

Exploring Roadside Revegetation Methods Using Culturally Important Plants to the

Gitga'at in Txalgiuw (Hartley Bay, British Columbia)

by

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Abstract

In Tsalgiuw (Hartley Bay, British Columbia), Gitga'at First Nation constructed a service road to support the development of a new hydroelectric dam, creating an opportunity for culturally informed land reclamation that restores ecosystem function, improves habitat connectivity, and supports cultural values. In partnership with Gitga'at First Nation, this study evaluated propagation and transplant methods for culturally important native plants, including salmonberry (*Rubus spectabilis*), fireweed (*Chamaenerion angustifolium*), and Alaskan bunchberry (*Cornus unalaschensis*), for roadside revegetation.

Experiments assessed roadside vegetative propagation using 10-cm rhizome segments (salmonberry, $n = 80$; fireweed, $n = 40$; bunchberry, $n = 160$), direct-to-roadside seeding with mulch treatments (salmonberry, $n = 800$; bunchberry, $n = 500$ per treatment), mulch soil amendments for roadside salmonberry rhizomes ($n = 80$), greenhouse propagation of salmonberry rhizomes ($n = 60$), biofertilizer effects on greenhouse-grown salmonberry (*Fucus distichus*, $n = 9$; *Oncorhynchus tshawytscha*, $n = 7$; Miracle-Gro, $n = 9$; control, $n = 9$), and the performance of greenhouse-grown ($n = 34$) versus roadside-grown salmonberry ($n = 21$) following roadside transplant.

Fireweed and salmonberry demonstrated strong revegetation potential, with emergence rates of 75% and 32.5% respectively, while bunchberry exhibited 40% overwinter survival despite extensive initial dieback. Mulch reduced salmonberry seed germination and establishment on the roadside, but did not have a significant effect on salmonberry leaf surface area. Rhizome origin, average site soil moisture, and maximum soil temperature all negatively influenced roadside salmonberry rhizome

emergence. Greenhouse propagation achieved 35% emergence, while wrapping rhizomes at active nodes appeared to reduce success. Biofertilizer treatments had no significant effect on growth. Following transplantation, greenhouse-grown salmonberry exhibited slower growth than roadside-grown plants, likely due to larger initial size and transplant shock. Overall, these findings support vegetative propagation, particularly for salmonberry and fireweed, for roadside revegetation and demonstrate that culturally important species can be effectively integrated into roadside revegetation planning.

Acknowledgements

I would like to thank my supervisor, Dr. Nicola Koper, for their guidance and supervision throughout this project. I am also grateful for Dr. Lisa Wood for her assistance in establishing this project in Hartley Bay and for her valuable statistical support, and Dr. Iain Davidson-Hunt for his thoughtful perspectives that helped positively shape my experience at the NRI. This work was supported by an NSERC Discovery Grant, the UNBC Dean's Research Grant, and the UM Graduate Fellowship.

I deeply appreciate the people I have met along the way and contributed to this research. I am especially grateful to Jo-Anne Joyce for her mentorship at the Crop Technology Centre and for our many insightful conversations; Carl Szczerski for providing the refrigeration space needed for seed stratification and for taking the time to design and 3D-print custom iButton capsules; and Erica Kreitz for her assistance during the early stages of this project, as well as her warm hospitality and friendship which made my time in Prince George especially memorable.

I extend my sincere gratitude to the members of the Hartley Bay community for their support, generosity, and kindness. Special thanks to Tyrone for watching over greenhouse-grown salmonberry plants during my absence; Stuart for his dependable assistance and access to maintenance vehicles; Stan for his conversations, insights, and gifts of canned fish; Rick and the NRC Storm Contracting Road Crew for their support in roadside operations; Donald for monitoring roadside plants and sharing his knowledge of Gitga'at Territory; and Jessel for providing fish scraps for the fertilizer trial. I am also grateful to Mavis, Moana, Megan, Vanessa, Kim-Ly, Raymond and many others for making my time in Hartley Bay so special.

Dedication

In memory of my Mum, whose trips to the library together sparked a love for knowledge and learning.

To my Dad, who has instilled in me the headstrong belief that I can do anything.

To Julian, whose unwavering support made this journey possible.

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Table 1

Transplanted Species Included in Each Planting Block for 2024 Roadside Vegetative Trials

Planting Block	Species
1	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>)
2	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>) and fireweed (haas ; <i>Chamaenerion angustifolium</i>)
3	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>) and Alaskan bunchberry (k'apk'oop ; <i>Cornus unalaschensis</i>)
4	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>), fireweed (haas ; <i>Chamaenerion angustifolium</i>), and Alaskan bunchberry (k'apk'oop ; <i>Cornus unalaschensis</i>)

Table 2

Seed Trial Plot Layouts Per Site

Plot	Species	Treatment	Number of seeds
1	Salmonberry	Mulched	800
2	Salmonberry	Not mulched	800
3	Bunchberry	Mulched	500
4	Bunchberry	Not mulched	500

Table 3*Summary of Statistical Models Used for Data Analysis*

Objective	Response	Model Type	Model Structure	
			Fixed Effects	Random Effects
2. Roadside Seed Trials	Salmonberry germination and establishment	GLMER	Treatment (mulch/control) + Bulk density	Site
2. Roadside Seed Trials	Bunchberry germination and establishment	GAM	Treatment (mulch/control)*Bulk density	Site
2. Roadside Seed Trials	Salmonberry leaf surface area	GLMER with robust standard errors	Treatment (mulch/control)	Site
4. Greenhouse Fertilizer Trial	Salmonberry plant height	Weighted Regression	Treatment (Fertilizer type/control) + Days since emergence (plant age)	N/A
5. Roadside Mulch Trials	Salmonberry rhizome emergence	GLM	Treatment + Rhizome origin + Bulk density + Soil moisture + Percent cover + Maximum soil temperature recorded	N/A
5. Roadside Mulch Trials	Salmonberry plant height	LM	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent cover + Days since emergence (age)	N/A
5. Roadside Mulch Trials	Salmonberry stem diameter	LM	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent Cover + Days since emergence (age)	N/A
5. Roadside Mulch Trials	Salmonberry average crown spread	LM	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent cover + Days since emergence (age)	N/A
6. Shrub Transplant Trial	Salmonberry plant height	Wilcoxon rank-sum	N/A	N/A

Table 3*Summary of Statistical Models Used for Data Analysis (continued)*

Objective	Response	Model Type	Model Structure	
			Fixed Effects	Random Effects
6. Shrub Transplant Trial	Salmonberry plant height	Wilcoxon rank-sum	N/A	N/A
6. Shrub Transplant Trial	Salmonberry stem diameter	Wilcoxon rank-sum	N/A	N/A
6. Shrub Transplant Trial	Salmonberry average crown spread	Wilcoxon rank-sum	N/A	N/A

Note. The “ns” prior to soil moisture indicates that the variable was fit with a natural spline.

Table 4*Comparisons Between Fertilizer Effects Candidate Models*

Model	Model Structure		Model Summary			
	Model Type	Fixed Effects	<i>df</i>	SE	Deviance	Adjusted r-squared
1	ANCOVA	Treatment + Days since emergence	29	2.86	237.8	0.30
2	Weighted Regression	Treatment + Days since emergence	29	1.24	44.65	0.40

Table 5*Comparisons Between Rhizome Emergence Candidate Models*

Fixed Effects	Model	
	1	2
Treatment (mulch or control)	+	+
Rhizome origin (M1 or M2)	+	+
Bulk density	+	+
Soil moisture (seasonal average)	+	+
Percent Cover (end of season)	+	+
Daily maximum temperature (seasonal average)	-	+
Maximum soil temperature recorded	+	-
Model Selection Summary		
Delta AIC	0.00	2.45
Weight	0.77	0.227

Table 6*Comparisons Between Candidate Plant Health Effects Models*

Response	Model Type	Model	Model Structure	Model Selection Summary	
			Fixed Effects	Delta AIC	Weight
Plant Height	LM	1	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent cover + Days since emergence	N/A	N/A
		2	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent cover + Days since emergence	0.00	0.958
Stem Diameter	LM	3	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + ns(Percent cover, df = 3) + Days since emergence	6.28	0.042
		4	Treatment + Rhizome origin + Bulk density + Soil moisture + ns(Percent cover, df = 3) + Days since emergence	19.41	0.00
Average Crown Spread	LM	5	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent cover + Days since emergence	0.00	0.876
		6	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + ns(Percent cover, df = 2) + Days since emergence	3.91	0.124

Note. The “ns” prior to the soil moisture variable indicates that the variable was fit with a natural spline.

