biodiversity and are reported to have higher species richness and productivity than other local forest types (Morgan & Lashmar 1993).

The shrub layer of these ecosystems plays an especially important ecological role. Because of the speed with which shrubs grow, they act as a resilient provider of ecosystem services in this regularly disturbed ecosystem. They filter and absorb chemicals and excess nutrients, preventing them from entering waterways. Their roots hold streambanks in place and reduce the flow of runoff and floods (Udd 2001). Many are fruit-bearing and provide physical structures that support the life cycles of birds and small mammals (Waterhouse & Harestad 1999).

Three of the common shrubs in these ecosystems are twinberry (*Lonicera involucrata*), salmonberry (*Rubus spectabilis*), and snowberry (*Symphoricarpos albus*). All three are commonly recommended for use in riparian plantings. This is because they all grow well as understory plants, tolerate moderate disturbance (especially flooding), root well from cuttings, have root systems that minimize erosion, and have physical structures that help break the flow of floods (Udd 2001).

All three shrubs were also used by local First Nations. Twinberry fruit is bitter and not generally considered edible. However, the twigs and bark were traditionally used as a medicine; a bark decoction was used as a treatment for skin ailments and the berries were used in small doses for stomach issues and as a laxative and diuretic (Angier 1978; Foster & Hobbs 2002; Pojar & MacKinnon 1994; Turner 2011; Lans 2016). Both salmonberry sprouts and berries are edible. They are one of the first berries to ripen in the spring. Groups or individuals in native cultures like the Nuu-chah-nulth could own berry patches and would be harvested to a certain extent by the owners before being able to be harvested by others. The ripening of salmonberries is associated with the song of the Swainson's thrush – often referred to as the salmonberry bird in local native languages (Pojar & MacKinnon 1994). A tea made from the bark was used for skin and digestive tract issues (Foster & Hobbs 2002). The juice of the berries was added to other medicines to make them more palatable (Angier 1978). Snowberry fruit was not used as a food source because consuming more than a couple berries at a time can be toxic. However, it was used medicinally in similar ways to twinberry – often to settle an upset stomach, as a laxative, or as a poultice for skin wounds or sores (Pojar & MacKinnon 1994). It was additionally used to treat sore eyes (Foster & Hobbs 2002).

Investigating facilitation in this ecosystem may lead to better restoration and management practices. Twinberry, salmonberry and snowberry are not only culturally important but also, as shade-tolerant shrubs, may be more likely to be involved in facilitative relationships. Facilitation is understudied in temperate, biodiverse ecosystems and my research may be an important first step in its investigation.

1.3. Research Goals and Objectives

The role of positive plant-plant interactions has important implications for the practice of ecological restoration. Riparian ecosystems in southwestern British Columbia are often the target of restoration activities and have been largely missed in past facilitation studies. In this project, I aim to investigate and apply potential facilitative effects in riparian ecosystems in southwestern British Columbia.

Goal 1: Identify potential facilitative interactions that may be used as a tool for the restoration of riparian ecosystems in southwestern British Columbia.

Objective 1: Assess potential facilitative effects of an established shrub layer on the survival, growth, flowering, and herbivory rates of planted twinberry (*Lonicera involucrata*) seedlings, over the course of one summer.

Objective 2: Assess the effect of salmonberry (*Rubus spectabilis*) on the survival, growth, flowering, herbivory, and leaf number of established snowberry (*Symphoricarpos albus*) plants, over the course of one summer.

Objective 3: Assess changes in soil temperature, moisture and electrical conductivity that resulted from the application of the treatments from Objectives 1 and 2, over the course of one summer.

Goal 2: Design a restoration plan, for the Suwa'lkh School Forest in Coquitlam, British Columbia, incorporating the ecological knowledge obtained from the experiment conducted for Goal 1.

Chapter 2. Methods

2.1. Study site

I conducted the experiment at the Coquitlam River Wildlife Management Area (CRWMA) (Figure 2.1, 2.2). The Coquitlam River Wildlife Management Area is a 16.7 ha area just north of the Fraser River in Coquitlam, British Columbia. I confined the experimental zones at this location to the north-eastern part of the CRWMA. The Biogeoclimatic Ecosystem Classification (BEC) system site series designation for this location ranges between Coastal Western Hemlock riparian forest variants CWHdm08-CWHdm10. The vegetation community at this site is typical for the site series – dominated by black cottonwood and diverse shrub species. Based on my personal observations, the black cottonwood canopy is extensive and gaps in the canopy are minimal. The adjacent Marry Hill Bypass highway and perimeter fence encompassing the CRWMA likely act as barriers to some large animals such as mule deer and black bear (pers. comm. Balke 2018). The soils here are Ladner clays (recent alluvial deposits) overlain with an organic layer developed by the forest community (Department of Agriculture 1938). The dominant disturbance regime is the flooding of the Fraser River, which is a significant event as the river drains an area of 220,000 km^2 and floods yearly from May-June.

2.2. Plant Species Information

I designed the research to identify facilitative effects under two sets of conditions. The first is the potential facilitative effects of a shrub layer on transplanted twinberry (*Lonicera involucrata*). The second is to determine the facilitative effects of the dominant upper shrub layer species salmonberry (*Rubus spectabilis*) on naturally established snowberry (*Symphoricarpos albus*). I selected snowberry in part because it is consistently present at all established experimental zones across the site. A vegetation survey revealed no other species to be present at all experimental zones and so the study was limited to snowberry. Both species are also of interest to my project partners at the Suwa'lkh School.

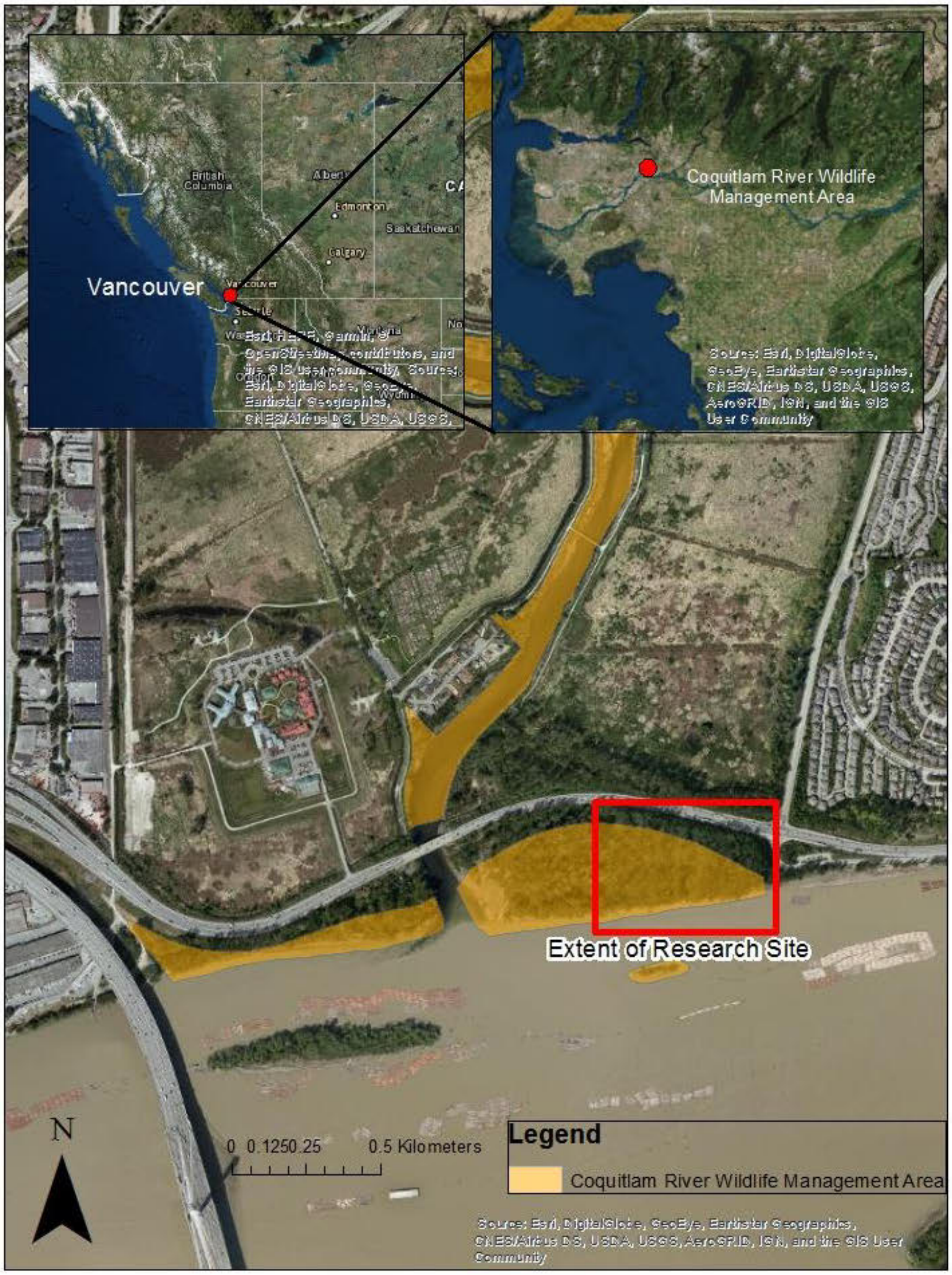

Figure 2.1. Location of the Coquitlam River Wildlife Management Area (CRWMA) experimental zones. Inset maps show the location of the CRWMA in relation to the rest of the Vancouver region (right inset) and the location of Vancouver in relation to the rest of British Columbia (left inset).

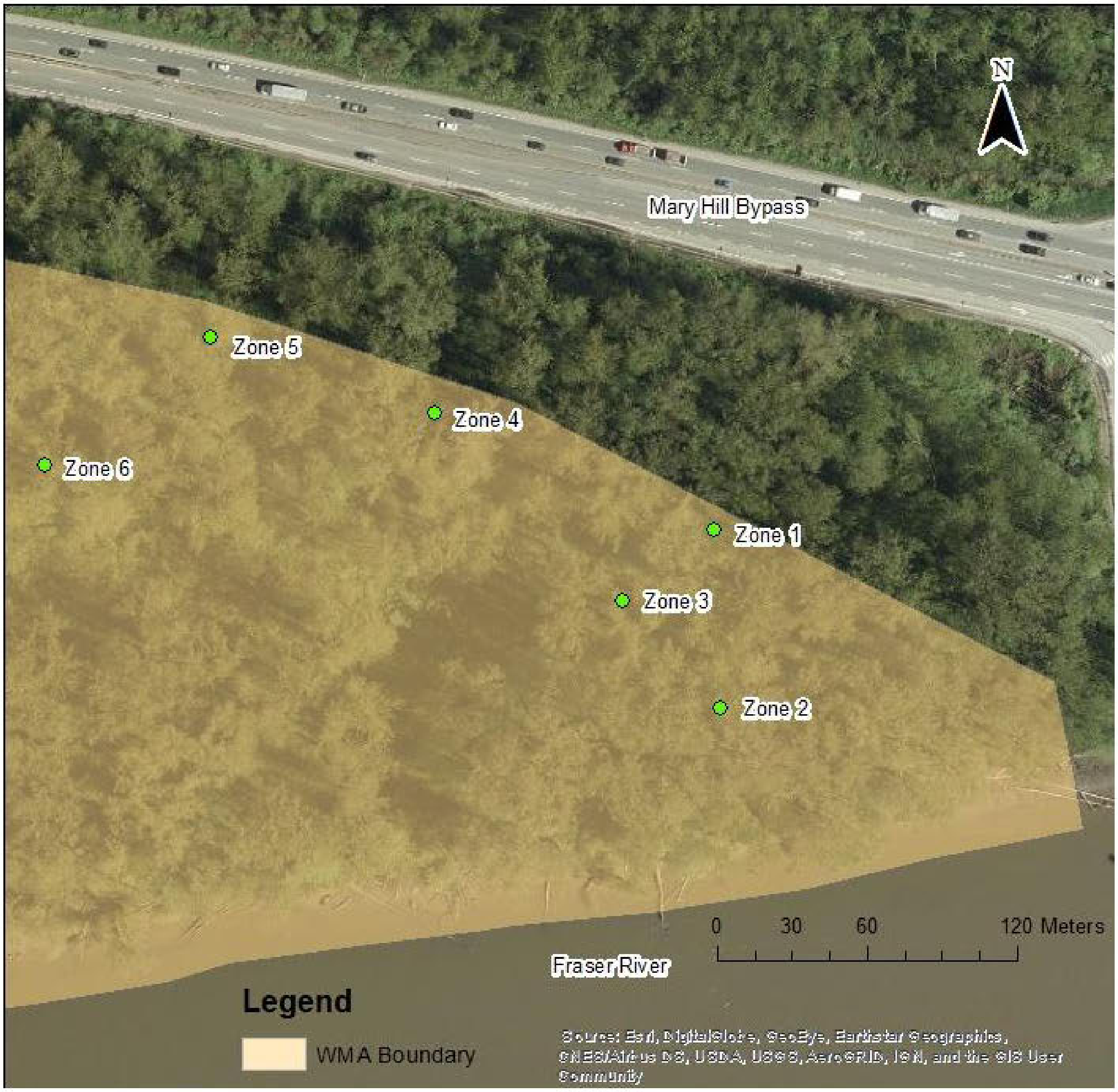

Figure 2.2 Aerial view of the Coquitlam River Wildlife Management Area (CRWMA). The area of the CRWMA polygon that was used for the facilitation experiment is indicated with the yellow polygon. The six zones where experimental plots were laid out are indicated with green dots.

Twinberry is a member of the honeysuckle family (Caprifoliaceae). It is a deciduous shrub native to most of central and western North America. It grows well under a canopy, especially in moist soils. It tolerates full sun but is more likely to grow well in shady understory conditions (Clason et al. 2008; Darris 2011). Twinberry is useful as a streambank erosion control plant, with root networks that prevent soil loss and a physical structure that breaks the flow of floods (Udd 2001). It produces black berries that are an important food source for bears, small mammals, and birds, but its foliage is not commonly used as browse by large herbivores (Darris 2011). I chose it for this study in part because of its ubiquity and usefulness in riparian restoration plantings.

Salmonberry is a member of the rose family (Rosaceae). It is a deciduous shrub native to the west coast of North America from Alaska to southern California (Favorite & Moore 2008). It prefers moist soils but can grow in a wide range of light conditions. Salmonberry can grow quickly in sunny gaps in riparian forests – filling in openings caused by disturbances and buffering light, temperature, and moisture levels at the forest floor (Roburn 2003). It produces large quantities of fruit that are eaten by a wide variety of animals.

Like twinberry, snowberry is a member of the honeysuckle family (Caprifoliaceae). It is also a deciduous shrub and is found naturally across North America from Alaska to southern California (Favorite & Moore 2008). As a result of its dense branch growth, snowberry contributes significantly to the structure of its ecosystem's lower shrub layer. This thick layer of branches provides important cover for birds and rodents. It grows well in both sun and shade (Udd 2001).

2.3. Experimental Design

I chose to develop a manipulative experiment to identify causal processes and minimize of the risk of false cause errors (which are fairly likely when studying complicated systems and effects that are likely indirect) (Callaway 2007). Other studies, such as Gomez-Aparicio et al. (2004), suggest that starting with dominant shrub species – especially those which fix nitrogen or provide physical defenses – is a reasonable choice when beginning studies in facilitation. Many studies of facilitation include the experimental manipulation of the canopy of potential nurse plants and a comparison of the effects under the canopy of nurse plants to the areas in between them (Choler et al. 2001; Dormann & Brooker 2002; Rodriguez-Echeverria et al. 2013; Soliveres et al. 2015). This method does come with limitations. If only the above ground biomass is removed and the facilitative mechanism is soil-based (for example, nutrient enrichment or mycorrhizal relationships), the experiment is unlikely to detect the effect. If the below-ground biomass is removed as well, the disturbance may have more of a negative impact on the vegetation than the absence of the nurse plant would, leading to an increased risk of error in the results (Callaway 2007). I decided that experimentally removing only aboveground shrub cover would be an appropriate first experiment into potential facilitative effects riparian ecosystems in southwestern British Columbia.

Experimental design based on the use of plots is common in the literature. Many studies use plots that are 2 m to 3.5 m a side (Caldeira et al. 2001; Zanini et al. 2006). This plot size is assumed to be large enough to capture shrub-related effects but are still small enough to manage easily. They are also generally buffered by at least 2 m to minimize the treatment impact on nearby plots (Gomez-Ruiz et al. 2013).

Transplanting species for observation is also common practice, especially in restoration-related studies (Levine 1999). This is usually an effort to minimize variability in the experiment by ensuring all the plants are the same age and grew up under the same conditions, rather than selecting natural plants that can have extremely varied histories.