Table 7*Rhizome Emergence and Overwintering Survival Across All Transplanted Species*

	Species		
	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>)	Fireweed (haas ; <i>Chamaenerion angustifolium</i>)	Bunchberry (k'apk'oop ; <i>Cornus unalaschensis</i>)
<i>n</i>	80	40	160
Rhizome emergence rate (%)	32.5 %	75.0%	-
Proportion of emerged rhizomes by rhizome origin			
<i>M1</i>	0.55	1.0	-
<i>M2</i>	0.15	-	-
<i>M3</i>	0.35	-	-
<i>M4</i>	0.25	-	-
Overwintering survival rate of rhizomes (%)	80.8%	93.3%	40%

Note. Bunchberry rhizomes did not have a reported emergence rate, as shoots existing before transplant were monitored for survival throughout the growing season.

Table 8*Roadside Seed Germination Rates Across Species and Treatments*

	Species	
	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>)	Bunchberry (k'apk'oop ; <i>Cornus unalaschensis</i>)
Seeds/m ²	800	250
Percent germinated and established by treatment		
<i>No mulch</i>	67.2 %	33.7 %
<i>Mulch</i>	32.8 %	19.2 %
Total seeds sown (<i>n</i>)	8,000	5,000
Total germinated	50.0 %	26.5 %

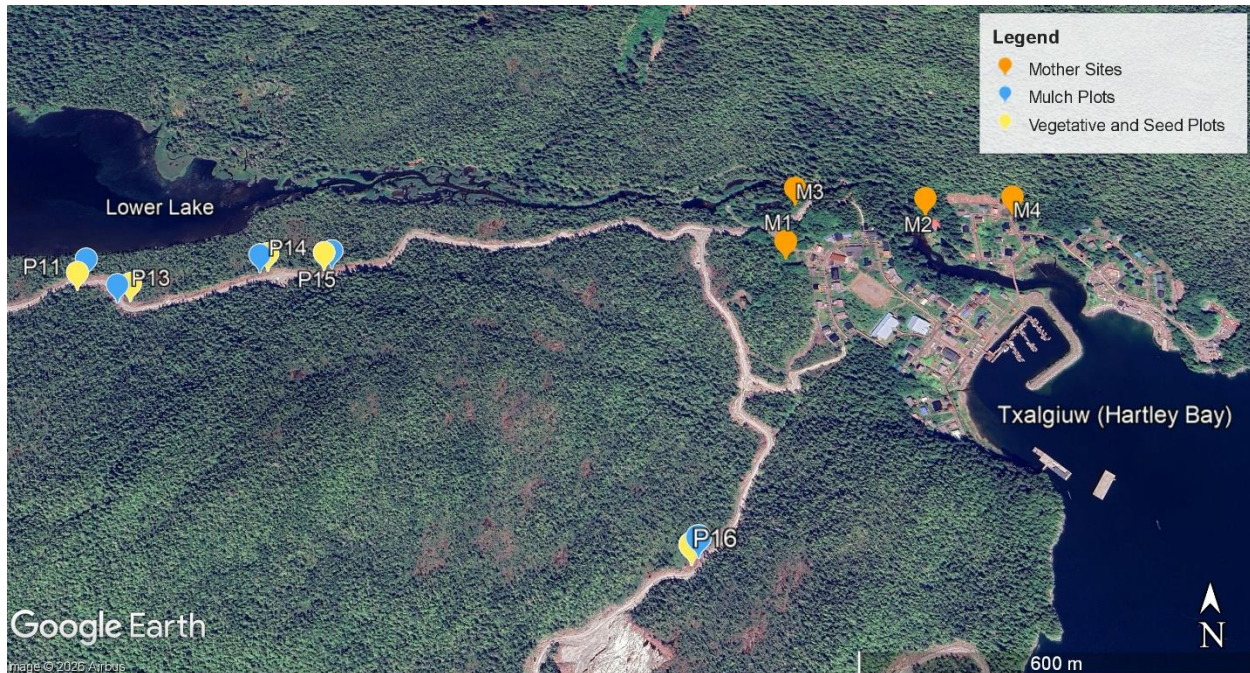
Table 9*Salmonberry Rhizome Emergence in Greenhouse Trial*

Viability Status	Number of Rhizomes
<i>n</i>	60
Immediate emergence (soil)	21
Immediate failure (soil)	21
Total with node growth (paper towel)	18
<i>Emerged</i>	8
<i>Failed</i>	10

List of Figures

Figure 1

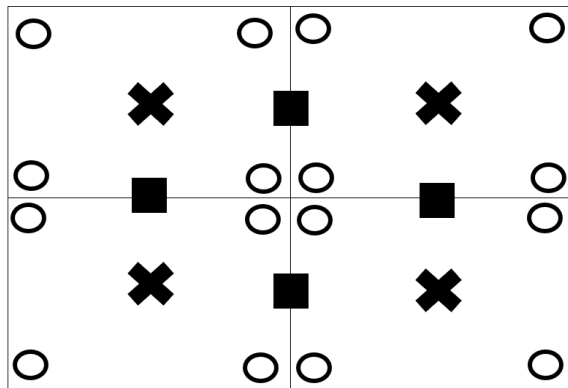
Map of Research Sites, Txalgiuw (Hartley Bay, BC)



Note. Yellow icons indicate the location of research sites that include vegetative and seed trial plots, while blue icons indicate the location of mulch trial plots conducted in 2025 in close proximity to the original research sites. Map data attributed to Google, Airbus (Google Earth, n.d.).

Figure 2

Spatial Configurations of Each Species within Roadside Planting Blocks



Note. A visual representation of treatment 4 with a quartered plot layout where X = salmonberry, ■ = fireweed, and O = Bunchberry.

Figure 3

Original Bunchberry Shoot Survival and New Growth Trends Across All Sites During the 2024 Monitoring Period

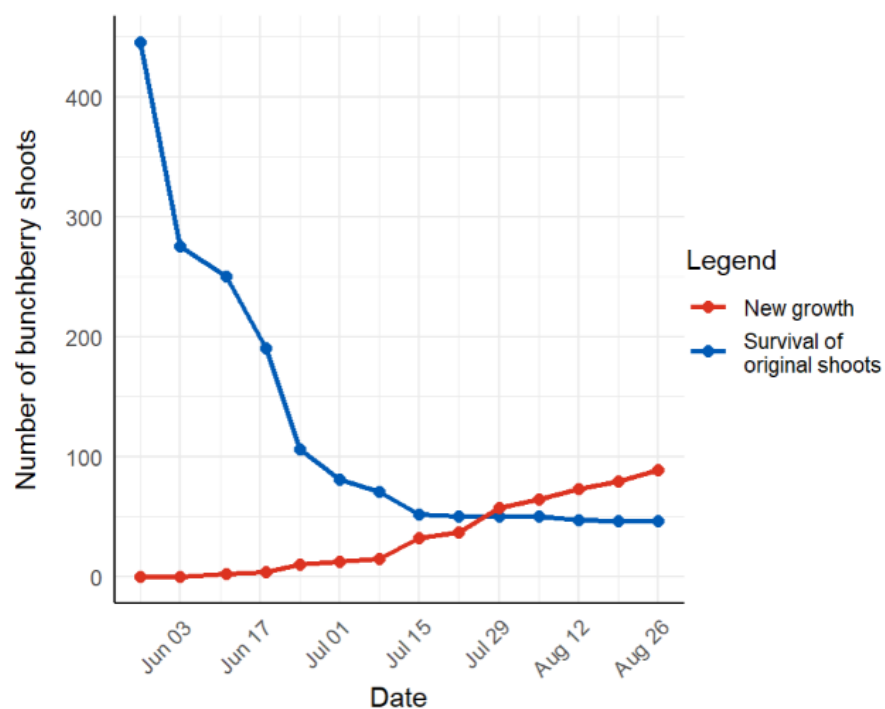
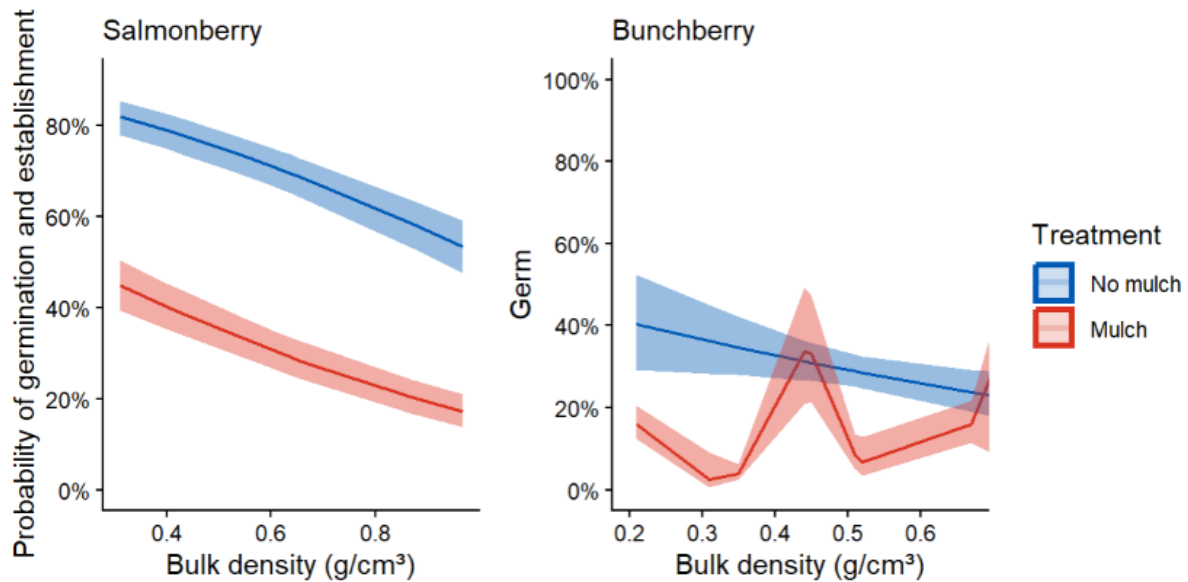


Figure 4

Effect of Soil Bulk Density and Mulching on the Probability of Roadside Seed

Germination Across Species



Note. Bunchberry predictions were limited to bulk density values ranging from 0.20 g/cm³ to 0.67 g/cm³ since predictions beyond this point were heavily extrapolated and result in large confidence intervals that should not be biologically interpreted. This is likely due to the limited overlap in bulk density values between the mulch and no-mulch treatments above 0.7 g/cm³.