Plant height and leaf size are common measures of growth while flowering rate can provide an indicator of the general health of the plant (Gomez-Ruiz et al. 2013; Cornelissen 2003). Measuring the effects on soil moisture and temperature is also common as a way to monitor the plot’s abiotic conditions (Schöb et al. 2012).

Based on the considerations discussed above, I implemented the following research design. I marked out six experimental zones at the CRWMA; chosen for their heavy salmonberry cover and distinct physical structure (See Figure 2.2, 2.3). Each zone was an 8 m x 8 m square which I divided into four 3 m x 3 m plots. The plot size allowed for a 2 m buffer between each of the plots to minimize interaction between the treatments. I randomly assigned each plot to one of the two concurrent studies and one of the two treatments in that study using a random number generator.

2.3.1. Twinberry Experiment

The experimental design consisted of a total of 12 plots (2 at each of the 6 experimental zones). I removed the shrub layer in half of the plots in the twinberry study (RemPlant) while leaving the shrub layer intact in the other half (Plant). I removed all aboveground biomass of the removed plants by severing them from their root systems at ground level using clippers. I left the roots in the ground to avoid creating additional disturbance.

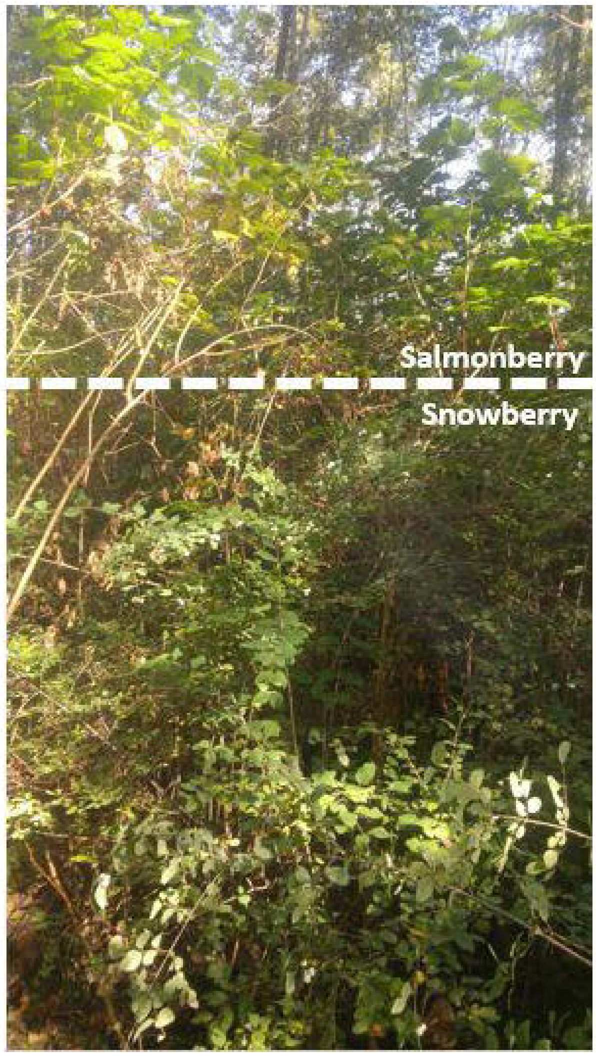

Figure 2.3. The physical relationship of salmonberry and snowberry common in the Coquitlam River Wildlife Management Area. Photo: MacCallum, K. 2018

I planted four twinberries in each plot (4 twinberries x 12 plots = 48 seedlings). I purchased the 48 twinberry seedlings from NATS nursery on May 28, 2018. All 48 were 77P plugs. I planted them the day after purchase to minimize the risk of damage.

I planted four twinberry seedlings in the four corners of an approximately 1 m x 1 m square in the center of each RemPlant and Plant plot. I chose this density because it permitted a balance between preventing crowding and increasing the number of experimental units for a more robust data set.

I measured survival, height, flowering, and herbivory damage on the transplanted twinberries every week from May 31st 2018 to September 6th 2018. I judged seedling survival by the presence of green leaf material. More in depth judgments of survival were not necessary. I measured height with the same measuring tape every week from the point at which the plant stem met the soil to the tip of its longest leaf. I measured flowering and herbivory with a simple yes/no as they occurred. I took photographs of all the twinberries at the end of the season to confirm the identification of herbivores, which I classified based on the herbivore group. Small holes or circular pieces of leaves missing, I identified as small invertebrate herbivores (snails, slugs, caterpillars, etc.) while leaves with brown lines were identified as leaf miners (larvae of beetles, flies, etc.). Both types of herbivory are depicted in Chapter 3: Results and are included in the results qualitatively.

2.3.2. Snowberry Experiment

The experimental design consisted of a total of 12 plots. I removed all the aboveground salmonberry biomass in half of the plots in the snowberry study (RemSal) while removing none of the vegetation from the other half (Sal). I severed all aboveground biomass of removed plants from their root systems using clippers. I left the roots in the ground to avoid creating additional soil disturbance.

I randomly selected four branches of snowberry in each plot. If I happened to randomly select more than one branch from the same plant, I conducted further random selections until no more than one branch was chosen from any one plant. I selected four branches because the plot with the least number of snowberry plants had four plants. I secured a tag indicating the branch number to each branch at the point where it met the main stem with a thin piece of wire that I bound tightly enough to the branch not to move easily but not so tightly that it would inhibit the branch’s growth. I monitored the tags over the course of the summer to ensure that they were not beginning to dig into the twigs and were twisted in such a way that they could be loosened if necessary. I also tagged the main branches with yellow tape to make them easier to find in the dense shrub layer.

I monitored the branches weekly for survival, length, number of leaves, flowering, herbivory damage, and number of leaves. I measured length from the piece of wire at the junction where the terminal branch met its main branch to the end of the terminal leaf (or to the end of the branch if the terminal leaves were missing). I recorded the number of leaves on the selected branches to provide another indicator of branch health. I recorded flowering and herbivory with a simple yes/no as it occurred. I took photographs of all the snowberry branches at the end of the season to confirm herbivore identification, which I classified by herbivore group. I identified small holes or circular pieces of leaves missing as small invertebrate herbivores (snails, slugs, caterpillars, etc.) while leaves with brown lines were identified as leaf miners (larvae of beetles, flies, etc.). Both types of herbivory are depicted in Chapter 3: Results, with the identifications included in the results qualitatively.

2.3.3. Soil Parameters

I measured physical soil conditions 6 times from May 31st 2018 to September 6th 2018. More frequent measurement was not logistically possible. I used a Decagon 5TE soil probe and a ProCheck sensor. I measured soil temperature (°C), volumetric water content (%), and bulk electrical conductivity (dS/m) in the centre of each of the plots. Ideal soil temperatures for the growth of most plants are between 18-21°C – root growth will generally not happen above 30°C and below 4°C (Chapman 2000). Volumetric water content can not surpass soil porosity; values can not be below 0% and do not typically exceed 50%. Typical soil electrical conductivity ranges between 0 dS/m and 1.4 dS/m for non-saline soils but can range up to 16 dS/m or higher for strongly saline soils (Whitney 1998).

2.4. Statistical Analysis

I analyzed the results using significance tests with the statistical package R 3.4.2 (Appendix A) (R Core Team 2017). However, not all the collected data required statistical analysis. Twinberry survival and flowering rates, and snowberry survival rate did not require analysis beyond the presentation of the results.

I used three different significance tests for the statistical analysis. I tested results with normally distributed data with two-tailed Welch two sample t-tests. Those with non-normally distributed data, I tested with the Mann-Whitney-Wilcoxon test. I tested soil temperature, moisture, and electrical conductivity using one-way ANOVAs to enable comparison of the results from all treatments across both concurrent studies.

First, I used a quantile-quantile plot to visually assess the normality of the data. If I determined the data to be approximately normally distributed, I used a two-tailed t-test to test for significance in the differences between the treatments. If not, I used a Mann-Whitney-Wilcoxon test.

I chose to use the two-tailed t-test because of the importance of determining the direction of the difference between the two treatments. I chose to use a Welch two sample t-test so as not to assume equal variances among groups. If the variances of the groups are equal, a Welch two sample t-test will still return very similar results to the standard Student's t-test (Ruxton 2006). Two-tailed Welch two sample t-tests depend on certain assumptions: that the data follow a continuous or ordinal scale, that simple random sampling is used, that the sample is large enough to represent the population, and that the data is normally distributed. The first three assumptions are taken care of with the experimental design. The data collected follows a continuous scale and sampling all of the planted twinberries is sufficient to circumvent the assumptions of simple random sampling and sufficiently large sample size. I assessed the assumption of normal distribution using the quantile-quantile plot detailed above.

I used the Mann-Whitney-Wilcoxon (MWW) test when the data did not sufficiently fit a normal distribution. The MWW test's assumptions are: sampling independence, one dependent variable that follows a continuous or ordinal scale, and one binary independent variable. All three of these assumptions are met with the experimental design. It is also necessary to know the similarity of the shape of the distribution of the data for each independent variable. I visually assessed this using boxplots.

I used ANOVAs in order to assess the effect of all treatments on soil conditions. The assumptions of ANOVAs are: sampling independence, equality of variances, and normal distribution of residuals. The requirement for sampling independence was met by the experimental design – the time between measurements was decided to be sufficient to allow the samples to be considered independent. I assessed the equality of variances was visually using boxplots. I determined the normality of the residuals as part of the ANOVA test.

2.4.1. Twinberry Study Data Analysis

Twinberry Survival, Flowering and Herbivory

I compared the rates of survival, flowering and herbivory between treatments. I recorded plants that experienced any of the above (1=died, flowered, experienced herbivory, 0=survived, did not flower, did not experience herbivory) and summed the occurrences to determine a total per plot (a number between 0 and 4). I then calculated the mean rate for each treatment and compared these values.

Twinberry Growth

I calculated the difference between plant height on May 31st and the last sampling date on September 6th. I calculated the average growth for each plot, leaving 6 values per treatment. I then calculated the grand mean growth per treatment. I used a quantile-quantile plot to assess the normality of the data and the used a two-tailed Welch two sample t-test to test for significance. The null hypothesis is that there was no difference in twinberry growth between the two treatments. The alternate hypothesis is that twinberry growth is significantly different between the two treatments.

2.4.2. Snowberry Study Data Analysis

Snowberry Growth

I calculated the difference in branch length and leaf number between May 31st and September 6th 2019. I first calculated the mean growth and leaf number change per plot (to avoid pseudoreplication), leaving 6 values per treatment. I then calculated the grand mean growth rate and leaf number change per treatment. I used a quantile-quantile plot to assess the normality of the data and then used a two-tailed Welch two sample t-test to test for significance. The null hypothesis is that there is no difference in snowberry growth or leaf number change between the two treatments. The alternate hypothesis is that there is a difference between snowberry growth or leaf number change between the two treatments.

Snowberry Flowering and Herbivory

I recorded the branches that flowered or experienced herbivory (1=flowered, experienced herbivory 0=did not flower, did not experience herbivory) and then summed the occurrences to determine a flowering and herbivory rate per plot (a value between 0 and 4). I used a quantile-quantile plot to assess the normality of the data and an MWW test to test for significance. The null hypothesis is that there is no difference in snowberry flowering or herbivory rates between the two treatments. The alternate hypothesis is that there is a difference in snowberry flowering or herbivory rates between the two treatments.

2.4.3. Analysis of Soil Parameters

Soil Temperature

I took the average of the soil temperature, moisture and electrical conductivity data from each plot individually. I then averaged those values for each treatment and calculated the standard errors. I first tested the assumptions and then used a one-way ANOVA to determine whether the majority of the data's variability came from the treatments or if it was the result of differences between the experimental zones. The null hypothesis is that there will be no difference in soil temperature, moisture or electrical conductivity between the two treatments. The alternate hypothesis is that at least one treatment has significantly different soil temperatures, moistures or electrical conductivities.

Chapter 3. Results

3.1. Twinberry

3.1.1. Twinberry Survival

All planted twinberries survived, regardless of treatment.

3.1.2. Twinberry Growth

The twinberries that were planted in plots where the shrub layer was removed grew more than those planted under shrubs. The mean growth of twinberries in plots with an intact shrub layer was 11 mm. The mean growth of twinberries in plots where the shrub layer was removed was 32 mm. This difference is not statistically significant (t stat = -1.7109, t crit = -1.9552, p-value= 0.1179).

A visual assessment of the Q-Q plot (See: Appendix B) determined that the data is sufficiently normally distributed. A single outlier is present which leads to a skew in the data.

3.1.3. Twinberry Flowering

Only a single plant flowered during the growing season. It was found in a RemPlant plot and the plant also grew the most of any twinberry in any plot.

3.1.4. Twinberry Herbivory

Every single plant suffered some degree of herbivory. Small grazers such as caterpillars, snail, slugs, and beetles were the most common herbivores, although some twinberries suffered damaged from leaf miners as well.

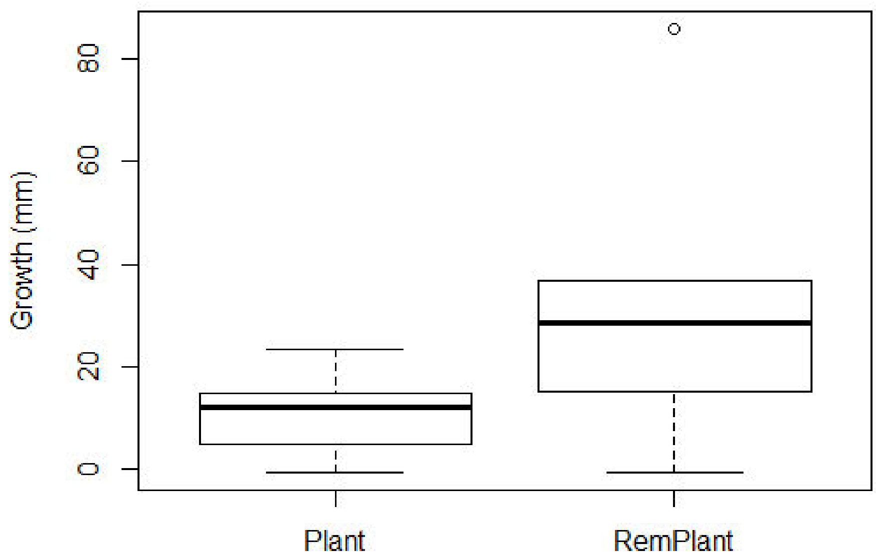

Figure 3.1. Median growth of planted twinberries (*Lonicera involucrata*) from May 31 2018 to September 6 2018 at the Coquitlam River Wildlife Management Area in Coquitlam, British Columbia. The bars extend up to 1.5 times the interquartile range, or to the maximum/minimum value. Values greater or less than this range are indicated by points.

3.2. Snowberry

3.2.1. Snowberry Growth Rate

The snowberries grew very little, regardless of treatment. The mean growth of snowberries in plots with an intact shrub layer was 1 mm. The mean growth of snowberries in plots where the shrub layer was removed was 3 mm. The difference in the results between the treatments was not statistically significant (t stat = 1.1448, t crit = -1.8148, p-value=0.2793).

A visual assessment of the Q-Q plot (See: Appendix B) determined that the data is sufficiently normally distributed. There is a slight skew in the data.