Figure 5

Predicted Effect of Mulch Treatment on Average Salmonberry Seedling Leaf Surface

Area

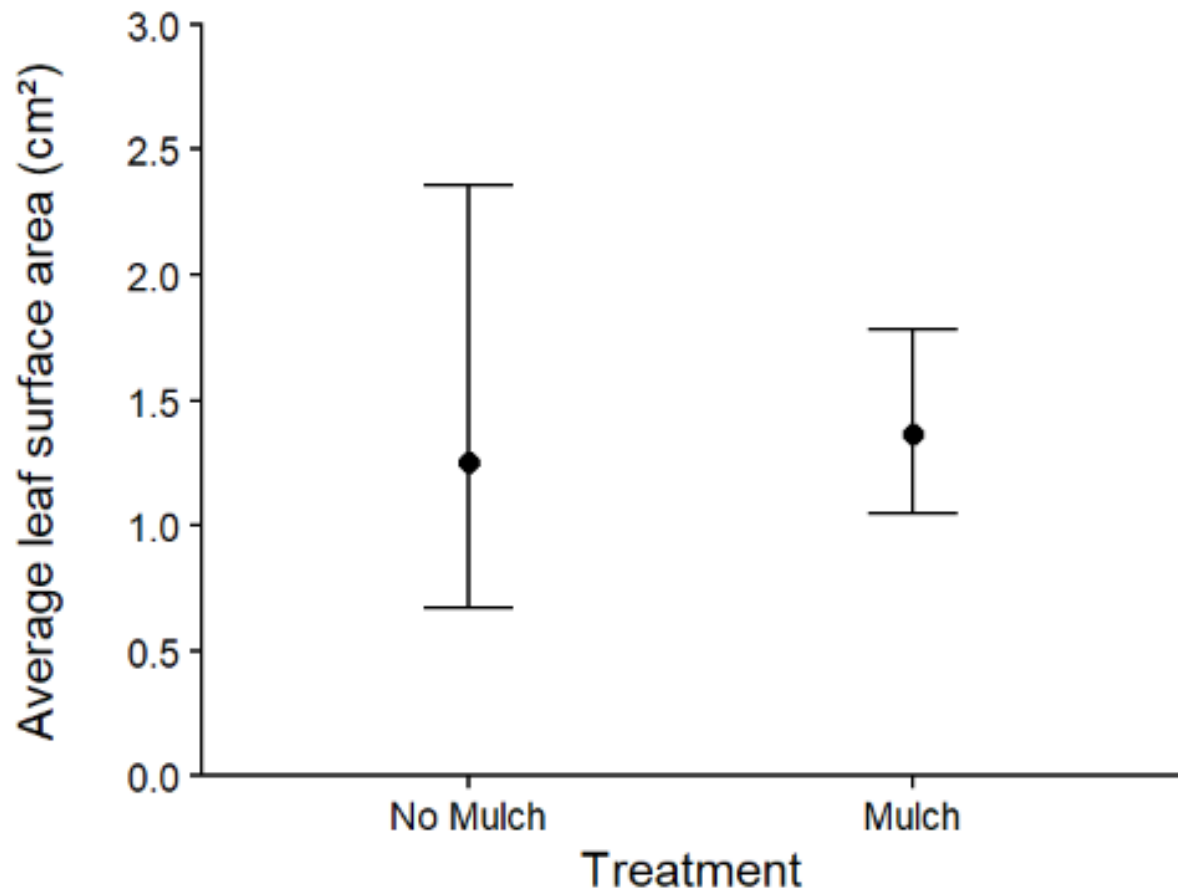


Figure 6

Predicted Heights of Salmonberry Plants with Respect to Greenhouse Fertilizer

Treatments

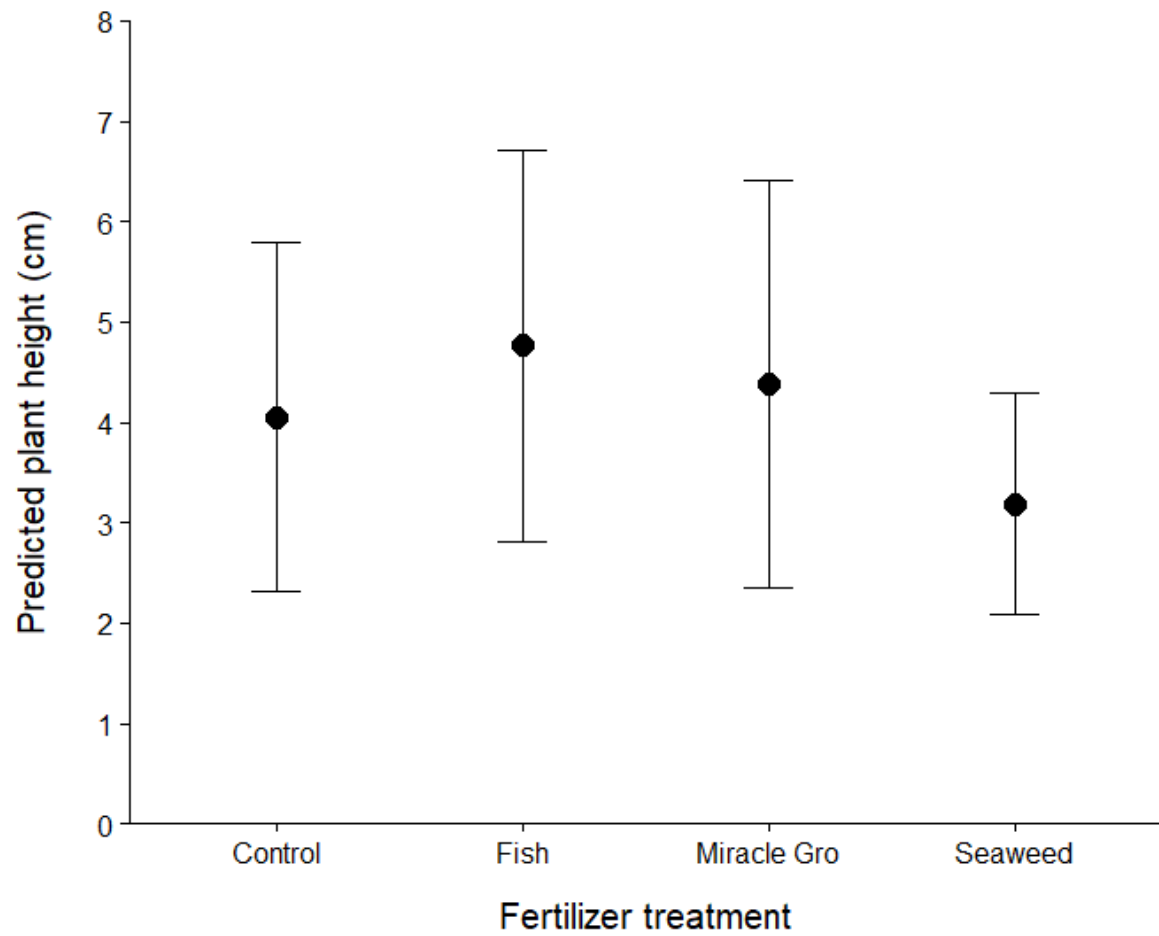


Figure 7

Predicted Stem Diameter of Salmonberry Plants with Respect to Greenhouse Fertilizer

Treatments

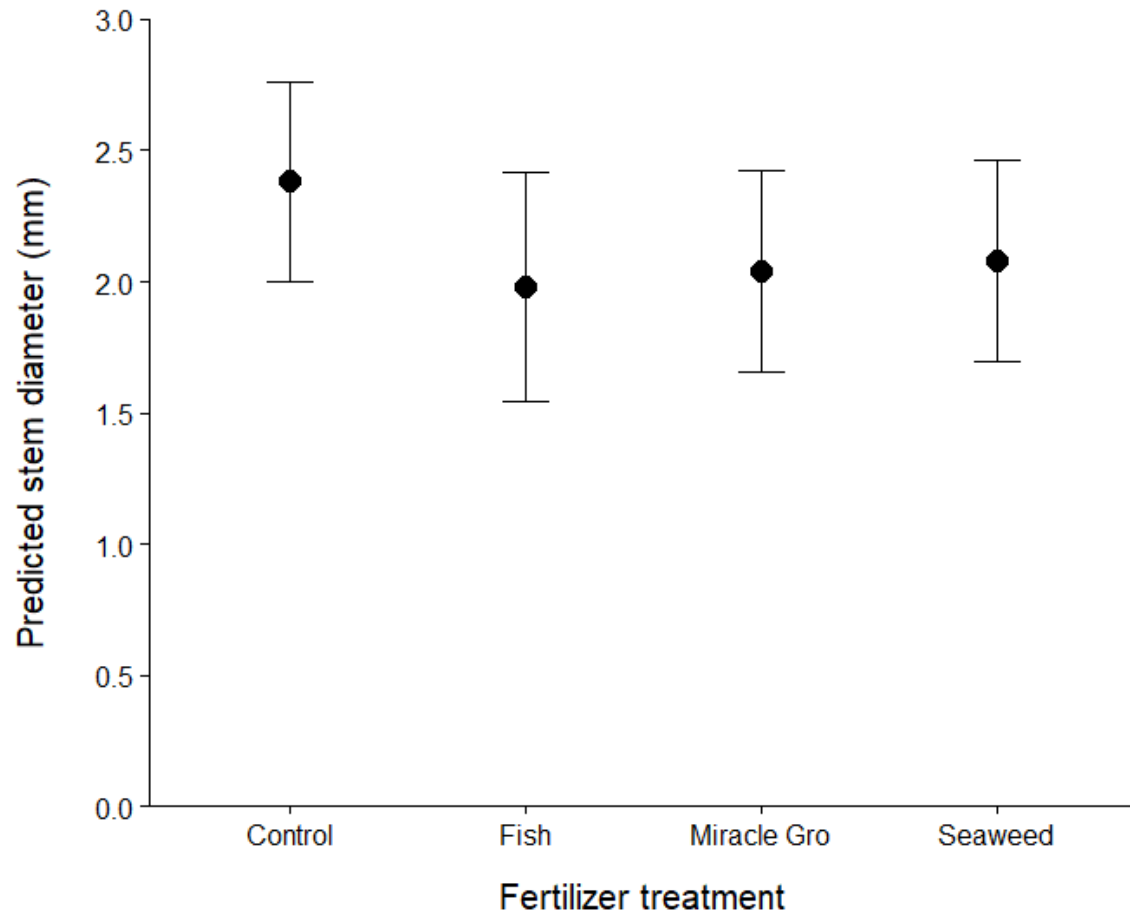
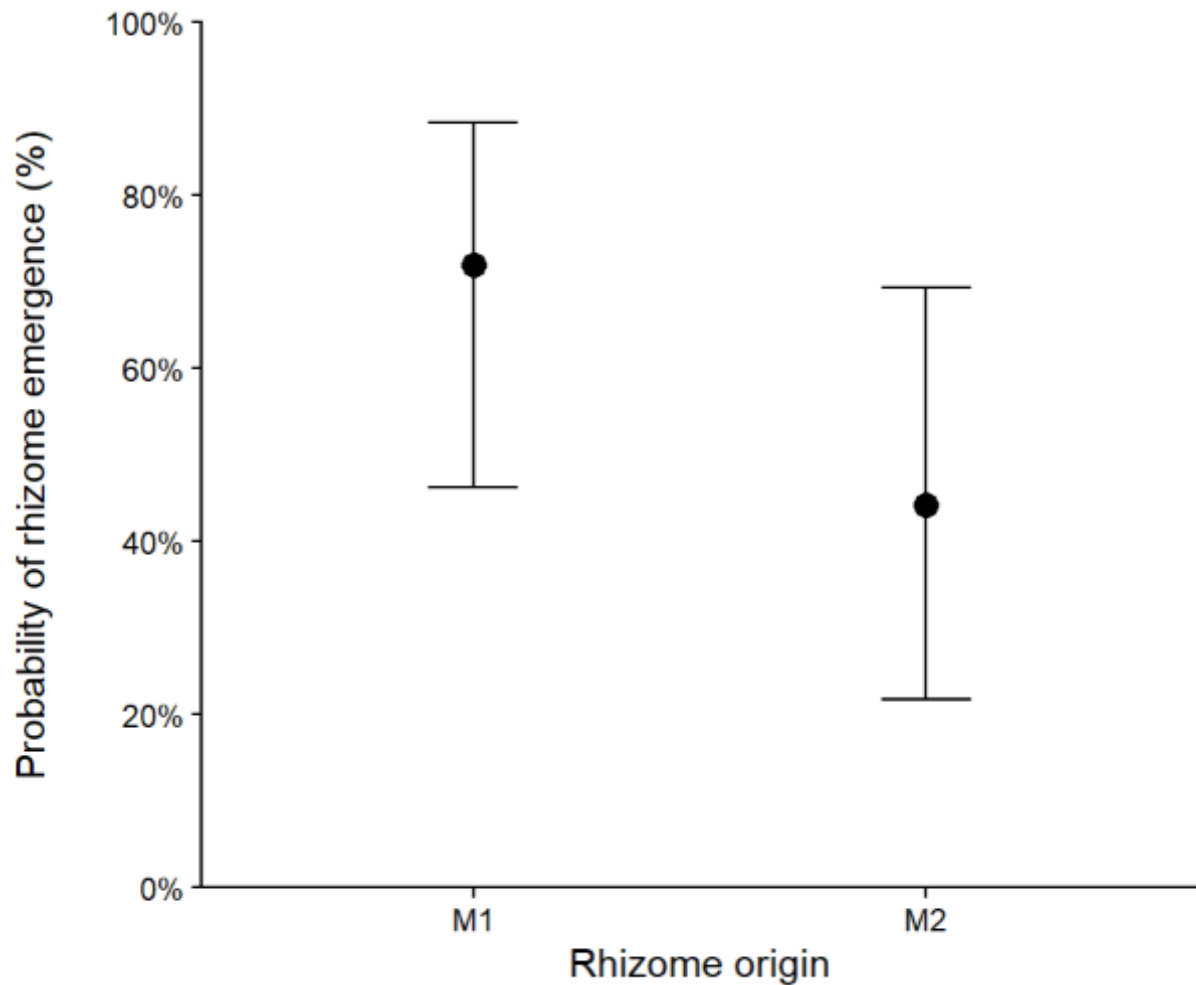


Figure 8

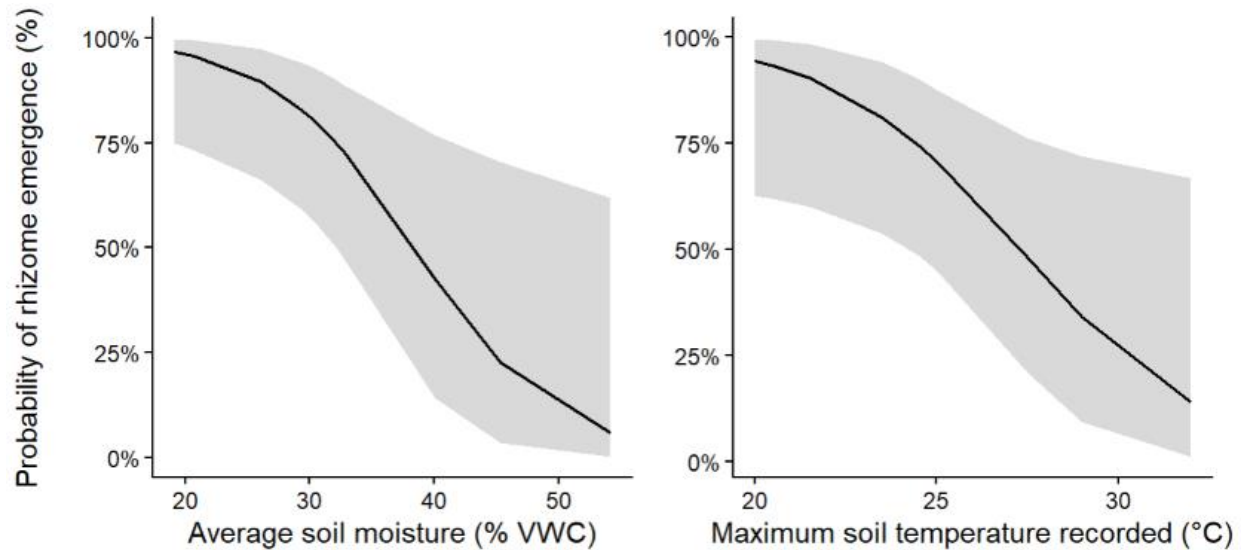
Predicted Roadside Emergence of Salmonberry Rhizomes with Respect to Rhizome Origin



Note. This figure was created using the R package ggeffects. This package calculates marginal predictions by holding categorical variables at their reference level, and numeric variables at their mean. Consequently, the effects of rhizome origin on emergence probability are displayed under no mulch conditions across average environmental conditions.