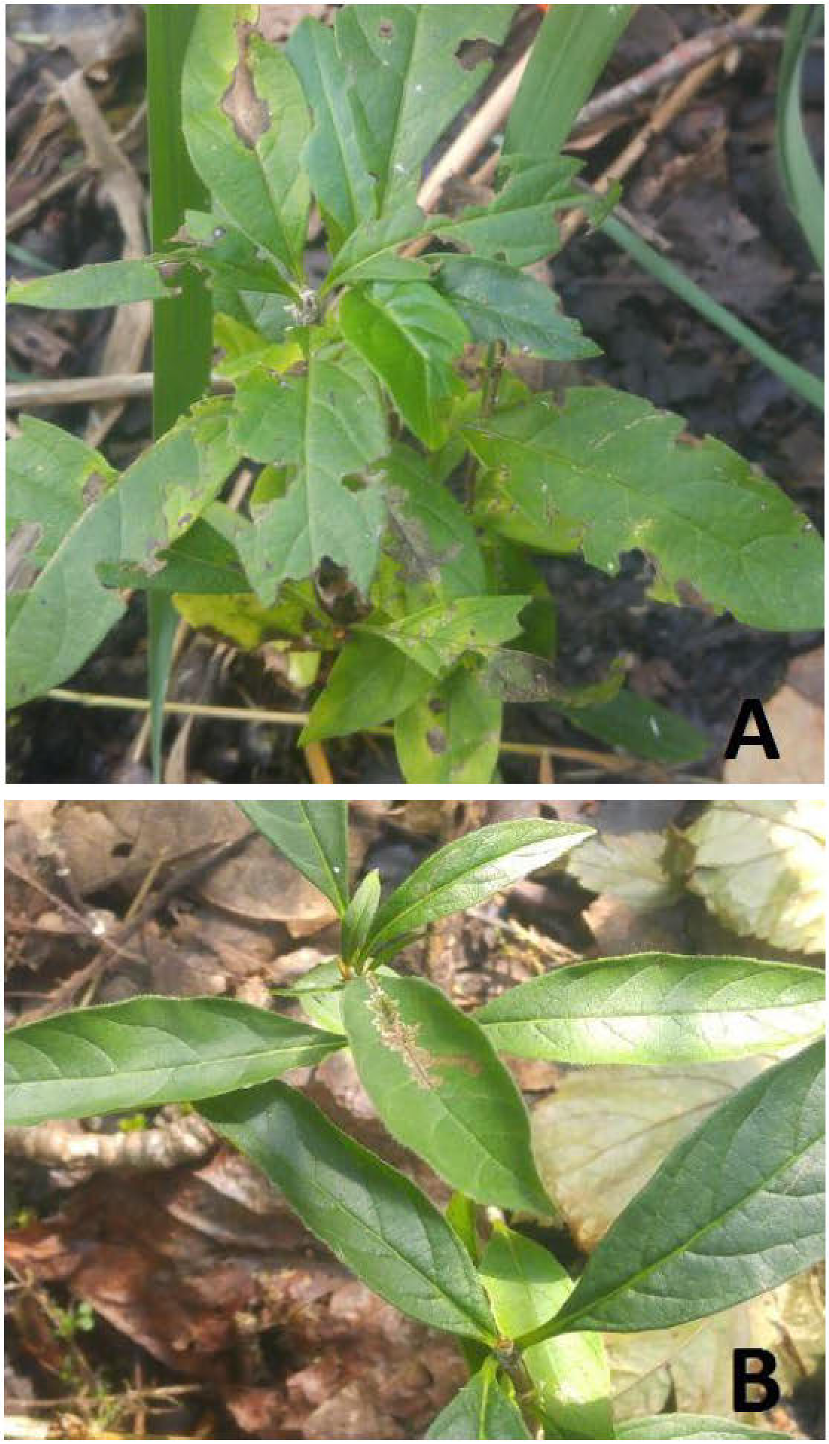

Figure 3.2. Panel A: Twinberry small grazer herbivory damage. Panel B: Twinberry having suffered leaf mining damage. Photo: MacCallum, K. 2018.

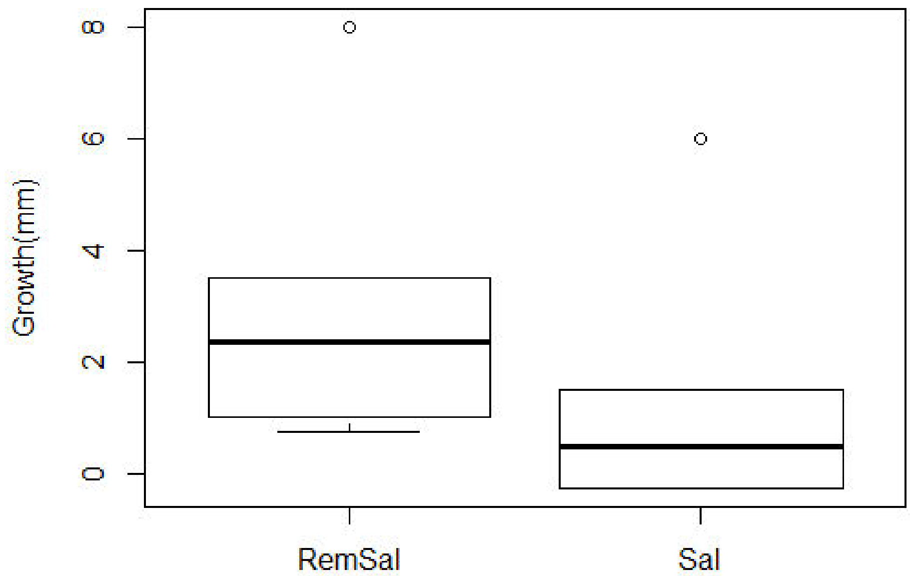

Figure 3.3. Median growth of monitored snowberries (*Symphoricarpos albus*) from May 31 2018 to September 6 2018 at the Coquitlam River Wildlife Management Area in Coquitlam, British Columbia. The bars extend up to 1.5 times the interquartile range, or to the maximum/minimum value. Values greater or less than this range are indicated by points.

3.2.2. Snowberry Number of Leaves

Branches were more likely to lose leaves in the plots where salmonberry was not removed than the plots were it was. Branches only had net leaf loss over the course of the growing season. Some branches grew leaves as well as losing leaves but none had a net gain. The mean number of leaves lost per branch in plots where salmonberry was removed was 1.125. The mean number of leaves lost per branch in plots where salmonberry was not removed was 1.5. This result is not statistically significant (t stat=1.1028, tcrit=-1.8218 p-value=0.2972).

A visual assessment of the Q-Q plot (See: Appendix B) determines that the data is sufficiently normally distributed.

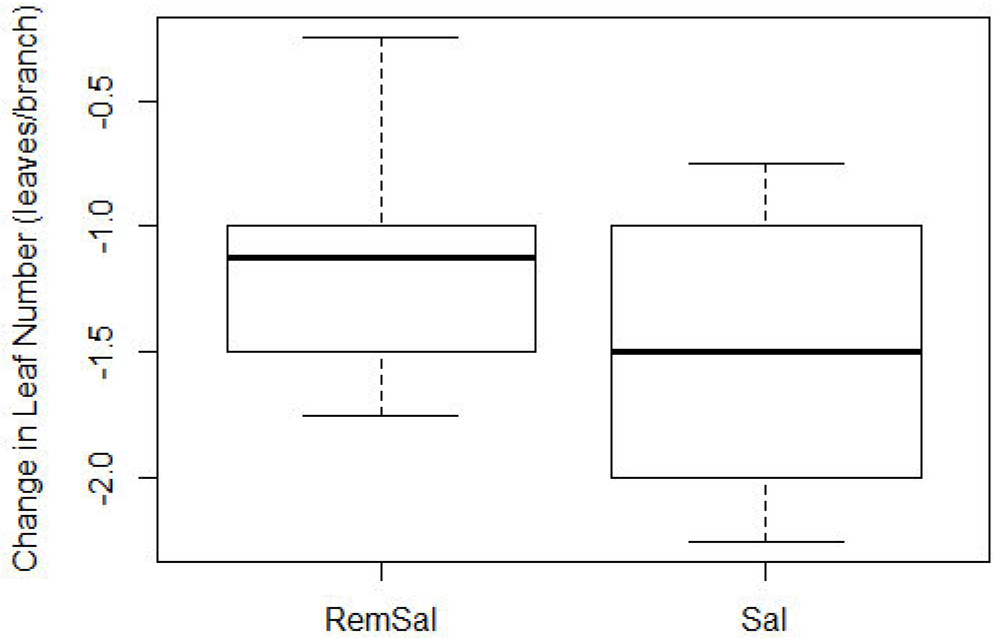

Figure 3.4. Median change in leaf number of monitored snowberries (*Symphricarpos albus*) from May 31 2018 to September 6 2018 at the Coquitlam River Wildlife Management Area in Coquitlam, British Columbia. The bars extend up to 1.5 times the interquartile range, or to the maximum/minimum value.

3.2.3. Snowberry Flowers

Only 6 branches flowered. Of those, 2 were in plots where salmonberry were removed and 4 were in plots where salmonberry was not removed. The mean flowering rate in plots where salmonberry was removed was 0.08. The mean flowering rate in plots where salmonberry was not removed was 0.17. The MWW test showed no significant difference between the flowering rates (p-value=0.5228).

A visual assessment of the Q-Q plot (See: Appendix B) determines that the data does not fit a normal distribution.

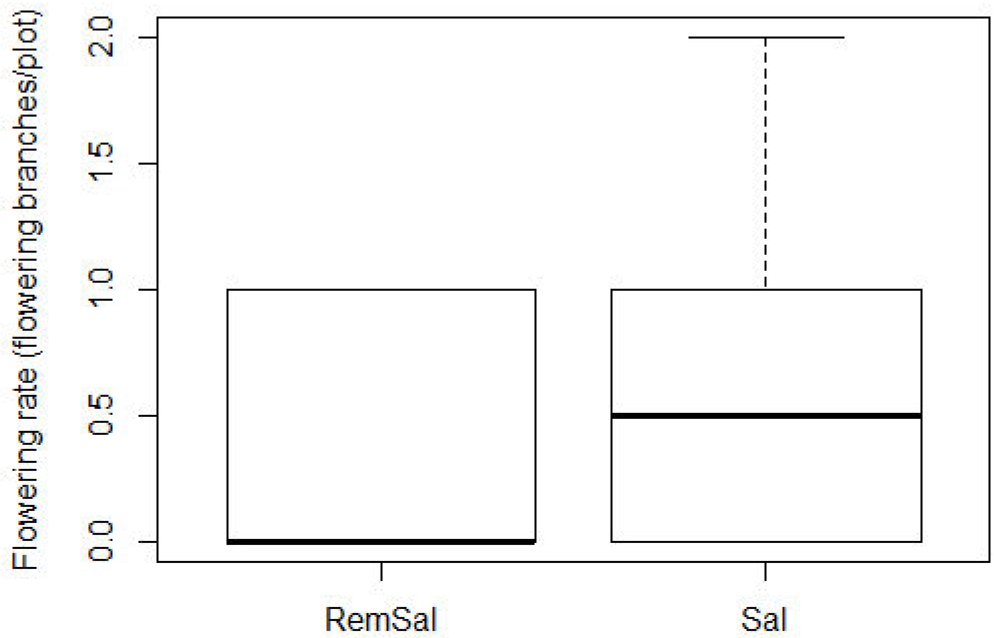

Figure 3.5. Median flowering rate (number of flowering branches/plot) of monitored snowberries (*Symphoricarpos albus*) from May 31 2018 to September 6 2018 at the Coquitlam River Wildlife Management Area in Coquitlam, British Columbia. The bars extend up to 1.5 times the interquartile range, or to the maximum/minimum value.

3.2.4. Snowberry Herbivory

The mean rate of herbivory per branch in plots where salmonberry was removed was 0.875. The mean rate of herbivory per branch in plots where salmonberry was not removed was 0.792. The MWW test did not detect any significant difference between the two treatments (p-value=0.6621).

A visual assessment of the Q-Q plot (See: Appendix B) determines that the data do not fit a normal distribution.

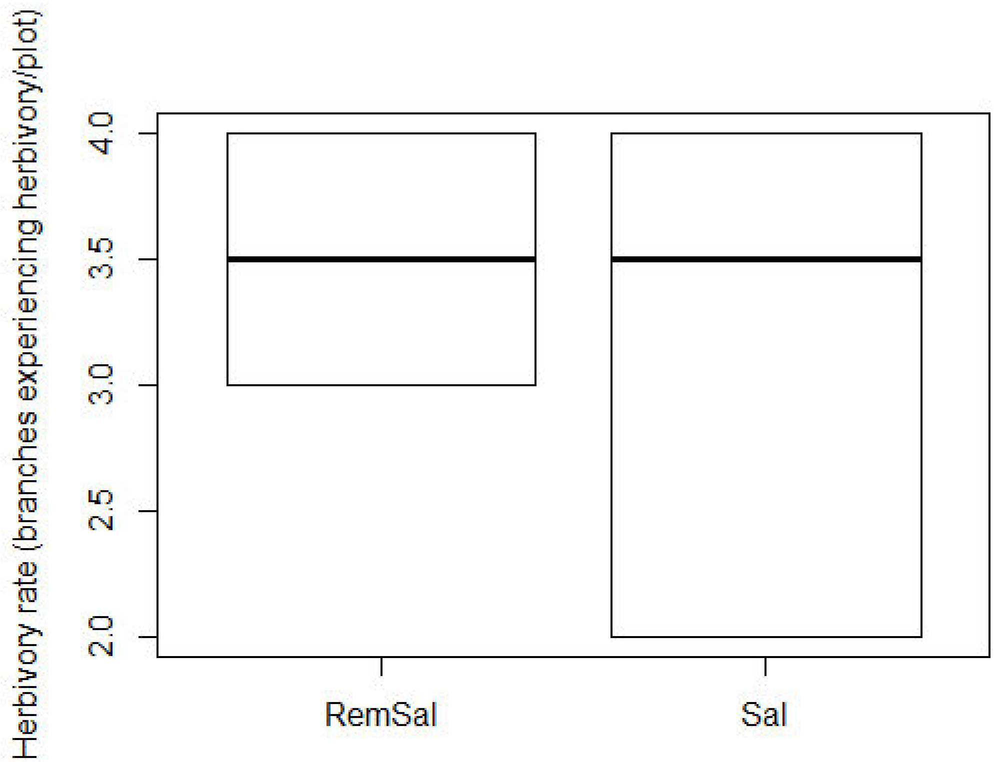

Figure 3.6. Median herbivory rate (branches experiencing herbivory/plot) of planted snowberries (*Symphoricarpos albus*) from May 31, 2018 to September 6, 2018 at the Coquitlam River Wildlife Management Area in Coquitlam, British Columbia.

It is also relevant to note that four branches did not survive the summer. All four branches suffered herbivory over time that resulted in their eventual death (pers. obs. 2018). Two of the branches were in plots where salmonberry was removed and the other two were in plots where salmonberry was not removed, making further statistical analysis unnecessary.

3.3. Soil

3.3.1. Soil Parameters

There was no significant difference in soil parameters measured between any of the treatments. The mean soil temperature was 22 °C. The soil moisture ranged from 24 % to 31 % volumetric water content. The electrical conductivity ranged from 0.6 dS/cm to 1.1 dS/cm. The mean values for each treatment can be found in Table 1 below. A visual assessment of the boxplots determined that the data were normally distributed and the ANOVAs determined that there was no significant differences between the treatments or the zones for any of the soil parameters (see Appendix B)

Table 3.1. Soil results.

Experiment	**Treatment**	**Temperature (°C)** **Mean ± SE**	**Volumetric Water Content (%)** **Mean ± SE**	**Electrical Conductivity (dS/cm)** **Mean ± SE**
Twinberry	Plant	22.1±0.3	25.7±2.0	1.1±0.1
	RemPlant	22.3±0.4	30.6±1.9	0.6±0.1
Snowberry	RemSal	22.2±0.3	24.8±1.5	1.0±0.2
	Sal	22.3±0.3	25.0±2.1	0.8±0.1

Chapter 4. Discussion

The purpose of this experiment was to begin assessing plant species in the CWHdm08-10 riparian ecosystems in southwestern British Columbia for potential facilitative effects that could be used in restoration. The study did not provide any evidence that the shrub layer of this ecosystem was providing facilitative effects for planted twinberry or naturally established snowberry. There are a number of potential explanations why facilitation was not detected between these species at this time and under the conditions tested in this experiment.

4.1. Twinberry

Twinberry ranges along the west coast of North America from Mexico to Alaska; southwestern British Columbia is close to the centre of its geographical range. Assuming that the relative stress-gradient hypothesis is accurate, plants that occur near the centre of their geographic range are less likely to benefit strongly from facilitation because the physical conditions of the site are already likely to be close to their ideal growing conditions (Soliveres, et al. 2015, Soliveres & Maestre 2014). As a result, it would be reasonable to expect that twinberry does not require facilitative effects to buffer it from the abiotic conditions experienced at the site.

4.1.1. Twinberry Survival

Twinberry is adapted to moist soil and partial shade. Since the black cottonwood canopy at this location is fairly continuous and the forest is fairly thick, it seems likely that the conditions for twinberry survival existed without the need for facilitation by a shrub layer. There is evidence that the tree canopy of a forest is the dominant control of light and moisture levels for understory plants (Seiwa 1998) and can have a significant impact on the survival of seedlings (Comita et al. 2009).

The first year after planting is also the time when the plants are most likely to die. NATS Nursery suggested that a survival rate of 90% (or approximately 43 out of the 48 twinberry seedlings) should be expected. The fact that all the twinberries seedlings survived suggests that they are very well adapted to the local conditions and are appropriate to consider for riparian restoration plans in southwestern British Columbia.