Figure 9

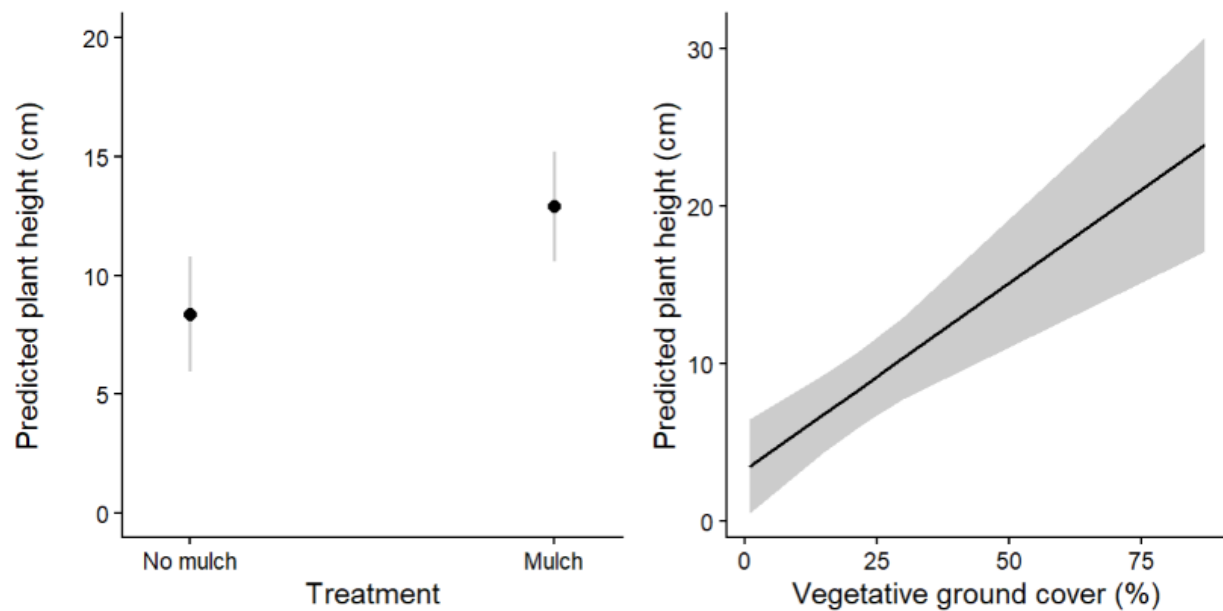
Predicted Roadside Emergence of Salmonberry Rhizomes with Respect to Average Soil Moisture (% VWC) and Maximum Recorded Soil Temperature (°C)



Note. This figure was created using the R package *ggeffects*. This package calculates marginal predictions by holding categorical variables at their reference level, and numeric variables at their mean. Consequently, the effects of average soil moisture and maximum soil temperature recorded on the probability of emergence are displayed under no mulch conditions across average environmental conditions.

Figure 10

Predicted Roadside Salmonberry Height by Treatment and Vegetative Percent Cover

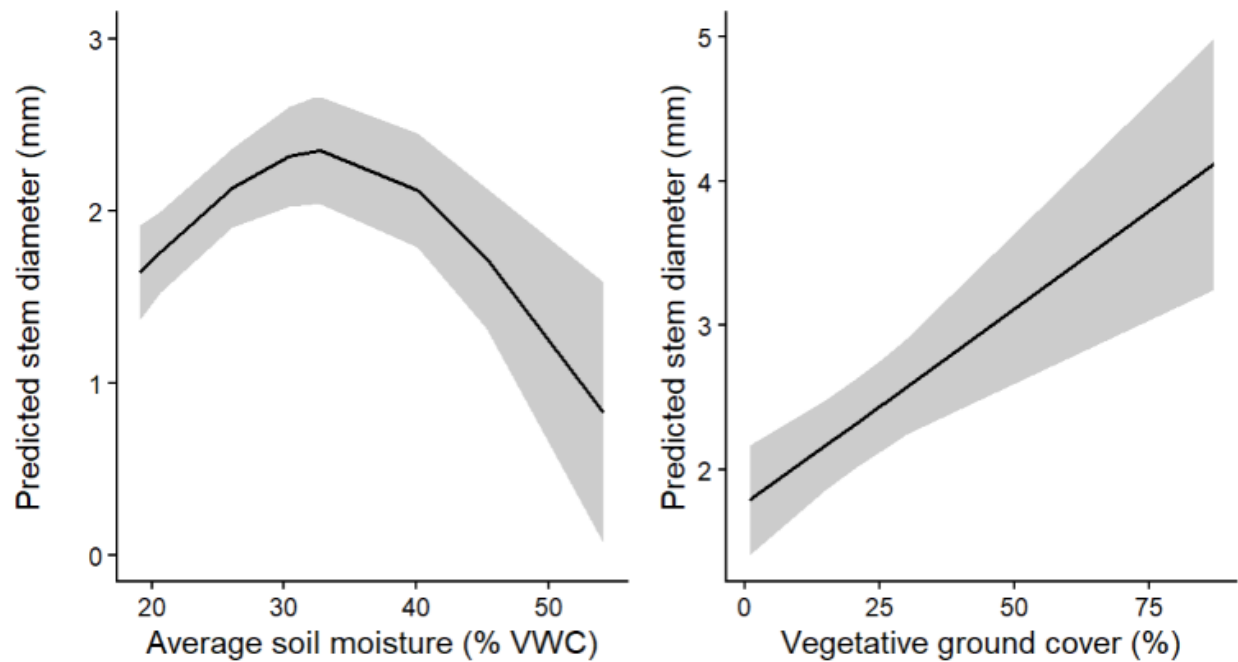


Note. This figure was created using the R package ggeffects. This package calculates marginal predictions by holding categorical variables at their reference level, and numeric variables at their mean. Consequently, the effects of treatment and vegetative ground cover on predicted plant height are displayed under rhizome origin M1 across average environmental conditions.

Figure 11

Effects of Average Soil Moisture and Ground Cover on Predicted Roadside

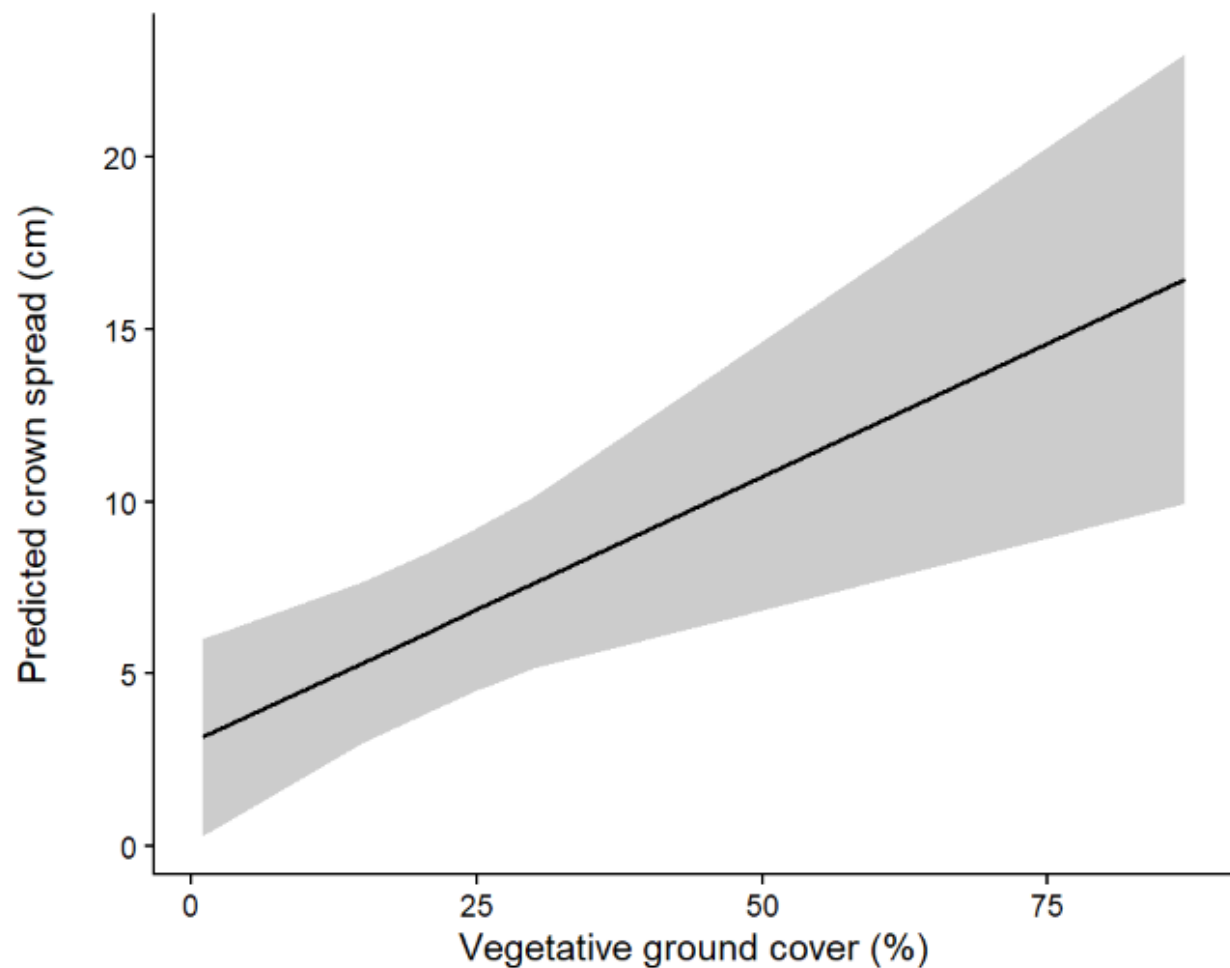
Salmonberry Stem Diameter



Note. This figure was created using the R package *ggeffects*. This package calculates marginal predictions by holding categorical variables at their reference level, and numeric variables at their mean. Consequently, the effects of soil moisture and ground cover are displayed under rhizome origin M1 and no mulch conditions across average environmental conditions.

Figure 12

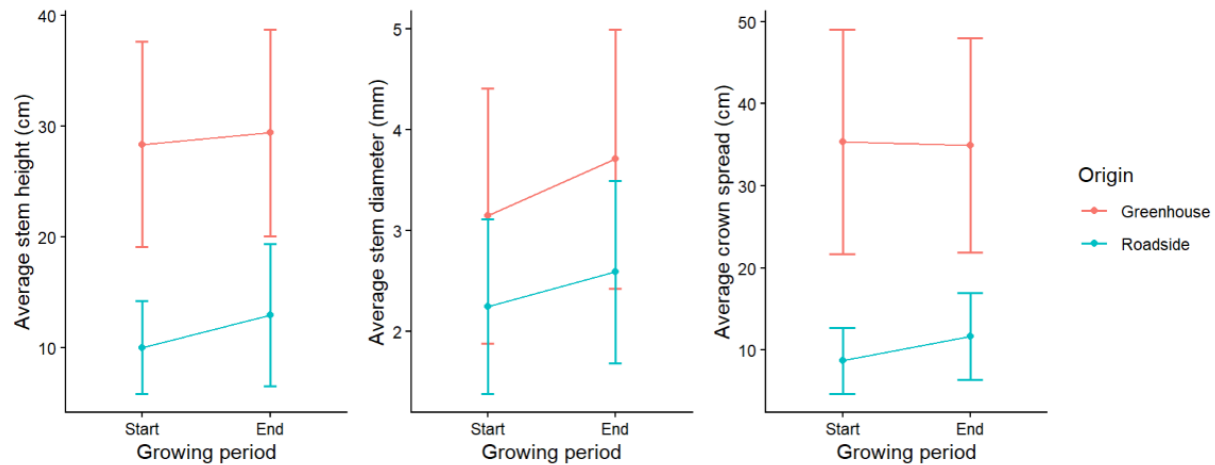
Effects of Vegetative Ground Cover on Predicted Average Crown Spread of Roadside Salmonberry



Note. This figure was created using the R package ggeffects. This package calculates marginal predictions by holding categorical variables at their reference level, and numeric variables at their mean. Consequently, the effects of ground cover are displayed under rhizome origin M1 and no mulch conditions across average environmental conditions.

Figure 13

Average Seasonal Roadside Growth of Both Greenhouse-Grown and Roadside-Grown Salmonberry Plants from the Shrub Transplant Trial



Note. Plant growth data was averaged and plotted to graphically showcase the average growth rates of stem height, stem diameter, and crown spread between groups (greenhouse-grown or roadside-grown plants) at the start and end of the growing season. Standard deviations were plotted to indicate the observed variation in plant height, stem diameter, and average crown spread within groups.

Chapter I: Introduction

Background

As the demand for accessible infrastructure in remote communities increases and natural resource industries continue to expand, the need for developing service roads becomes pertinent. In Hartley Bay, British Columbia, a 5.7- kilometre service road has been built to access an area for a new hydroelectric dam. While the road will provide critical access to the new dam which will secure renewable energy for the community, its construction does not come without consequences. For example, fragmenting habitat with roads alters the landscape, disrupts ecosystem services, redistributes flora and fauna, and reduces biodiversity (Mitchell et al., 2015). This is because roads create a hard, anthropogenic ecological edge that changes the microclimates of peripheral forest, therefore increasing plant mortality and altering flora community structures; these effects have secondary impacts on other organisms, ultimately leading to the alteration of fauna behaviour, dispersal, and survival (Spellerberg, 1998).

However, many negative impacts of roads can be mitigated by roadside revegetation. Revegetation reduces forest edge exposure (Coffin, 2007) as well as improves organism dispersal by increasing available habitat and connectivity (Denneboom et al., 2021). While there are many methods and approaches to land reclamation and revegetation of disturbed areas, Gitga'at First Nation chose to revegetate patches of roadside habitat with local transplants of berry species and other culturally important herbs. In the future, fruit produced by single-species berry patches

will provide benefits to the broader ecosystem by supplying a food source to vertebrates including mammals and birds (Willson, 1993). Once grown, multi-species berry patches will serve as an early-successional space that provides growing habitat for both shade tolerant and intolerant plant species (Armstrong et al., 2021), while simultaneously providing nesting and foraging habitat for birds due to the complex vegetation structures provided by graminoids, herbs, and berry shrubs. Not only will these berry patches lead to an overall increase in biodiversity at reclaimed roadsides, revegetation with berry species may also improve Gitga'at food security and health by increasing access to berries and other medicines, while simultaneously increasing social sustainability by providing culturally important resources.

Transplanting as part of revegetation efforts is an effective way to promote local plant community compositions in disturbed roadside habitats (Mehlhoop et al., 2022). Using local transplants rather than industrial plant stock or seed mixtures will ensure that transplants are genetically adapted to grow successfully (Bucharova et al., 2017) in Hartley Bay, while reducing the threat of spreading invasive plants. Tsimshian Ancestral Law, **Ayaawx**, maintains that the land, plants, animals, and humans must be treated with respect on the basis that they are all alive and have spirit (Vickers, 2008). Respect, **loomsk**, means holding life sacred and valuing the relationships among all human and non-human members of the community. Using local transplants for revegetation offer a way of ensuring that local ecological and spiritual relationships between the land, plants, animals, and people will be maintained.

Transplant studies in this context have mainly assessed the effect of transplant methods on plant survival and growth (Mallik & Karim, 2008; Mehlhoop et al., 2022;

Weber, 2021). However, it is less clear how to effectively transplant locally harvested plant material across various propagation methods, and how this varies among species and location. Based on a comprehensive literature search, reclamation of roadsides through an early-successional approach with berry species has not been attempted in Canada. Determining how reconstructed plant communities respond to roadside transplanting is relatively unexplored.

This research followed the principles and best practices put forth by the Truth and Reconciliation Commission of Canada, the International Union for the Conservation of Nature (IUCN), and the United Nations Declaration of the Rights of Indigenous Peoples (UNDRIP) for working in collaboration with Indigenous Peoples. This study was designed with Gitga'at First Nation since its inception and was approved by them in principle.

Purpose, Objectives, and Hypotheses

The purpose of this study was to assess the propagation methods and transplant capacity of culturally important plants for revegetating roadside locations in Tsalxgiuw, Gitga'at Lax Yuup (Hartley Bay, British Columbia). To achieve this goal, the following objectives were to:

1. Evaluate the success of vegetative transplanting as a roadside revegetation method using target species.
2. Evaluate the germination and establishment capacity of seeds with and without mulch in a roadside setting.

3. Assess the vegetative propagation success of salmonberry under greenhouse conditions.
4. Test the effects of local, natural fertilizers on greenhouse-grown salmonberry plants produced through vegetative propagation.
5. Assess the effects of mulch on the roadside emergence and growth of salmonberry vegetative propagates (rhizomes).
6. Compare the seasonal growth of greenhouse-grown and roadside-grown salmonberry plants following roadside translocation.

Together, these objectives will help inform future revegetation efforts in Txalgiuw by creating a better understanding of which propagation methods and soil amendments best support the transplant success of culturally important plants on the roadside, in addition to documenting important environmental factors that influence the success of propagating this study's focal species under roadside conditions.

Justification for Research

My research supports early-successional habitat, which is generally at risk of replacement by human-altered habitats world-wide (Bardgett et al., 2021). It also contributes to the exploration of novel and culturally sensitive roadside reclamation methods, and provides suggestions for which culturally important species may be viable as roadside transplants.