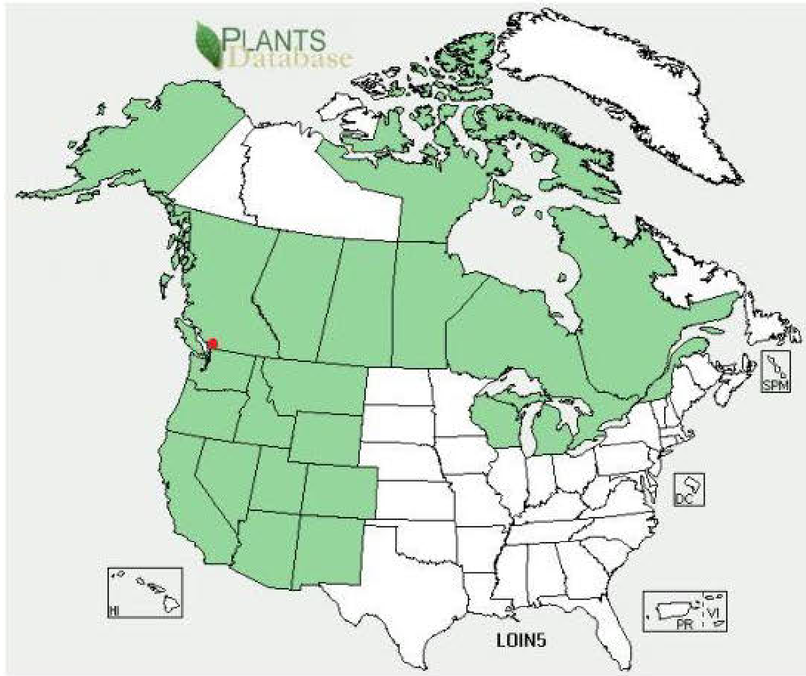

Figure 4.1. Range of black twinberry (*Lonicera involucrata*). The red dot indicates the location of my project. Darris 2011.

In years of more extreme physical conditions (drought, flooding, etc.), the additional protection provided by the shrub layer may have been more beneficial to the survival of twinberries. This is supported by studies such as Grant et al. 2014, Khan et al. 2014, and O'Brien et al. 2017, which found that nurse plants benefit facilitated plants most during periods of abnormal abiotic stress. Many studies of facilitation also span multiple years for the very purpose of incorporating this climatic variation (Castro et al. 2004).

4.1.2. Twinberry Growth

Twinberries planted in plots where the shrub layer was removed grew more than those in plots where it was not. This provides evidence that twinberry's ideal growing conditions were more closely met in the open plots than under the shrub layer.

Twinberry is tolerant of full sun, but grows best in partial shade (Darris 2011). Partial shade is non-specific term. The findings of this study would suggest that a shrub layer may provide too much shade, while a black cottonwood canopy may be more appropriate. In order to be confident in this conclusion, plots would have to be set up outside of the cottonwood canopy to test twinberry growth in full sun conditions.

Again, a longer study would be more likely to reveal significant differences in the treatments.

4.1.3. Twinberry Flowering

Only one twinberry flowered. The twinberry plug that flowered also grew the most of all the twinberry plugs in all treatments. It was in a plot where the shrub layer was removed. More flowering would be necessary to make any conclusions regarding treatment effect.

In conversation with NATS Nursery, it was indicated that flowering in the first year after planting is abnormal. However, when plugs are transplanted to pots in the nursery under ideal growing conditions, some are always expected to flower in the first year (pers. comm. 2018).

The triggering of flowering in plants is complex, but is generally the result of a combination of photoperiod and temperature, and inhibited by biotic stress, nutrient and water deficiencies, and extreme abiotic conditions (such as heat waves) (Cho et al. 2016). A relatively long-lived plant like twinberry requires fairly specific conditions before it will flower. If even one twinberry flowered in its first year after planting, it means that the conditions at the site meet its light and temperature requirements quite closely and that the plant experienced no unmanageable stress. It could also be the case that this individual twinberry happened to be surprisingly robust, as no information on the provenance of the plants was provided by NATS Nursery (i.e. whether all the seedlings came from the same stock).

This suggests that this area is a very good location in which to plant twinberry – a fact that should be considered when planning restoration plantings under similar conditions (i.e. riparian forests in southwestern British Columbia with intact black cottonwood canopies).

4.1.4. Twinberry Herbivory

Every seedling experienced some degree of herbivory. The major culprits were small grazers (caterpillars, snails, slugs, and beetles). This form of herbivory is evidenced by missing pieces of leaves, both on the edge and the centre of the leaf. Unfortunately, identifying herbivory more specifically usually depends on observing it happen. There was also a minor amount of leaf mining. Leaf miners can be moths, flies, sawflies or beetles. The degree of herbivory experienced by the twinberrie sin this experiment is counter to the findings of some similar studies (such as McAuliffe 1986) but agrees with others (such as Talamo 2015).

No twinberries died during the first season as a result of herbivory. Given the diversity of herbivory, it is possible that this is an indication of a well-functioning ecosystem with a healthy population of predators maintaining the herbivore populations at levels low enough to avoid eliminating any seedlings. This result may not be consistent at other sites where large herbivores are not excluded.

There was no difference in the rate of herbivory between the twinberries planted under a shrub layer and those with the shrub layer removed. This suggests that the shrub layer has no effect on the presence of these small herbivores.

4.2. Snowberry

Snowberry is found all across North America. British Columbia is very near the centre of its geographical range (Favorite & Moore 2008). This again suggests that it is unlikely to be near the edge of its range of tolerance of physical conditions, and therefore less likely to experience facilitation.

4.2.1. Snowberry Growth

Snowberry grew very little, regardless of treatment. This suggests that the change in conditions does not have a large impact on the growth of snowberry. There are a couple possible explanations for this result.

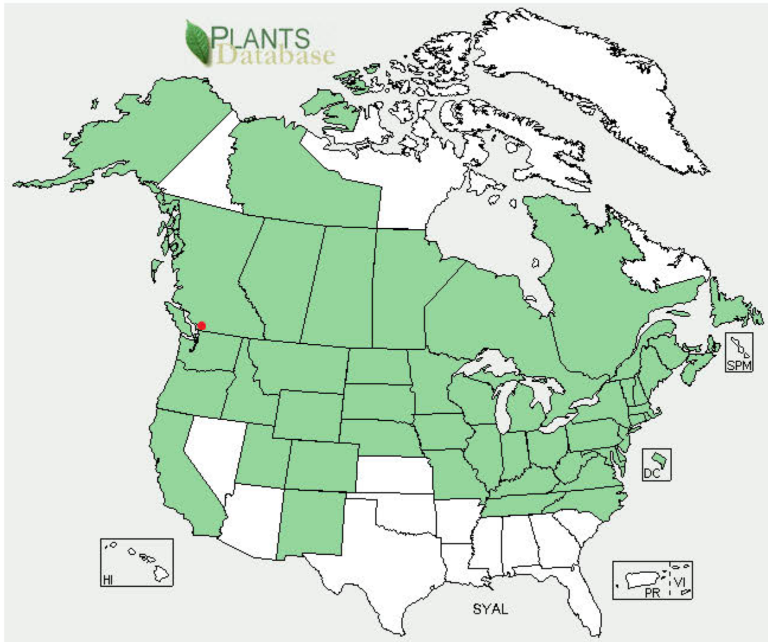

Figure 4.2. Range of common snowberry (*Symphoricarpos albus*). The red dot indicates the location of my study. Darris 2011.

The first is the timing of the study's observation period. Many plants in the southwestern British Columbia slow their growth during the dry summer months. Snowberries grow from late winter to early spring, and since observation of the snowberry did not being until May 31, much of the yearly growth may have already occurred (McWilliams 2000)

Salmonberry could be outcompeting snowberry for light. If the two plants began growing at the same time, but the conditions were more ideal for salmonberry, it could outgrow and overtop the snowberry. This may even be a sustainable relationship, since snowberry is also shade-tolerant, although this is only speculative.

An alternative explanation is that salmonberry may germinate and begin growing before or more quickly than snowberry. This could be explained if conditions immediately post-disturbance favour salmonberry growth. The conditions would then be changed as a result of the additional shading from salmonberry, which may encourage snowberry germination and growth. This facilitation may then become less important at later life stages, like those tested, leading to an increasingly competitive relationship between the two plants. This phenomenon of inconsistent facilitation is speculative in this case but has been observed in other plant-plant relationships (Holmgren et al. 1997).

4.2.2. Snowberry Number of Leaves

Snowberry branches lost slightly more leaves in Sal plots than in RemSal plots, although this difference was not statistically significant (p-value=0.2972). The majority of lost leaves were lost through herbivory. Some branches also grew new leaves, but never more than the leaves they lost.

Since the change in number of leaves of a branch can be used as an indicator of branch health, we might conclude that snowberry is not healthy at the CRWMA. However, this conclusion is likely to be heavily influenced by the timing of the observation. Branches did have leaf growth but all branches lost more leaves than they gained. Leaves were generally lost either through herbivory or as a result of a lack of water. Plants that go into slowed growth patterns during the dry summer months put less energy into producing new leaves. By not capturing the initial spring leaf growth, this result may be more skewed towards leaf loss than the plants actually experience and any conclusions drawn from this result should be considered very carefully.

4.2.3. Snowberry Flowers

The variation among the rates of flowering makes it difficult to draw any meaningful conclusions from the flowering rate of the snowberry. Overall, there is no significant difference between flowering among plants that were in plots where salmonberry was removed and those in plots where salmonberry was not removed.

As previously stated, flowering occurs according to appropriate photoperiod and temperature, as long as a lack of nutrients, biotic pressures or water stress don’t inhibit it. Since flowering occurred in all experimental zones, the conditions are likely to be appropriate across the whole site.

4.2.4. Snowberry Herbivory

There was no difference in the rate of herbivory on snowberry branches between plots with salmonberry and plots without. This suggests that salmonberry does not provide protection from herbivory for mature snowberry plants.

Again, the major herbivores were small grazers (caterpillars, beetles, slugs, and snails) and leaf miners (moths, flies, sawflies, and beetles).

Four snowberry branches died as a result of herbivory. All four were in the same experimental zone (zone 6), two in the RemSal plot and two in the Sal plot. There was no readily apparent explanation for this and it may have simply been the result of uneven distribution of herbivores at the site.

The death of snowberry branches by herbivory when twinberry seedlings did not die might suggest the influence of a favoured food source for these herbivores. More research would have to be done, but it may be that the planted twinberries experienced less herbivory because of locally abundant preferred food sources.

As with twinberry, these results may not hold true for areas where large herbivore browsing is not excluded.

4.3. Soil

There is very little difference in the soil conditions between the treatments. This could be the result of the black cottonwood canopy being the dominant factor in maintaining the soil conditions. Further studies that include soil conditions outside of the black cottonwood canopy would clarify this.

4.3.1. Soil Temperature

There was no significant difference in soil temperature between the experimental zones. Soil temperature in forests is generally maintained by the degree of solar radiation that reaches the soil and the temperature of the air at the soil surface (You et al. 2013). The lack of difference between treatments suggests that the continuous black cottonwood canopy is the dominant factor in maintaining soil temperatures. However, without soil temperature data from outside the canopy, this conclusion can not be made with confidence.

4.3.2. Soil Moisture

There was no significant difference in soil moisture across the different treatments. The results were within the normal range for riparian forests (James et al. 2003). This could suggest that, like with soil temperature, the black cottonwood canopy is the major factor in maintaining soil moisture on site. Without data from outside the canopy, this conclusion can not be made with confidence.

Again, this pattern would be further clarified by extending the length of the study. The opportunity to include data from years with varying weather would capture any changes in how important the shrub layer is in maintaining suitable growing conditions. This would be consistent with other findings on the variability of facilitation - notably Gomez-Aparicio et al. 2004.

4.3.3. Soil Electrical Conductivity

Soil electrical conductivity is a measure of the salt content of the soil. Normal values for non-saline soils range from 0.5 dS/m – 4.0 dS/m (Richards 1954). Almost all values fall within this range and no plot was consistently high. The one measurement above 4.0 dS/m also had a low outlier for soil moisture, meaning it is more likely the result of incidentally high local evaporation than the result of a treatment effect.

Chapter 5. Conclusions and Future studies

Facilitation is an important field of study for anyone interested in ecological restoration. It is important to understand the potential for using existing vegetation to aid in rebuilding an ecosystem. I conducted an experiment assessing the potential of a riparian ecosystem's shrub layer as a facilitative structure for twinberry and failed to detect any such effect. Likewise, the presence or absence of salmonberry did not seem to differentially affect established snowberry plants. There was no difference between the measured soil parameters between treatments – suggesting that other factors were dominant in creating and maintaining the abiotic conditions at the site. Plants that are near the edge of their geographic range are more likely to experience intolerable abiotic conditions (Maestre et al. 2009). Neither twinberry nor snowberry is close to the edge of their geographic range in southwestern British Columbia, which could explain the lack of observed facilitation. The relative stress-gradient hypothesis would suggest that this decreases the likelihood that they benefit from facilitation in these circumstances. It could also be the result of other biotic and abiotic factors – such as canopy cover by black cottonwoods.

To further understand the conditions necessary to maximize seedling survival in more highly disturbed sites, it would be helpful to conduct a study that included test plots outside of a natural forest ecosystem. Plots that contained the dominant shrubs but lacked the black cottonwood canopy would help determine if the canopy is a major factor in creating ideal growing conditions for these plants as well as assess the possibility of the shrubs providing partially beneficial conditions. While this may not be as applicable to the many restoration projects that are taking place in ecosystems with black cottonwood canopies, it could help expand the applicability of the research to more recently disturbed sites. Increasing the length of the study would allow for a much better comparison between climatic conditions. Expanding the study to include sites that experience browsing by large herbivores could help determine whether protection from herbivory by large mammals is a facilitative effect of salmonberry, or the shrub layer in general. This would be especially useful knowledge for the restoration of sites that, unlike the CRWMA, are visited frequently by large herbivores. Including a study of snowberry at the seedling stage would help clarify whether its interaction with salmonberry is consistent through all life stages. Finally - if logistics allow it - planting earlier in the season (February-March) would capture more of the relevant growing season since many plants grow much more slowly (or not at all) during the dry summer months.

Chapter 6. Restoration Plan for the Suwa'lkh School Forest

The following restoration plan has been created at the request of the Suwa'lkh School and Fresh Roots for the Suwa'lkh School Forest in Coquitlam. The results of the above study (See: Chapters 1-5) have been incorporated into the plan as much as possible. However, since facilitative effects have not been detected from the dominant shrub layer species, a more traditional planting plan has been recommended. The plan also addresses the site's dominant impacts (i.e. invasive plant species, stream bank erosion, and human activity) and includes plans for their mitigation, management, or reversal.

6.1. Introduction

Ecological restoration is the practice of aiding the recovery of an ecosystem that has been degraded, damaged or destroyed. The practice has come to prominence in the last 40 years with many community groups around the world working to restore their local ecosystems. One such group – composed of staff at Fresh Roots, and staff and students at the Coquitlam District School Board - is working to restore the urban Suwa'lkh School Forest.

This approximately 1 ha site in Coquitlam, B.C. has been the target of past ecological restoration activities. This past work has mainly focused on water quality, in-stream fish habitat enhancement, and associated riparian area plantings. Between 2000-2002, small woody debris was introduced (Fitzpatrick 2003). In 2009, Diamond Head Consulting Ltd. Installed large woody debris and conducted supplemental plantings (Diamond Head Consulting Ltd. 2009). Today, the site hosts a number of invasive species and is under active management to contain these species and improve the habitat for terrestrial organisms.

The site is currently used for recreational, cultural, and educational purposes. The site is part of traditional Kwikwetlem territory and provides the students of the Suwa'lkh School with direct cultural and educational experience. Enhancing the well-being of this urban forest ecosystem will further these opportunities.

This document will provide site information, suggestions for ongoing invasive species management, and planting plans that can be used to increase the health, resilience, and biodiversity of the ecosystem. Also included are an outline of a monitoring plan that can be used to judge the success of restoration interventions and a proposed budget designed to provide more information on the possible costs of the required materials for the proposed restoration plan.

6.2. Site Description

6.2.1. General

The Suwa'lkh School Forest (SSF) is located on the Suwa'lkh School property in Coquitlam, British Columbia (Figure 6.1). The forest is approximately one hectare in size and its geographic location is 49.239 N, -122.854 W. Como Creek runs though the site from a culvert in the northeastern corner to the southwestern corner where it passes off of the Suwa'lkh property. The Como Creek watershed is approximately 9 km^2 and includes Como Lake and Como Creek down to its confluence with the Fraser River (Adamah Consultants 2007). School District 43 (Coquitlam) owns the site and is the primary stakeholder for this project. Fresh Roots, the Galiano Conservancy, and the Como Watershed Group are also involved with the ongoing restoration of the site and associated projects. Involving the community, especially local First Nations, is a priority (M. Key, 2017, pers. comm.). As a result, Fresh Roots has taken on the active management of the SSF and a small greenhouse and nursery has been built on site to support these efforts.