It will also have important implications for Indigenous food security, health, and cultural practises, as culturally important species that successfully adapt to roadside

transplanting will significantly increase the future availability of local berries and medicine for the Gitga'at to harvest. Furthermore, the improved accessibility and abundance of berries may offer unique opportunities for economic benefit within the community, since berries may be made into marketable products. The knowledge generated through this study will benefit Gitga'at First Nation for future revegetation projects throughout Gitga'at Territory, as well as other First Nations that are considering transplanting culturally significant species in their own restoration projects. I recognise that this study may not be completely transferrable to other coastal First Nations due to climatic and soil differences, as well as variability in culturally important species.

Chapter II: Literature Review

What is Succession and Early-Successional Ecosystems?

Early-successional ecosystems develop shortly after disturbance and are characterized by their well-developed groundcover and lack of closed tree canopy (Greenberg et al., 2011) . In secondary succession, early-successional ecosystems emerge when surviving plant species recolonize a newly opened patch. Without further disturbances, early-successional patches follow a successional pathway and grow into a climax community whose floral compositions and abundances may or may not match that of the original. The vegetation structures, or seral stages, that are classified as early-successional can vary by author. Here, I define early-successional as a plant community aged less than 20 years after disturbance, and includes one of the following vegetation stages defined by the Resources Inventory Committee (1998) in British Columbia, Canada: sparse, herb, and shrub/herb.

Ecological Benefits of Early-Successional Ecosystems and Habitat

Early-successional patches provide an array of ecological benefits. While plant species diversity throughout succession may be dependant on disturbance type (Denslow, 1980), early-successional spaces are abundant in species that cannot germinate or survive in the low-light conditions brought on by later successional stages (Bazzaz, 1979). In the first years following disturbance, species that are ruderal, opportunistic, or open-habitat specialists quickly establish and dominate as groundcover

without the barrier of a closed canopy (Swanson et al., 2011). This sparse, or herb stage, is abundant in graminoids (grasses, sedges, rushes), herbs (herbaceous annuals and perennials), and ferns (Elliott et al., 2011). Over time, shrubs that have reestablished begin to dominate the patch while herbaceous and graminoid species continue to co-exist. It is this early-successional shrub/herb stage that offers a unique plant community composition compared to later successional stages.

Early-successional patches also increase animal diversity due to the variety of plant species and vegetation structures present. In British Columbia, both grizzly bears (*Ursus arctos L.*) and black bears (*Ursus americanus*) opportunistically select for early-successional habitat during the foraging seasons to feed on the abundant forbs and berries found at early-successional sites (Ciarniello, 2006; Davis et al., 2006). Other mammals are known to rely extensively on early-successional habitat; Fuller and DeStefano (2003) report a number of species with home ranges in BC that show preference for early-successional habitat over other habitat types when studied in eastern North America: lynx (*Lynx canadensis*), bobcat (*Lynx rufus*), moose (*Alces Alces*), red fox (*Vulpes vulpes*), ermine (*Mustela erminea*), southern red-backed vole (*Myodes gapperi*), and several lagomorphs (*Lepus americanus*, *Sylvilagus floridanus*, *Sylvilagus transitionalis*).

Physical attributes of vegetation such as plant height, form, and size can attract avifauna that are associated with open habitats or edges. Fontaine et al. (2009) found that avian species richness in open-habitat aged less than 20 years after disturbance was greater than that of mature temperate forest, indicating that early-successional habitat provides extensive benefits to avian communities. This is because species that

are specialised to nest in certain vegetation structures use the diverse heights and dimensions provided by early-successional habitat to their advantage. Ground nesting or ground foraging species monopolize on the protection created by ground cover and shrubs that are unlikely to be present in mature forest. For example, various sparrow (Dark-eyed junco; *Junco hyemalis*, Fox Sparrow; *Passerella iliaca*, Spotted towhee; *Pipilo maculatus*, and White-crowned sparrow; *Zonotrichia leucophrys*) and warbler species (Wilson's warbler; *Cardellina pusilla*, Orange-crowned warbler; *Leiothlypis celata*, and Nashville warbler; *Leiothlypis ruficapilla*) in BC are associated with early-successional habitat due to their tendency to nest on the ground hidden among shrubs and grasses, while other passerine species nest within the shrubs themselves (Song sparrow; *Melospiza melodia*, and MacGillivray's Warbler; *Geothlypis tolmiei*) (Altman & Hagar, 2007). Cavity nesters such as house wrens (*Troglodytes aedon*), bluebirds (*Sialia currucoides*, *Sialia mexicana*), northern flickers (*Colaptes auratus*), and swallows (*Tachycineta bicolor*, *Tachycineta thalassina*) take advantage of snags that remain after disturbance. Due to the many species attracted to early-successional habitat, early-successional patches result in complex food webs otherwise not present in surrounding forest (Swanson et al., 2011).

Additionally, early-successional patches provide vital breeding habitat for species at risk. Two blue-listed avian species in BC, the Purple martin (*Progne subis*), and the Common nighthawk (*Chordeiles minor*) (BC Conservation Data Centre, 2021, 2022) are aerial insectivores that benefit from the abundance of flying insects in forest openings, as well as snag cavities for nesting. The common nighthawk, in addition to the Olive-sided flycatcher (*Contopus cooperi*) are also listed nationally as a species of special

concern by the Committee on the Status of Endangered Wildlife in Canada (Committee on the Status of Endangered Wildlife in Canada (COSEWIC), 2019; COSEWIC, 2019). The avian species described above, apart from the Spotted Towhee, Nashville warbler, and Purple martin, can be found in north-central BC, including the community of Hartley Bay (Bowling, 1998).

Factors that Drive Successional Plant Communities and Successional Pathways

Plant community compositions of early-successional stages are not strictly defined, as species vary drastically according to geographic region and local environmental constraints. Trade-offs between species can extensively drive the species composition of plant communities during succession. Initial colonization after disturbance is thought to be determined by species trade-offs in nutrition competition, light competition, and herbivory (Tilman, 1990). These trade-offs can be exhibited through functional or life history traits. Early-successional species that allocate more resources to seed production rather than root growth are more likely to colonize an area quicker, but are unlikely to stay as a dominant species because they are outcompeted for nutrients over time. Additionally, species that have larger stems and broader leaves are better suited to monopolize light, and are likely to outcompete species focused on seed production and dispersal. In the circumstance where herbivory is significant during early-successional stages, species that are resistant to herbivory are more likely to survive in the long term, while species that allocate their resources to seeds would be consumed. To summarize, an early-successional plant community will initially be

abundant in species that allocate resources to seeds and seed dispersal (r-selected), but is likely to succeed to species that allocate resources to roots, photosynthetic structures, and herbivore defence (k-selected). Bohn et al. (2014) point out that plant community composition and diversity can be heavily influenced by the intensity of r- (colonisers) and k-selection (competitors) among species.

Interspecies interactions in early succession can also be influenced by facilitation. Facilitation is described as positive plant interactions where one species benefits the fitness of another. Species facilitation may be direct by improving resource availability, mitigating harsh temperatures and light intensities, or changing aspects of the substrate, or indirect by reducing competitors and herbivory, or attracting beneficial organisms such as pollinators (Callaway, 1995). Brooker et al. (2008) suggests that facilitation may play an important role in high stress environments, and therefore should not be overlooked when studying plant interactions in early-successional communities. Forest gardens created and maintained by First Nations in British Columbia are a unique cultural example of how facilitation may occur in purposefully created early-successional patches. In their study, Armstrong et al. (2021) found a greater number of shade-tolerant plants in garden patches compared to surrounding forest. While this finding was unexpected, it is suggested that the shade provided by different structural layers of vegetation facilitated the growth of these shade-tolerant species that otherwise weren't supported by the closed canopy of the surrounding forest. While I will not be studying species facilitation in mature plants where shading is likely to be a major mechanism, the concept of facilitation has played an important role in the choice of

species for treatments by considering how species facilitation will benefit plants as time progresses and shrubs have matured for berry production.

In the context of my study, exploring theories on inter- and intraspecies dynamics is essential for understanding how companion plants impact the performance of focal berry species. This is particularly important because we are not strictly using a reference ecosystem for reclamation treatments, but rather choosing species according to cultural value and proposed patch function. Thus, the species interactions we may observe are relatively unexplored, especially since they don't necessarily appear together in natural early-successional habitats. Since the goal of the overall project is to increase the availability of berries for community harvest, experimentally determining successful combinations of species for patches is essential. It is vital in this context to ascertain if selected species inhibit or facilitate the growth of berry plants, so that they can be considered for further trials or included in future roadside patch treatments.