6.2.2. Historical Conditions

The area was occupied by the Kwikwtlem First Nation for at least 9000 years. The area was used especially for trade between the Kwikwetlem, Tsleil-Waututh, Katzie, and Kwantlen First Nations (M. Key 2017, pers. comm.). Because of the abundant food sources, this site (and most riparian sites) were some of the most densely populated areas in North America. Since seasonal hunting and gathering was the primary source of food, the abundant and diverse plant and animal communities that used riparian areas

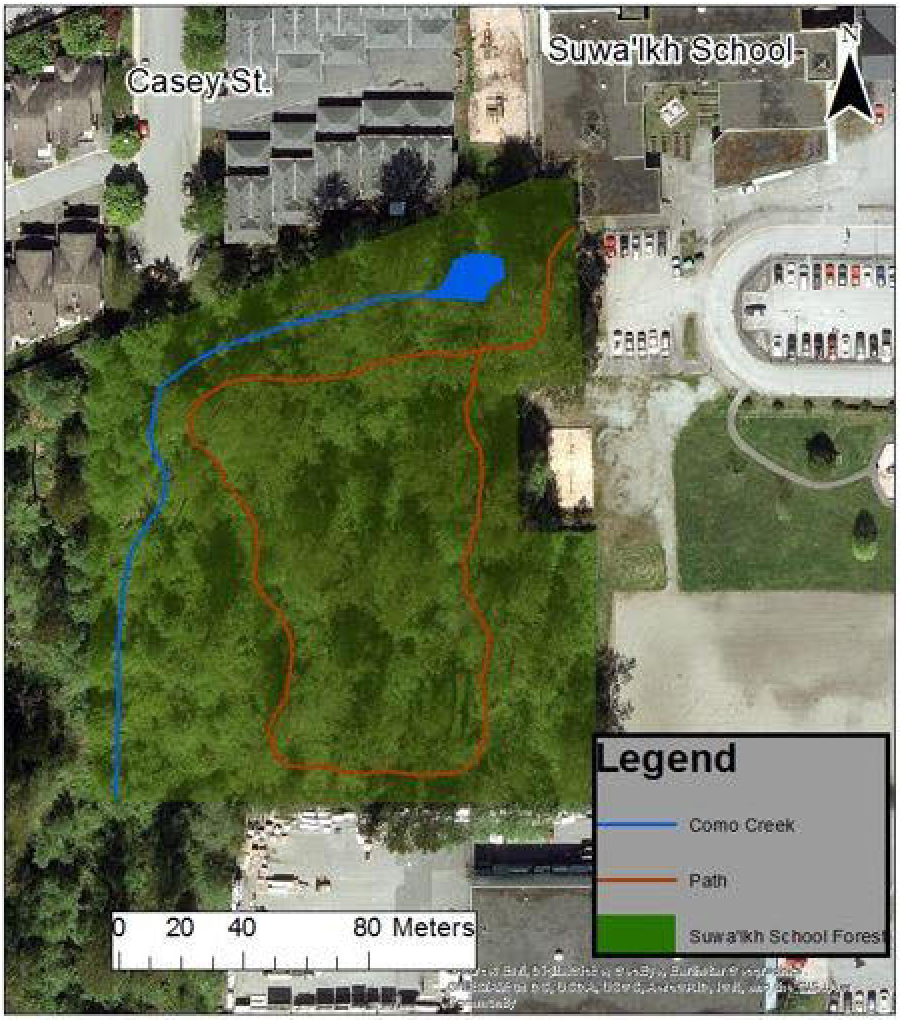

Figure 6.1. Aerial view of the Suwa'lkh School property, including the extent of the restoration site, Como Creek, and the path that has been created for access within the site.

made them especially important. This was even more true since riparian areas protect and support the stream habitats of the culturally important salmon species (Fraser Basin Council 2013). After colonization, the area was logged by the nearby Fraser Mills lumber mill. In the 1900s, Como Creek watershed underwent development to residential, commercial, and light industrial land use. Much of the length of Como Creek was straightened and culverted during this development (Chevalier 2003).

Historically, the SSF site would have been on the northern edge of the Fraser River floodplain. As part of the watershed's development, the Millside Elementary School was built on the site in 1907. The school was open until 2007, when it was closed due to declining enrollment and reopened as the Suwa'lkh School in 2012 (Strandberg 2014).

6.2.3. Topography

The site is generally flat. There is only a very slight decline towards the southwest corner of the site. Its elevation is approximately 11 m.a.s.l. The microtopography of the site is fairly complex. Different vegetation types trap sediments differently during the flood season and produce organic matter at different rates, leading to variable soil depths. Proximity to the stream and vegetation cover also influences the soil lost to erosion during the flooding season.

6.2.4. Soil

The soils of this site were historically Ladner Clays (Soil Survey Branch 1938). They are alluvial deposits from the Fraser River, and to a lesser extent, Como Creek. The deposition and decomposition of biological material from the forest on this site has led to a developed organic soil layer on top of the clays. The soils are nutrient-rich, and moist to wet depending on the time of year and recent precipitation or flooding events.

The creek substrate is mostly gravel and cobble with siltier depositions where the water flow slows around sharp bends.

6.2.5. Hydrology

Como creek runs through the site, entering at the culvert and leaving at the southwestern corner. It runs east to west before turning southwest, and eventually south towards Lucille Star Way.

Como creek floods the site regularly. This flooding disturbance regime is essential for maintaining the state of the ecosystem. Without it, conifers are likely to colonize this site (Green & Klinka 1994). The stream gradient is roughly 5 percent

The water table is very often near or at the surface of these sites. These areas can be identified by the change in vegetation.

6.2.6. Vegetation

The BEC site series for the Suwa'lkh School Forest is CWHdm08-10 (Government of British Columbia 2018). These sites series represent the riparian variants of the Coastal Western Hemlock forest and are dominated by a canopy of black cottonwood (*Populus trichocarpa*) trees. Conifers are found more frequently at slightly higher elevation microsites while water-loving plants like willows and sedges are found at microsites that are slightly lower (often, but not always, closer to the stream). This differentiation is what separates the specific site series (CWhdm10 for high bench sites and CWHdm08 or low bench sites). Red alders (*Alnus rubra*) are a dominant first colonizer on these sites, and an important nitrogen fixer. The shrub layer is characteristically dominated by salmonberries (*Rubus spectabilis*), with other shrubs such as red osier dogwood (*Cornus stolonifera*), black twinberry (*Lonicera involucrata*), thimbleberry (*Rubus parviflorus*), snowberry (*Symphoricarpos albus*), and red elderberry (*Sambucus racemosa*) also being common (Teversham & Slaymaker 1976, Mackenzie & Moran 2004).

6.2.7. Wildlife

While it is uncommon for large animals to take up residence in highly ecologically degraded urban areas, the fragmented urban forest ecosystems within these landscapes still play an important role in their survival. Many animals use these ecosystems as transit corridors, as well as critical food sources (Zabel & Anthony 2003). Many of the dominant shrubs are fruit-bearing and support native fructivores (Waterhouse & Harestad 1999).

A surprisingly large diversity of animals has been observed at this site, given its size and landscape. Birds include red-tailed hawk (*Buteo jamaicensis*), black capped chickadee (*Poecile atricapillus*), red-winged blackbird (*Agelaius phoeniceus*), (Olsen 2002) Anna's hummingbird (*Calypte anna*), great blue heron (*Ardea Herodias*) (K. MacCallum 2018 pers. obs.), bald eagle (*Haliaeetus leucocephalus*), barred owl (*Strix varia*) (G. Orion 2018 pers. comm.). Aquatic species include western brook lamprey (*Lampetra richardsoni*), coho salmon (*Oncorhynchus kisutch*), chinook salmon (*Oncorhynchus tshawytscha*), chum Salmon (*Onchorhynchus keta*), cutthroat trout (*Oncorhynchus clarkii*) (J olsen), largescale sucker (*Catostomus macrocheilus*), northern pikeminnow

(*Ptychocheilus oregonensis*), three-spined stickleback (*Gasterosteus aculeatus*) (Diamond Head Consulting Ltd. 2009). The observed presence of apex predators - both aquatic and terrestrial – suggests that this site supports prey species (such as small mammals and aquatic invertebrates) and is valuable habitat within its landscape.

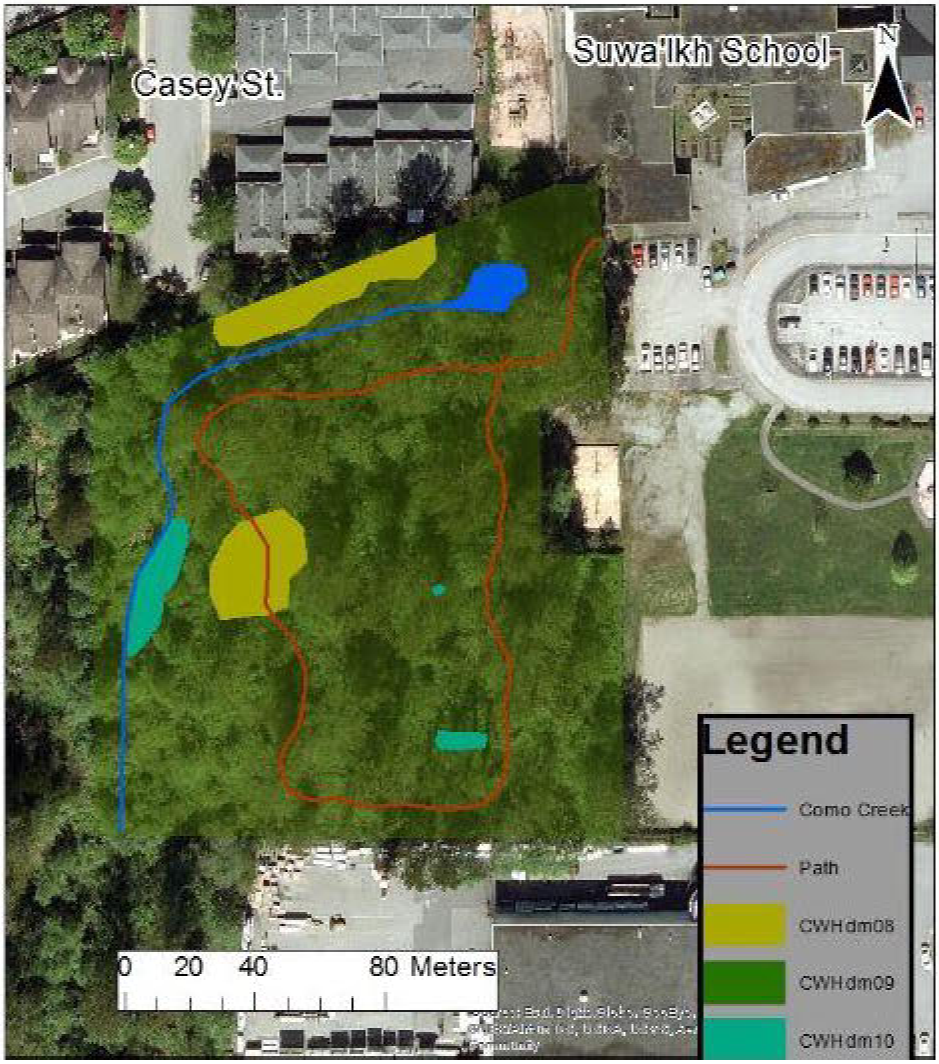

Figure 6.2. Outline of BEC Site Series found at the Suwa'lkh School Forest.

6.2.8. Invasive Species

Invasive plant species management is one of the biggest challenges currently facing the SSF. Invasive plant species observed at the site include: Himalayan blackberry (*Rubus armeniacus*), knotweed (*Fallopia spp.*), English ivy (*Hedera helix*), English holly (*Ilex aquifolium*), and yellow archangel (*Lamiastrum galeobdolon*).

Himalayan blackberry is a known colonizer of disturbed sites (including flooded riparian areas). Its canes can grow over 10 m long and are covered in prickly spines, making removal harmful without proper protective equipment. Blackberry is tolerant of a large range of soils conditions and reproduces both through seed and vegetatively through the spread of stem fragments. If left unmanaged, it can smother and outcompete native vegetation. It forms impenetrable thickets that can block natural animal movement. Its shallow root system does little to prevent erosion but does make it easier to remove manually (ISCBC 2014).

There are currently four different invasive knotweed species in British Columbia. Three are of the *Fallopia* genus and one is of the *Polygonum* genus. They vary slightly in appearance but are ecologically similar and are known to hybridize. They grow quickly and form impenetrable monocultures that outcompete native vegetation. Most are sterile but they all reproduce very easily from small fragments (as little as 0.7 grams) of root or stem. As a rhizomatous plant, it can be difficult to effectively treat or remove. Knotweed is able to grow through concrete, making it a threat to infrastructure (ISCBC 2017a).

English ivy grows as a vine or small shrub. It shades and smothers native plants of all sizes and can lead to an 'ivy desert' if left untreated long enough (Okerman 2000). It grows well in almost any conditions but does best in moist forests. It climbs existing vegetation to gain access to increased sunlight. When it begins to get enough, it changes growth forms and sends out reproductive limbs which flower and seed. Its seeds are eaten infrequently by native birds but regularly by the invasive european starling (*Sturnus vulgaris*) – which contributes to its spread. It can also reproduce vegetatively from fragments of pre-existing plants, making proper disposal essential. English ivy can also damage infrastructure. Luckily, its shallow root system makes it relatively easy to remove and control (ISCBC 2017b).

English holly grows as a large shrub or tree, up to 10 m tall, and casts deep shade which can prevent the establishment and growth of native species. It consumes large amounts of water to the detriment of native species. Its leaves are thick and glossy, making them resistant to treatment by herbicide. They are also spiny and sharp, making removal potentially harmful without proper protective equipment. It can spread both vegetatively and from seed (ISCBC 2018).

Yellow archangel prefers shady, rich forests but can also survive environmental extremes. It can grow very quickly, making early detection and management essential. However, it has a shallow root system, making manual removal easy. It reproduces by vegetatively and from seed (ISCBC 2017c).

6.2.9. Site Stressors

Human use is the largest current stressor on the site. Students from the school and the general public both access the site on a regular basis. This can introduce (or reintroduce) invasive species and cause disturbance to the site.

The disturbance caused by the students themselves is not of particular concern to the ecological integrity of the site. Students generally stick to the paths when not engaging in ecological restoration activities. The sense of stewardship among the students towards the forest also supports this positive relationship.

Of greater concern is the use of the forest by the public. People bring their dogs to swim in the pool, litter, set temporary camps, and dump plant matter. These activities are vectors for invasive species (as shown by the invasion of yellow archangel in the northern section of the forest) as well as the introduction of litter and the general degradation of the site.

Contaminants and excess nutrients from upstream in Como Creek could also be impacting the site. This stressor is likely to affect the site in discrete, damaging events (such as the 2007 styrene spill). If the long-term conditions have not significantly changed since 2003, it's possible that the site still has relatively good water quality (Chevalier 2003).

6.2.10. Recent Restoration Activities

Many of the restoration activities in southwestern British Columbia have focused on riparian areas – often the site of relatively intact forests in otherwise heavily developed landscapes. In 1993, British Columbia's Coastal Fisheries/Forestry

Guidelines required retention of trees on coastal streams. The Forest Practices Code (implemented in 1995) legislated riparian buffer zones. These were put in place largely because of the realization of the role that functioning riparian forests play in maintaining fish stocks. Since then, a great deal of effort has been put into the restoration of these areas (Poulin et al. 2000).

Restoration work has been done in the past in the SSF. The most notable was the in-stream river habitat enhancement that took place in 2009. Several pieces of large woody debris were introduced to the stream, riffles were created, and the banks were stabilized with riparian plantings (Diamond Head Consulting Ltd. 2009). In addition, ongoing invasive species management has taken place at the site (M. Key 2017 pers. comm.).

6.3. Restoration Goal and Objectives

Goal 1: To restore the Suwa'lkh School Forest to a state of high ecological value and function.

Objective 1: To remove the invasive species (Himalayan blackberry, knotweed, English ivy, English holly, and yellow archangel) from the site.

Objective 2: To plant supplemental plants in order to mitigate the risk of invasion by invasive species, increase species and habitat diversity, and support the stabilization of the creek banks.

Objective 3: To control or mitigate the impacts of the use of the forest by the public.

6.4. Restoration Strategy and Implementation Plan

The restoration strategy for this site focuses on the removal of invasive plant species and their replacement with a native plant community. This focus is accomplishable with even a fairly small group of dedicated volunteers but the work still needs to be conducted with care and monitored frequently in order to be effective. This is especially true along the stream bank where there is a high risk of erosion.

It is highly recommended that this plan be implemented in stages. Target an area of the forest, remove all the invasive species and follow up quickly with supplementary planting and seeding. This will also allow for the effective use of volunteers in invasive species removal and supplementary planting. This will also enable the Suwa'lkh School nursery to contribute as much as possible to the plants used in the supplemental planting, which will minimize the cost of the plant material. Smaller areas can be left unplanted in order to assess the composition of the seedbank as long as preparations are made to remove the strong regrowth of invasive species that is likely to happen.

6.4.1. Invasive Species Management Plans

The Invasive Species Council of British Columbia has produced a number of Best Management Practice (BMP) documents for local invasive species. Where possible, these documents should be referred to for greater detail on the management of these invasive species. Removing invasive plant species in the short term will prevent them from becoming more established at the site and causing more harm to native species. It will also reduce the effort required to permanently remove the species from the site.

Himalayan Blackberry

Himalayan blackberry is prevalent across the site. Particularly large patches are marked on the map below (Figure 6.4).

Because of its shallow roots, hand-pulling is one of the most effective treatments for the management of Himalayan blackberry (ISCBC 2014). Appropriate protection is essential since Himalayan blackberry's thorns can cause deep cuts. Cutting and removing the Himalayan blackberry's canes first is recommended since it will allow better access to the plant's roots. When hand-pulling Himalayan blackberry, try to remove as much of the root material as possible; root fragments can resprout. Multiple treatments will almost certainly be necessary (ISCBC 2014; Gaire et al. 2015). There is probably an established seedbank of Himalayan blackberry on the site and removal of all root fragments during the first treatment is unlikely. Based on previous experience removing Himalayan blackberry on this site, it is estimated that it will take approximately 80 work hours to do the initial removal for the whole site by hand-pulling. Follow up treatment and monitoring should be done at least once every six months and will require much less time.

Figure 6.3 Himalayan blackberry thicket. ISCBC 2014

Mowing is another potentially effective treatment (ISCBC 2014; Gaire et al. 2015). It requires much less time than hand-pulling. It also requires a lot more equipment and expertise, and increases the risk of unintentional damage to neighbouring desirable plants. Greater care must be taken to remove all plant fragments from mowing equipment in order to prevent the spread of the species. Given the riparian nature of the site, the high public access, and the concerns of the stakeholders, herbicide use is not recommended for this site. Biological controls are not available for Himalayan blackberry.

Knotweed

Only one small patch of knotweed has been observed on site. It has been marked on the map below (Figure 6.5).

If left untreated, knotweed can form dense thickets (Figure 6.6) (ISCBC 2017b). Hand-pulling should be conducted with great care. Given knotweed’s rhizomatous nature, it can take many years of hand-pulling to exhaust the plant (Clements et al. 2017). As much of the rhizomes should be removed as possible. The removed material (stems and rhizomes) should be stored where it is not in contact with the ground since it

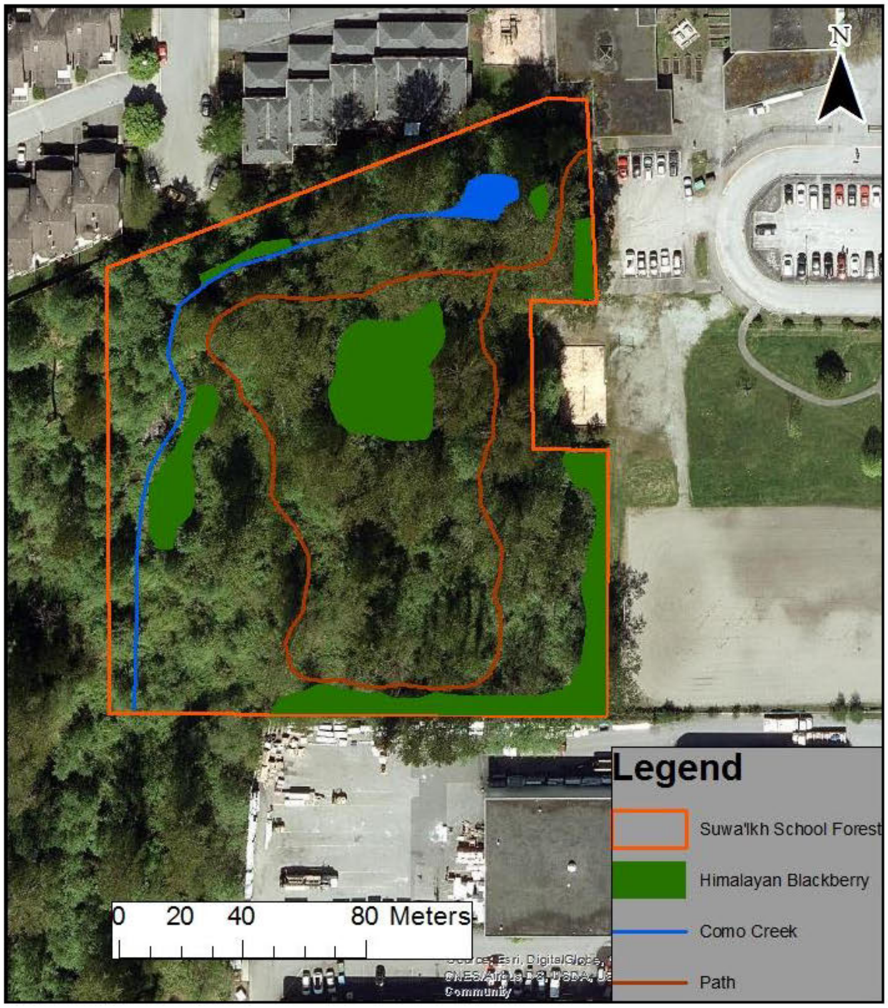

Figure 6.4 Extent of the largest patches of Himalayan blackberry (Rubus armeniacus) in the Suwa'lkh School Forest

can reroot very easily (ISCBC 2017b). A first treatment has already been conducted. The area (i.e. the site of the original patch and a 3 m radius around the original patch)

should be monitored for regrowth at least once every six months. This can be done visually and should not take much work.

Mechanical removal is not recommended. The risk of spreading root and stem fragments is very high. In addition, most mechanical removal treatments (ex. mowing, weed-whacking) only remove above-ground biomass, which encourages regrowth and underground rhizomatous spreading (Clements et al. 2017; ISCBC 2017b).

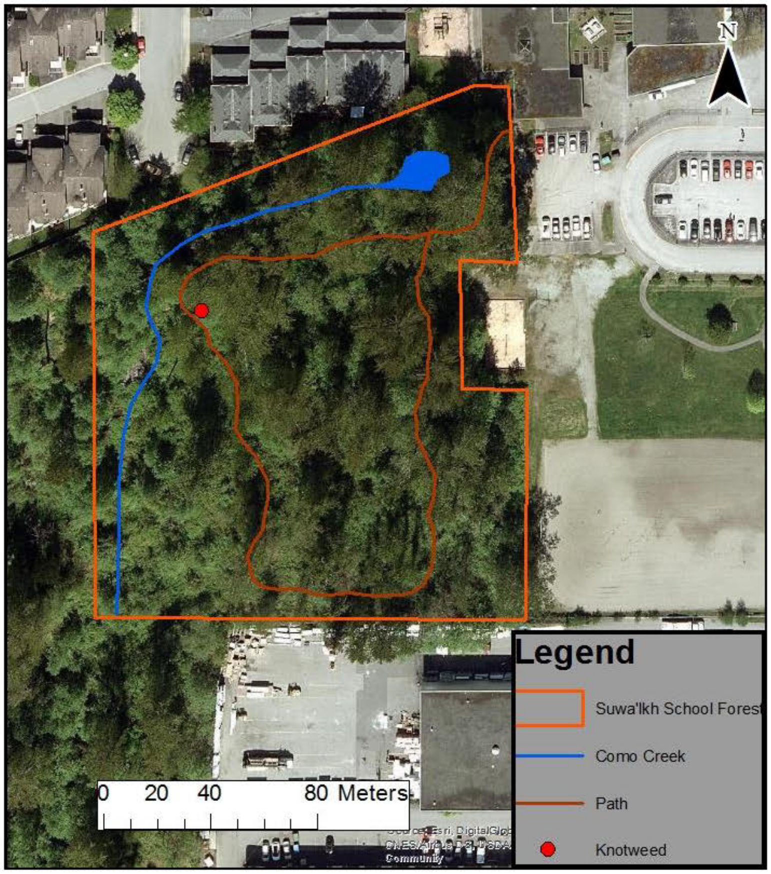

Figure 6.5. Location of the patch of knotweed (*Fallopia spp.*) found in the Suwa'lkh School Forest.

Figure 6.6. Knotweed thicket. ISCBC 2017.

Given the riparian nature of the site, the high public access, and the concerns of the stakeholders, herbicide use is not recommended for this site. Biological controls are not currently available for knotweed.

English Ivy

English ivy is mainly present on the northern and eastern sides of the site. Particularly large patches have been marked on the map below (Figure 6.7).

English ivy (Figure 6.8) has a very shallow root system and can easily be hand-pulled (Young et al. 2012; ISCBC 2017a). Some people report a rash as a result of skin contact with English ivy, so gloves should be worn. Ivy that has climbed a tree can be cut at chest height and the bottom section pulled away from the tree. The ivy remaining in the tree should die within a couple weeks. In order to prevent rerooting, ivy should be stored where it can not come in contact with the ground (ISCBC 2017a). Removing the English ivy from this site should take approximately 40 work hours. Monitoring should be done at least once every six months to prevent reestablishment.

Mechanical removal is less likely to be effective than hand-pulling. Mechanical removal increases the risk of spreading root and stem fragments that can reroot (ISCBC 2017a).

Given the concentration required to kill English ivy, the riparian nature of the site, the high public access, and the concerns of the stakeholders, herbicide use is not recommended for this site. Biological controls are not available for English ivy.

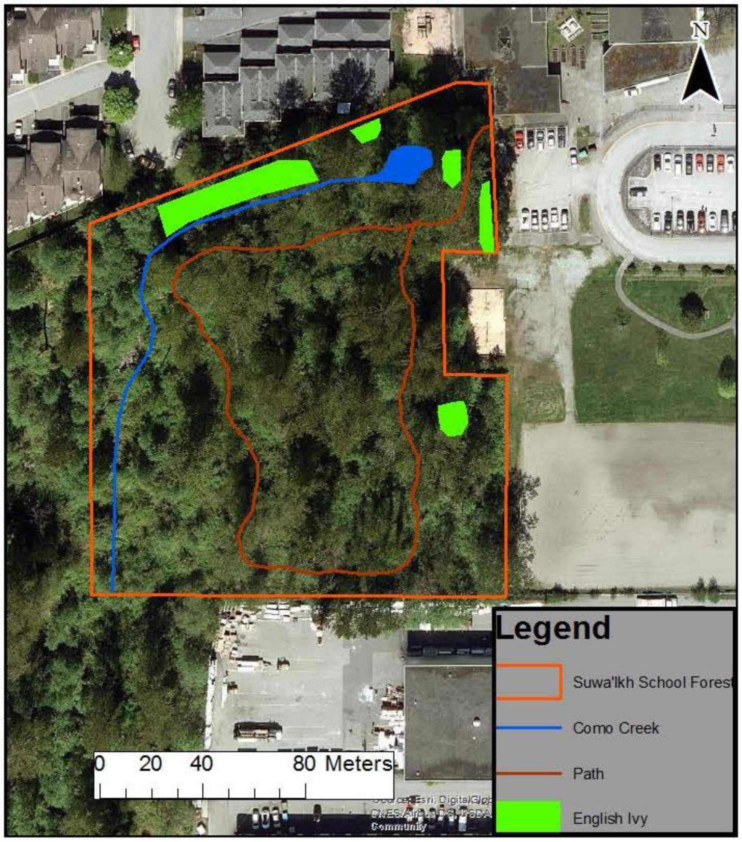

Figure 6.7. Extent of the largest patches of English ivy (*Hedera helix*) in the Suwa'lkh School Forest.

Figure 6.8. English ivy. ISCBC 2017.

English Holly

English holly has established in small patches throughout the site (Figure 6.10). Some of the major patches have been indicated on the map below, but a thorough sweep of the whole site should be done to prevent missing plants. Many of the English holly plants on this site are young seedlings, making them more difficult to find and remove. Because of their tendency to be spread by birds, holly trees should be treated before they produce fruit, as much as possible (Figure 6.10) (Zika 2010).

English holly has sharp and spiny leaves. This can cause harm when removing English holly by hand – appropriate safety gear should be worn. Small holly seedlings can be removed effectively by hand. This is best done during the winter when most native vegetation has lost its leaves, making holly easier to find from a distance (ISCBC 2018).

Figure 6.9. English holly with fruit. ISCBC 2018.

Larger holly trees can be ringbarked (Figure 6.11). This involves removing a ring of the inner bark of the holly tree. Herbicide can be carefully applied immediately after ringbarking to increase the effectiveness of the treatment. Holly is notorious for producing suckers (small shoots growing from the root system) when its main stem is compromised. Any tree that has been ringbarked should be monitored for suckers. These can be removed and herbicide can be reapplied. Larger, healthier trees may require repeated treatments to be managed effectively. There are no known biological controls for English holly (ISCBC 2018).

Given the extent of English holly on the site, it is estimated that at least 40 work hours will be required to remove this species. Since it is likely to regrow and to be present in the seedbank, monitoring should be done at least once every six months.

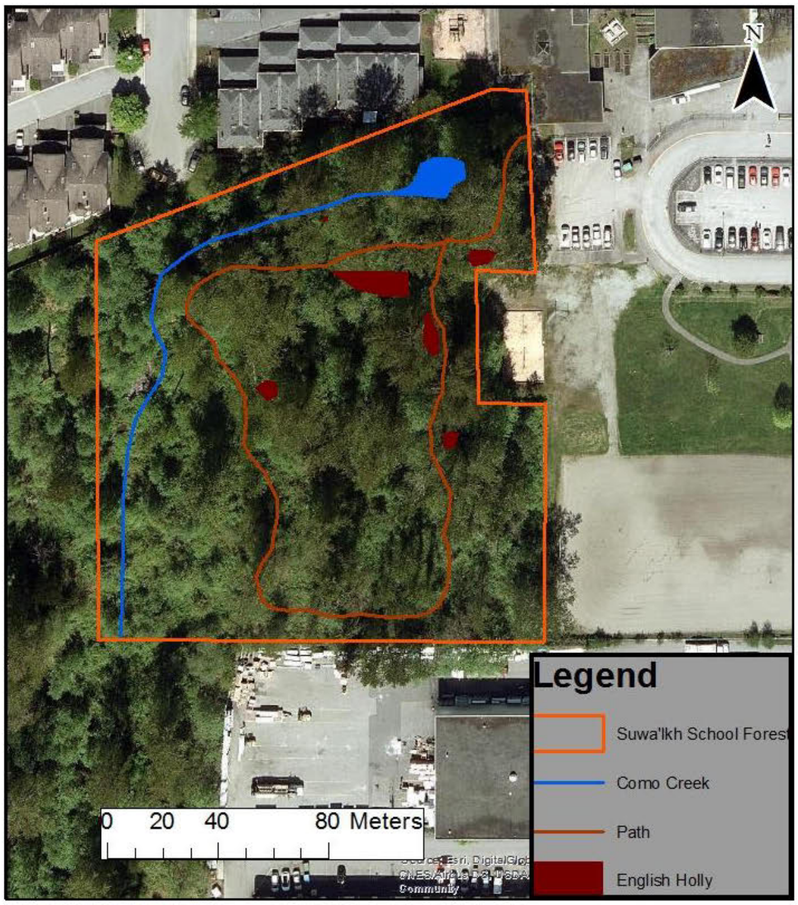

Figure 6.10. Extent of the largest patches of English holly (*Ilex aquifolium*) in the Suwa'lkh School Forest.

Figure 6.11. Girdled English holly tree. Nickelson 2014.

Yellow archangel

Two small patches of yellow archangel have been found on the site (Figure 6.12). They are both on the north side of Como Creek. They are marked on the map below (Figure 6.13).

Figure 6.12. Yellow archangel. ISCBC 2017.

Hand-pulling is the best choice for yellow archangel (ISCBC 2017c, Peace River Regional District 2017). It has a shallow root system that can easily be removed by hand. It does reroot, but can be easily managed with repeated treatments. As much of the root system as possible should be removed with the plant. Removed material should be stored where it will not be in contact with the ground to prevent rerooting (ISCBC 2017c). Given the limited extent of the species on this site, removal is only estimated to take 2 work hours.

Mechanical removal is unnecessary for such a small infestation and would increase the risk of spreading the species. Herbicide application is not recommended since the patches are in riparian areas. There are no known biological controls for yellow archangel (ISCBC 2017c).

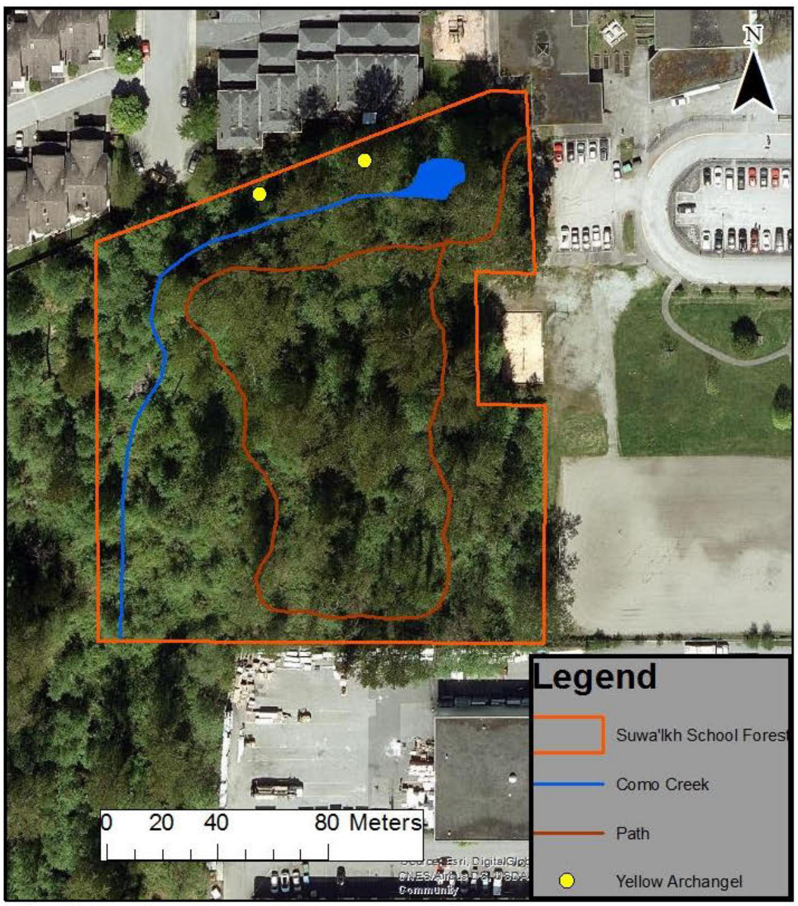

Figure 6.13. Location of the two patches of yellow archangel (*Lamiastrum galeobdolon*) in the Suwa'lkh School Forest.

6.4.2. Revegetation Plan

Revegetation Following Invasive Species Removal

All areas where invasive species are removed should be planted with native species. This can help prevent reinvasion of the now-disturbed area. When planting is done, it should include a variety of species and ages (i.e. seeds, seedlings, adult plants). This will minimize the risk of single-species or single-age stands of species developing, and will increase the diversity of available habitats. The structural diversity this practice introduces can also make the site more resilient to a range of disturbance types (large plants may be more susceptible to strong winds, while seedlings may be more susceptible to drought).

Variation among cleared areas should be accommodated – some areas will be too small to support as large a diversity of plants as others and this should not be cause for concern. In addition, some areas are wetter or drier than others and the planting list should be adjusted to reflect this. For this reason, a general list of appropriate species has been compiled for use by the relevant stakeholders (Table 6.1). Subsets of this list should be selected based on the conditions of the cleared area and availability of plants.

Seeding with a native seed mix is also recommended. The soil seedbank in the Suwa'lkh School Forest is very likely to have a strong presence of invasive species. Seeding can help combat this problem and introduce other native species that will establish quickly. However, species composition in commercial seed mixes should be carefully evaluated before purchase and use. They often consist of blends that include non-native agronomic species, such as alfalfa, which are not desirable. Seeds collected on site or propagated from the Suwa'lkh School nursery would be ideal for inclusion in these seed mixes.

It is estimated that it will take approximately 80 work hours to complete all the replanting of the areas where invasive species are removed. This includes the riparian stabilization-specific planting detailed below (Table 3).

Table 6.1. Plant species characteristic of Coastal Western Hemlock CWHdm08-10 sites suggested to be included in revegetation of the Suwa'lkh School Forest.

Site Series	Life Form	Species Name	Common Name	Shade Tolerant	Suggested Planting Size
CWHdm08	Tree	*Alnus rubra*	Red alder	Needs sun	1 gal
	Tree	*Populus trichocarpa*	Black cottonwood	Needs sun	1 gal
	Tree	*Thuja plicata*	Western redcedar	Yes	1 gal
	Tree	*Acer macrophyllum*	Bigleaf maple	Yes	1 gal
	Shrub	*Rubus spectabilis*	Salmonberry	Sun or shade	Plugs
	Shrub	*Sambucus racemosa*	Red elderberry	Sun or shade	Plugs
	Shrub	*Oplopanax horridus*	Devil's club	-	Plugs
	Shrub	*Symphoricarpos albus*	Common snowberry	Sun or shade	Plugs
	Herb/Fern	*Polystichum munitum*	Sword fern	Yes	Plugs
	Herb/Fern	*Tolmiea menziesii*	Piggy-back plant	-	Plugs
	Herb/Fern	*Smilacina stellata*	Star-flowered false Solomon's-seal	-	Plugs
	Herb/Fern	*Athyrium filix-femina*	Lady fern	Yes	Plugs
CWHdm09	Tree	*Alnus rubra*	Red alder	Needs sun	1 gal
	Tree	*Populus trichocarpa*	Black cottonwood	Needs sun	1 gal
	Tree	*Acer macrophyllum*	Bigleaf maple	Yes	1 gal
	Shrub	*Rubus spectabilis*	Salmonberry	Sun or shade	Plugs
	Shrub	*Sambucus racemosa*	Red elderberry	Sun or shade	Plugs
	Shrub	*Oplopanax horridus*	Devil's club	-	Plugs
	Shrub	*Lonicera involucrata*	Black twinberry	Sun or shade	Plugs
	Shrub	*Symphoricarpos albus*	Common snowberry	Sun or shade	Plugs

Site Series	Life Form	Species Name	Common Name	Shade Tolerant	Planting Size
CWHdm09	Shrub	*Cornus sericea*	Red osier dogwood	Sun	Plugs
	Herb/Fern	*Athyrium filix-femina*	Lady fern	Yes	Plugs
CWHdm10	Tree	*Alnus rubra*	Red alder	Needs sun	1 gal
	Tree	*Populus trichocarpa*	Black cottonwood	Needs sun	1 gal
	Shrub	*Rubus spectabilis*	Salmonberry	Sun or shade	Plugs
	Shrub	*Oplopanax horridus*	Devil's club	-	Plugs
	Shrub	*Salix lucida*	Pacific willow	Full sun to partial shade	Plugs
	Shrub	*Cornus sericea*	Red osier dogwood	Needs sun	Plugs
	Herb/Fern	*Carex obnupta*	Slough sedge	Needs sun	Plugs

Trees and shrubs should be clustered, as much as possible, with herbs/ferns filling the open spaces between the clusters. If a seed mix is used, it should be spread as evenly as possible after the rest of the planting has been completed.

Trees and shrubs should be planted at least 2 m apart. Shrubs could be planted at a density of up to approx. 1 plant/m^2. Herbs/ferns should be planted at a density of 4 plants/m^2. Below is a planting schematic that shows an example of what a clustered planting design could look like. This plan is not intended to prescribe exact planting locations, but as a general guide to help demonstrate clustering and spacing.

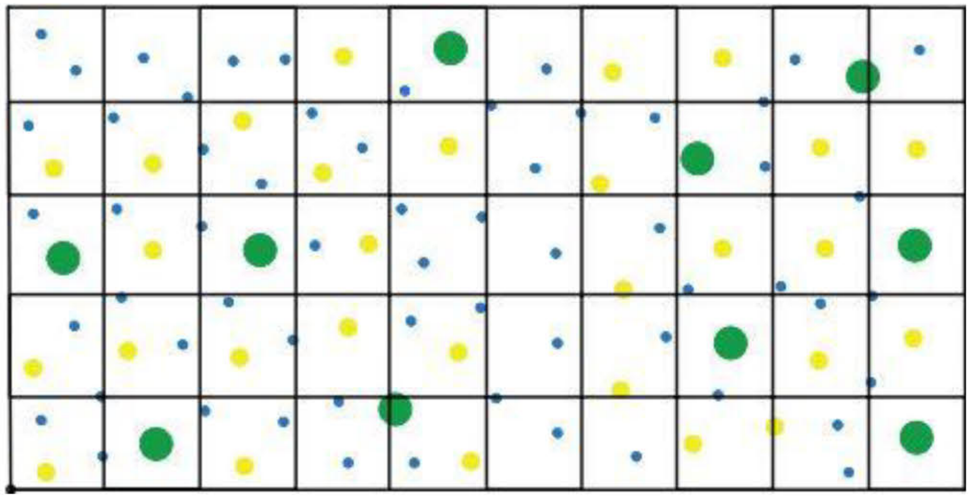

Figure 6.14. Potential 10 m x 5 m planting matrix design for general us at the Suwa'lkh School Forest.

Revegetation for Riparian Area Stabilization

Special consideration should be given when replanting riparian areas. The invasive species found on this site tend to have shallow root systems, making them unhelpful in limiting erosion during flooding. When they are removed, erosion will be even more of a risk. Plants should be ready to be planted as soon as possible after the removal of the invasive species. Focus should be given to plants that grow deep, erosion-resistant roots.

Fascines are an effective tool for controlling the erosion of stream banks (Figure 6.15) (Evette et al. 2009). Woody species that grow well from cuttings (e.g. red osier dogwood, pacific willow) are selected and bound into bundles. This woody material can be collected easily from the Suwa'lkh School Forest. These bundles are embedded into the streambank and secured with live stakes. Fascines establish quickly and will help reduce the effect of erosion during flooding (Figure 6.16) (Richet et al. 2017).

Figure 6.15. An example of the installation of a fascine. Short Hills Provincial Park, Ontario, Canada. Ian Smith 2018.

Figure 6.16. An example of a fascine/live crib wall two years post-installation. dogwood/willow fascine was installed on the right hand stream bank. Ian Smith 2013.

Soil treatments can be added to the site to minimize the risk of erosion during the early stages after planting. Straw, leaf litter, or wood chips can be used to cover exposed ground as well as protecting, and providing additional nutrients for recently planted seedlings (Fernandez & Vega 2014).

Extra care needs to be taken during riparian zone planting to make sure that the bank is not further destabilized by planting activities. Rivers are also vectors for the spread of invasive species. The planting should be conducted with clean equipment, separately from invasive species management work, to minimize the risk of spread.

Table 6.2. Plant species characteristic of Coastal Western Hemlock CWHdm10 riparian sites suggested to be included in revegetation of the Suwa'lkh School Forest.

Life Form	Species	Common Name	Shade Tolerance	Planting size
Tree	*Alnus rubra*	Red alder	Needs sun	1 gal
Tree	*Populus trichocarpa*	Black cottonwood	Needs sun	1 gal
Shrub	*Rubus spectabilis*	Salmonberry	Sun or shade	Plugs
Shrub	*Oplopanax horridus*	Devil's club	-	Plugs
Shrub	*Salix lucida*	Pacific willow	Full sun to partial shade	Plugs
Shrub	*Cornus sericea*	Red osier dogwood	Needs sun	Plugs
Herb/Fern	*Carex obnupta*	Slough sedge	Needs sun	Plugs

6.4.3. Public Use Mitigation Plan

Members of the public use the forest in a variety of ways that can lead to its ecological degradation. People leave behind litter, let their dogs of leash to swim in the pond, set up temporary camps, and dump plant matter.

Education can be an effective tool in influencing public actions. Posting a sign near the gate stating: “Ecologically sensitive area – please stay on trails and keep dogs on leash” or something similar, would be an effective start. Adding information concerning the restoration activities being conducted at the site can help engage the public and gain support for the requests.

Engaging with local landholders can help minimize the dumping of plants. The Invasive Species Council of Metro Vancouver specializes in public education concerning invasive species and would be excellent support in effectively discussing concerns over plant material dumping with local landholders.

6.5. Monitoring Plan

After removing invasive species from an area, that area should be monitored in order to be aware of any reinvasion. Monitoring should take place at least twice a year (four times is recommended) at any site where invasive species have been removed. A thorough sweep of the area should be done by a person experienced in identifying young plants of the relevant invasive species. Any plants found should be removed as soon as possible, following the procedures describer in Section 6.4. Restoration Strategy and Implementation. Monitoring should be conducted continuously until no more new invasive plants are observed for at least three consecutive years.

Once a year, the entire site should be assessed for any new points of invasion. March-April would be the ideal time for this monitoring to match the early emergence of the invasive seedlings. This should be done by someone who can identify all growth forms of the known invasive species in southwestern British Columbia. It is recommended that the Invasive Species Council of Metro Vancouver or the Invasive Species Council of British Columbia be contacted if assistance of expertise is needed.

6.6. Budget

The following budget is an estimate of the costs involved in this restoration project. Because of the nature of the project, most (possibly all) of the labour can be accomplished by volunteers. This is likely preferable as it will help since it will also help accomplish the goal of creating opportunities for Suwa’lkh students to reconnect with their landscape. Many of the plants will be able to be propagated and grown in the Suwa’lkh Nursery. If a multiple stage approach is taken, the cost of purchasing plants during each stage could be relatively minimal.

Table 6.3. Estimated Budget for Restoration of Suwa'lkh School Forest.

Item	Quantity	Cost per unit ($)	Total ($)
Plants (1 gal)	1500	7	10500
Plants (plugs)	6000	1.5	9000
Labour (Invasive Species Management) (hours)	162	20	3240
Labour (Planting) (hours)	80	20	1600
Labour (Monitoring) (hours per year)	32	20	640
Total			24980

6.7. Conclusion

The restoration of the Suwa'lkh School Forest is an ongoing process that continues to achieve positive results. The main issues that require continued focus are the removal and management of invasive species, and the reintroduction of native species. Luckily, many of the invasive species on site are known to respond well to management. Attention to detail during removal and consistent monitoring will be needed to prevent regrowth. Supplemental planting will increase structural and species diversity on site, which will help reduce the risk of reinvasion by invasive species. Given the findings of the associated study (see Chapters 1-5), shrub cover is unlikely to be an important consideration for the success of the plantings. With continued care, the Suwa'lkh School Forest will continue to support an impressive diversity of plant and animal species, for the benefit of the students at the Suwa'lkh School and the community at large.

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Appendix A: R Code

```
setwd("~/Ecological Restoration/MSc/ARP/Report/R Data")
#Twinberry/Snowberry
TGrowth=read.csv('TwinGrowth.csv')
SGrowth=read.csv('SnowGrowth.csv')
SLeaves=read.csv('SnowLeaves.csv')
SFlower=read.csv('SnowFlower.csv')
SHerb=read.csv('SnowHerb.csv')
TGMean=tapply(TGrowth$Growth, TGrowth$Plot, mean)
TGTreatments=c('Plant','RemPlant','RemPlant','Plant','Plant','RemPlant','Plant','RemPlan
        t','Plant','RemPlant','RemPlant','Plant')
TGplot=data.frame(TGTreatments, TGMean)
TGGrandMean=tapply(TGplot$TGMean, TGplot$TGTreatments, mean)
boxplot(TGMean~TGTreatments, data=TGplot, ylab="Growth (mm)")
qqnorm(TGMean, main=NULL)
qqline(TGMean)
TGttest=t.test(TGMean~TGTreatments, data=TGplot)
SGTreatments=c('RemSal','Sal','Sal','RemSal','Sal','RemSal','RemSal','Sal','Sal','RemSal'
        ,'Sal','RemSal')
SGMean=tapply(SGrowth$Growth, SGrowth$Plot, mean)
SGplot=data.frame(SGTreatments,SGMean)
SGGrandMean=tapply(SGplot$SGMean,SGplot$SGTreatments, mean)
boxplot(SGMean~SGTreatments, data=SGplot, ylab="Growth(mm)")
qqnorm(SGMean, main=NULL)
qqline(SGMean)
SGttest=t.test(SGMean~SGTreatments, data=SGplot)
SLMean=tapply(SLeaves$Growth, SLeaves$Plot,mean)
SLplot=data.frame(SGTreatments, SLMean)
SLGrandMean=tapply(SLplot$SLMean,SLplot$SGTreatments, mean)
boxplot(SLMean~SGTreatments, data=SLplot, ylab="Change in Leaf Number
        (leaves/branch)")
qqnorm(SLMean, main=NULL)
qqline(SLMean)
SLttest=t.test(SLMean~SGTreatments, data=SLplot)
SFMean=tapply(SFlower$Growth, SFlower$Plot, sum)
SFplot=data.frame(SGTreatments,SFMean)
SFGrandMean=tapply(SFplot$SFMean, SFplot$SGTreatments, mean)
boxplot(SFMean~SGTreatments, data=SFplot, ylab="Flowering rate (flowering
        branches/plot)")
qqnorm(SFMean, main=NULL)
qqline(SFMean)
SFttest=wilcox.test(SFMean~SGTreatments, data=SFplot)
SHMean=tapply(SHerb$Growth,SHerb$Plot, sum)
SHplot=data.frame(SGTreatments,SHMean)
SHGrandMean=tapply(SHplot$SHMean, SHplot$SGTreatments, mean)
boxplot(SHMean~SGTreatments,data=SHplot,ylab="Herbivory rate (branches
        experiencing herbivory/plot")
qqnorm(SHMean, main=NULL)
```

```
qqline(SHMean)
SHttest=wilcox.test(SHMean~SGTreatments,data=SHplot)
#Soils
Temp=read.csv('STemp.csv')
Mois=read.csv('SMois.csv')
Cond=read.csv('SCond.csv')
TePl=subset(Temp, Treatment=='Plant')
TePlSE=sd(TePl$Temp)/sqrt(length(TePl$Temp))
TeRe=subset(Temp, Treatment=='RemPlant')
TeReSE=sd(TeRe$Temp)/sqrt(length(TeRe$Temp))
TeSa=subset(Temp, Treatment=='RemSal')
TeSaSE=sd(TeSa$Temp)/sqrt(length(TeSa$Temp))
TeNo=subset(Temp, Treatment=='Sal')
TeNoSE=sd(TeNo$Temp)/sqrt(length(TeNo$Temp))
boxplot(TePl$Temp,TeRe$Temp,TeSa$Temp,TeNo$Temp,
    names=c("Plant","RemPlant","RemSal","Sal"), ylab="Temperature °C")
summary(aov(Temp~Zone*Treatment, data=Temp))
MoPl=subset(Mois, Treatment=='Plant')
MoPlSE=sd(MoPl$Mois)/sqrt(length(MoPl$Mois))
MoRe=subset(Mois, Treatment=='RemPlant')
MoReSE=sd(MoRe$Mois)/sqrt(length(MoRe$Mois))
MoSa=subset(Mois, Treatment=='RemSal')
MoSaSE=sd(MoSa$Mois)/sqrt(length(MoSa$Mois))
MoNo=subset(Mois, Treatment=='Sal')
MoNoSE=sd(MoNo$Mois)/sqrt(length(MoNo$Mois))
boxplot(MoPl$Mois,MoRe$Mois,MoSa$Mois,MoNo$Mois,
    names=c("Plant","RemPlant","RemSal","Sal"), ylab="Volumetric Moisture Content
    (%)")
summary(aov(Mois~Zone*Treatment, data=Mois))
CoPl=subset(Cond, Treatment=='Plant')
CoPlSE=sd(CoPl$Cond)/sqrt(length(CoPl$Cond))
CoRe=subset(Cond, Treatment=='RemPlant')
CoReSE=sd(CoRe$Cond)/sqrt(length(CoRe$Cond))
CoSa=subset(Cond, Treatment=='RemSal')
CoSaSE=sd(CoSa$Cond)/sqrt(length(CoSa$Cond))
CoNo=subset(Cond, Treatment=='Sal')
CoNoSE=sd(CoNo$Cond)/sqrt(length(CoNo$Cond))
boxplot(CoPl$Cond,CoRe$Cond,CoSa$Cond,CoNo$Cond,
    names=c("Plant","RemPlant","RemSal","Sal"), ylab="Electrical Conductivity
    (dS/cm)")
summary(aov(Cond~Zone*Treatment, data=Cond))
```

Appendix B: Additional Figures

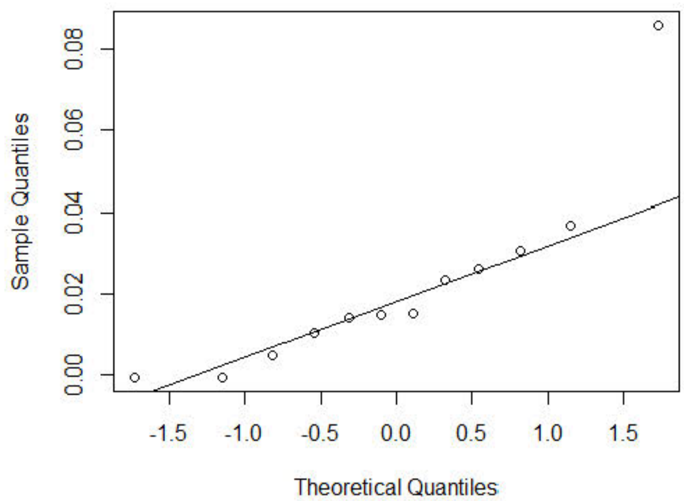

Figure B.1. Q-Q plot assessing the normality of the twinberry growth data. With the exception of a single outlier, the data fit the trendline closely. This shows that data are normally distributed.

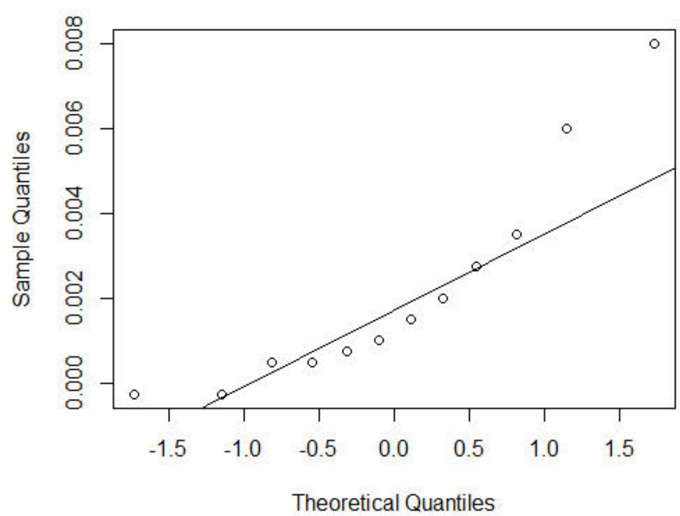

Figure B.2. Q-Q plot assessing the normality of the snowberry growth data. With the exception of two outliers, the data fit the trendline closely. This shows that data are fairly normally distributed.

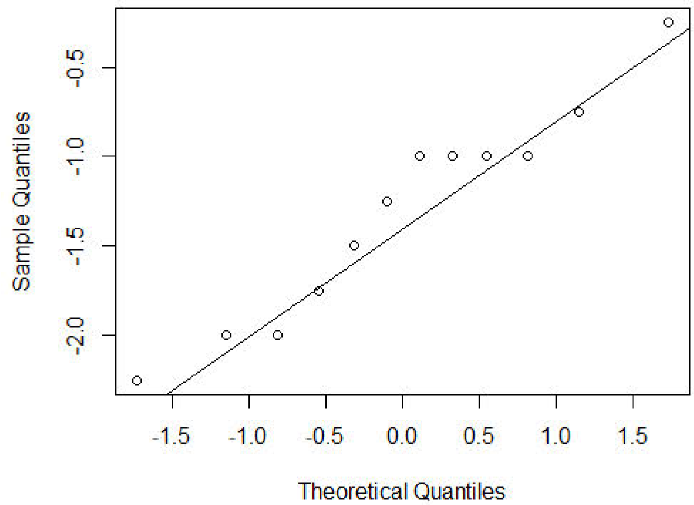

Figure B.3. Q-Q plot assessing the normality of the change in number of leaves on snowberry branches. The data fit the trendline fairly closely. This shows that data are normally distributed.

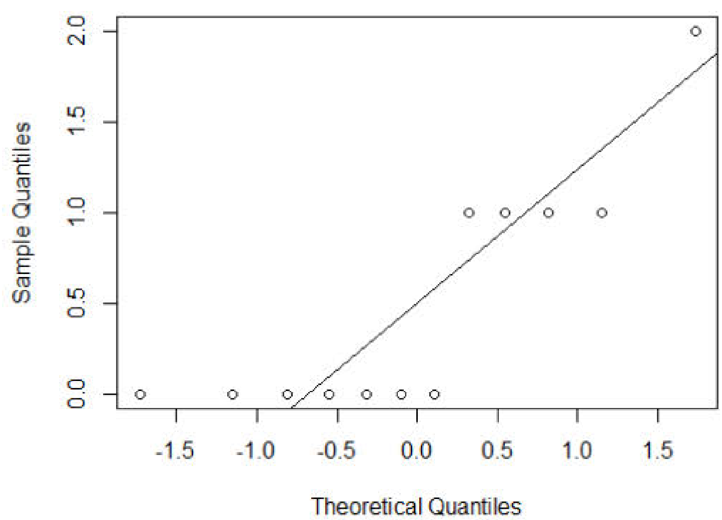

Figure B.4. Q-Q plot assessing the normality of the snowberry flowering data. The data do not fit the trendline closely. This shows that data are not normally distributed.

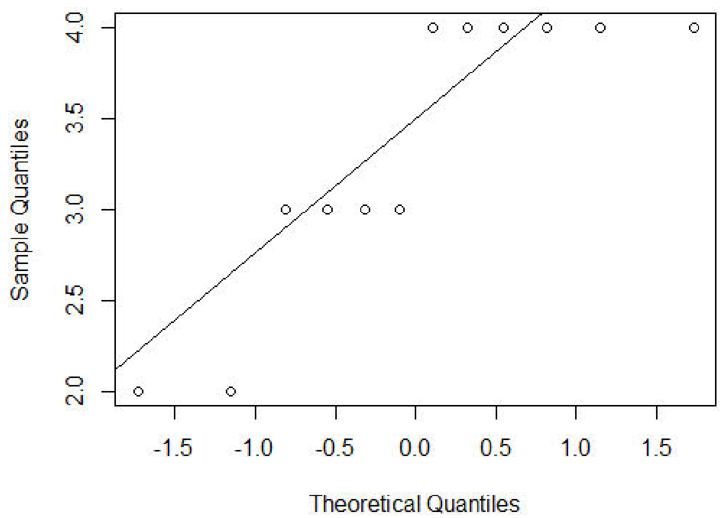

Figure B.5. Q-Q plot assessing the normality of the snowberry herbivory data. The data do not fit the trendline closely. This shows that data are not normally distributed.

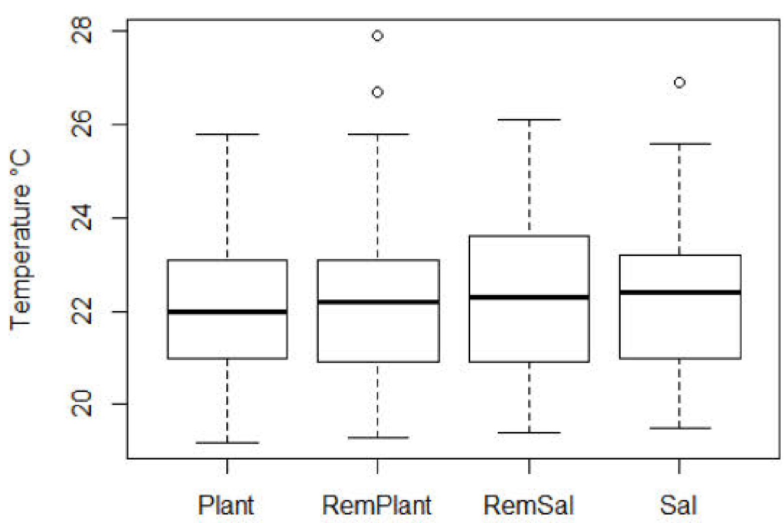

Figure B.6. Soil temperature boxplots. The variation between the treatments is roughly equal and therefore meets the requirement of the one-way ANOVA.

Table B.1. One-way ANOVA table for soil temperature data.

	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F-value	Pr(>F)
Zone	1	1.3	1.315	0.395	0.531
Treatment	3	1.0	0.347	0.104	0.957
Zone:Treatment	3	3.3	1.091	0.328	0.0805
Residuals	124	412.5	3.327		

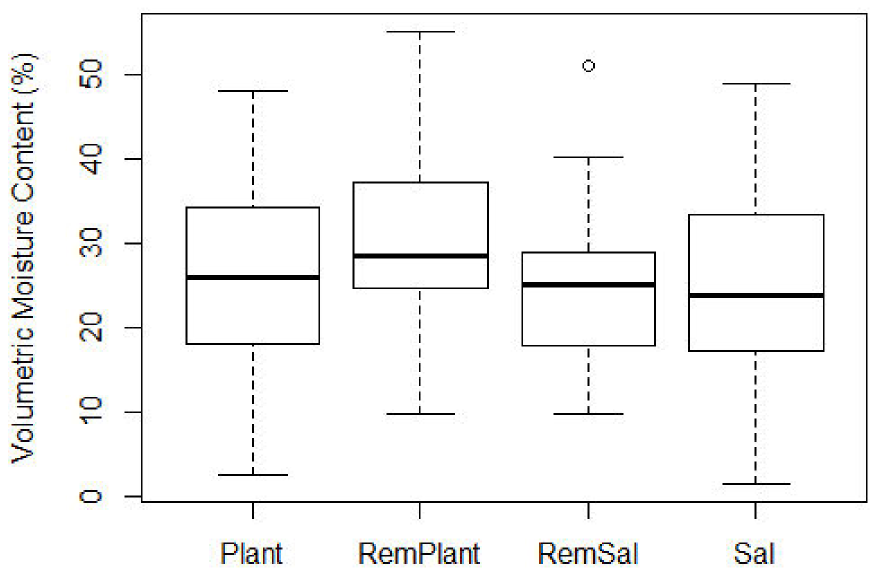

Figure B.7. Soil moisture boxplots. The variation between the treatments is roughly equal and therefore meets the requirement of the one-way ANOVA.

Table B.2. One-way ANOVA table for soil moisture data.

	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F-value	Pr(>F)
Zone	1	362	362.5	3.175	0.0772
Treatment	3	741	246.9	2.163	0.0958
Zone:Treatment	3	331	110.4	0.967	0.4107
Residuals	124	14155	114.2		

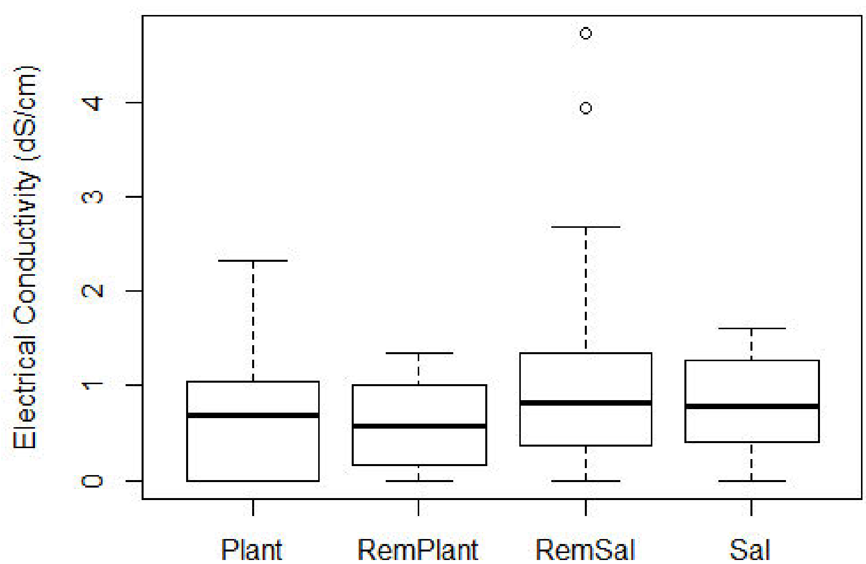

Figure B.8. Soil electrical conductivity boxplots. The variation between the treatments is roughly equal and therefore meets the requirement of the one-way ANOVA.

Table B.3. One-way ANOVA table for soil electrical conductivity data.

	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F-value	Pr(>F)
Zone	1	0.07	0.0728	0.140	0.7091
Treatment	3	4.00	1.3345	2.566	0.0578
Zone:Treatment	3	1.42	0.4731	0.910	0.4386
Residuals	118	61.37	0.5201		