Plant Communities in British Columbia: Coastal Western Hemlock Zone (CWH)

Biogeoclimatic units represent ecosystems which occur under the same regional climate (Demarchi, 2011) and can be used as general references for estimating plant communities in British Columbia. Hartley Bay, BC belongs to the Coastal Western Hemlock biogeoclimatic unit, and is located in the Very Wet Hypermaritime subzone (CWHvh2) (Government of British Columbia, 2022). Generally, the CWHvh2 consists of coastal old-growth rainforest, with stands dominated by western redcedar (*smgán*; *Thuja plicata*), yellow cedar (*wat*; *Xanthocyparis nootkatensis*), western hemlock (*gyiik*;

Tsuga heterophylla), mountain hemlock (*Tsuga mertensiana*), and lodgepole pine (**sginiis**; *Pinus contorta*). Abundant shrub species include salal (**dzawes**; *Gaultheria shallon*), red huckleberry (**sgan wüleéxs**; *Vaccinium parvifolium*), pacific crab apple (**malkst**; *Malus fusca*), stink currant (**sgan waakyil**; *Ribes bracteosum*), and Nootka rose (**gan k'alaams**; *Rosa nutkana*). Common herb species found throughout the CWHvh2 include deer fern (**miiya mam**; *Blechnum spicant*), sword fern (**miiya mam**; *Polystichum munitum*), fern-leaved golden thread (*Coptis asplenifolia*), cordilleran bunchberry (**k'apk'oop**; *Cornus unalaschensis*), false lily-of-the-valley (**k'axaays**; *Maianthemum dilatatum*), small twistedstalk (*Streptopus streptopoides*), rattlesnake-plantain (*Goodyera oblongifolia*), and prince's pine (*Chimaphila umbellata*) (Banner & Columbia, 1993).

It is important to note that dominant understory species of herbs and shrubs vary across zonal or site units. The CWHvh2 subzone is split into 22 zonal units for forests, floodplains, and non-forested sites such as bogs and fens. These site units better identify plant communities based off the landscape, and the nutrient and moisture regimes of local soils. Once soil samples are analysed, each site unit can be cross referenced with vegetation abundance and prominence tables to describe a plant community that is likely to be supported by the site.

Natural Disturbances in the CWH

Across British Columbia, disturbances such as wildfires, pathogens, avalanches, floods, windstorm blowdowns, and herbivorous grazing all contribute to the development of early-successional habitat. The type of natural disturbance, as well as

its frequency and severity differ across the region due to variation in landscape, physiography, and climate (Dorner & Wong, 2003). More specifically, succession in BC's coastal temperate rainforests have historically been driven by fine-scale canopy gaps rather than wildfire activity (Daniels & Gray, 2006). For this reason, the CHWvh2 subzone is classified as having rare stand-initiating events (NDT1) (BC Ministry of Forests, 1995), meaning that naturally occurring early-successional patches are relatively small.

First Nations of British Columbia have also shaped and maintained early-successional habitat through their traditional plant management systems since time immemorial. In fact, the primary cause of historic fires in some areas of coastal temperate rainforests were due to First Nation's fire use (Hoffman et al., 2017), as maintaining early-successional habitat was vital for the long-term availability of important cultural plants and grazing areas of hunted animals (Fort Nelson First Nation & Shifting Mosaics Consulting, 2015). Without these strategies, succession would prevail and canopy openings would close, leading to the decline of early-successional plant and animal species that were used for sustenance and medicine. Although practices vary by nation and tribe, First Nations management approaches in BC include, but are not limited to, burning at both the landscape and local level, weeding, pruning, transplanting roots or whole plants, and disseminating seeds and fruit (Turner et al., 2013). Shrubs and herbaceous perennials were often the subject of such management practises due to their ability to provide abundant foods and to be harvested cyclically (Deur & Turner, 2005). Berry species in particular are an important food source for many

Indigenous People across Canada, and many traditional management practises are well described (Migicovsky et al., 2022).

Natural Disturbances Post Colonization: An Ecosystem Under Threat

Large-scale alteration of naturally occurring early successional ecosystems in British Columbia has occurred since European colonization of the region. To support new settler communities, grasslands and forests were cleared to expand settlements, agricultural land, and the livestock industry. Native grasslands were particularly sought out for the abundant forage available for sheep, cattle, and oxen. As a result, most major grasslands in BC were degraded for over 100 years by overgrazing livestock, while the grasslands of the Boreal Plains Ecoprovince were cleared and plowed for agriculture post World War I (Grasslands Conservation Council of British Columbia, 2017). Today, less than one percent of BC lands are native grasslands, whose plant communities have been modified with invasive or introduced species (Iverson, 2004). The abundance and estimated landcover of other early-successional habitats are poorly described.

The frequency and intensity of both natural and anthropogenic disturbances in BC forests have also drastically shifted since European settlement. While industrial logging has undoubtedly resulted in an increase of open patches, single-species replanting efforts aimed to restock prized timber species have substantially changed the species compositions of what would be natural early-successional plant communities (Swift & Ran, 2012). The provincial government's drive to protect economically

important timber products by enacting fire suppression policies such as the Bush Fire Act of 1874 (Parminter, 1981) has further jeopardized naturally occurring early-successional ecosystems. Brookes et al. (2021) found that colonial fire suppression has disrupted historical fire regimes, resulting in fewer fire disturbances of low- to moderate-severity, while increasing the frequency of high-severity fires. These low- to moderate-severity fires promote the establishment of early-successional plant communities by improving nitrogen availability in soils and increasing light intensity without killing reproductive seed banks or root systems of early-successional herbs (Elliott et al., 2011). On the other hand, forest soils under high intensity fire have reduced organic matter, increased hydrophobicity, lowered structural stability, and fewer nutrients (Brookes et al., 2021), making regeneration for early-successional plant species difficult. Furthermore, the systematic relocation of Indigenous People and the criminalization of cultural burnings have prevented the traditional maintenance of the landscape and early-successional habitat (Hoffman et al., 2022).

The development of infrastructure such as roads and powerline corridors have changed BC's forested landscape by increasing fragmentation and open areas. While these disturbances would normally encourage the growth of early-successional plant communities, they also create a high-risk scenario for the introduction of invasive species. Non-native plant species used for soil and slope stabilization on road rights-of-way, as well as increased soil compaction from heavy machinery (Daigle, 2010) can have profound impacts on vegetation composition and structure. In BC, powerline corridors are maintained by the electric utility company BC Hydro, whose standard practises for "controlling" vegetation surrounding power lines include grooming,

brushing, mowing, and herbicide applications (British Columbia Hydro and Power Authority, 2023). These management practises can negatively impact non-target species, as well as increase the risk of contamination with invasive plants or noxious weeds. It is notable that BC Hydro is not subject to the BC Weed Control Act, which legally requires landowners to control the spread of noxious weeds (Weed Control Act, 1996).

The negative impacts of development on early-successional ecosystems are not only occurring in BC and across Canada, but globally. Early-successional habitat worldwide, including that of grasslands, has historically been converted or replaced by human-altered habitats (Bardgett et al., 2021). Remaining early-successional habitats have had their ability to provide ecosystem functions limited by the effects of human induced climate change, such as drought (Smith et al., 2024).

Current Restoration and Reclamation Efforts of ES Spaces

Early-successional ecosystems have largely been ignored by conservationists across North America (Askins, 2001). Instead, conservationists and government management agencies have focussed on protecting and regenerating “pristine” environments and mature forests that are economically prosperous. In the field of ecological restoration research, forested ecosystems have been studied more than any other ecosystem type in Canada, with reforestation being a major aspect of restoration practices since the 1960s (Alamenciak et al., 2023). Askins (2001) proposes that human values are partially to blame, as early-successional patches of shrub and herb species are considered uninteresting and fall outside society’s perceptions of beauty. Many

initiatives for the conservation and maintenance of early-successional habitat have been to improve hunting for wild game (Harper & Gruchy, 2009).

Recognition of conservation values for early-successional habitats has grown throughout North America relatively recently, particularly due to their relevance for species at risk (Litvaitis et al., 2021), breeding birds (DeGraaf & Yamasaki, 2003; King & Schlossberg, 2014), biodiversity (Speelman, 2018), and non-timber forest products (Duchesne & Wetzal, 2002; Gobster, 2001). In the past 20 years, the concept of natural disturbance-based management has gained traction, wherein logging regimes aim to mimic historical natural disturbances while maintaining the biodiversity, ecosystem functions, and species re-assemblies of the affected forest system (Drever et al., 2006; Kuuluvainen et al., 2021). Natural disturbance-based management strategies will support ES ecosystems by taking a holistic approach to managing logged areas and recreating natural plant communities through successional pathways. However, this strategy is limited by the lack of data on successional pathways, early stage community compositions, and historic natural disturbance trends. Research on the successional ecology of Canadian forests have largely focussed on tree species regeneration after disturbance, rather than documenting changes in herb and shrub stages (Anyomi et al., 2022). Early-successional pathways across the diverse biogeoclimatic zones of BC forests remain understudied, with the most comprehensive report being conducted on Vancouver Island by the Canadian Forest Service (Ryan et al., 2009).

While the concept of natural disturbance-based management has been applied to forestry, this practise, to the best of my knowledge, has not been implemented for roadside reclamation. As the demand for accessible infrastructure in remote

communities increases, urban expansion grows, and distant areas are accessed for natural resource extraction, roads will continue to be built. As previously discussed, fragmenting forested habitat comes with ecological consequences; however, road rights-of-way offer a unique opportunity to explore novel strategies for early-successional habitat reclamation.

Canadian Land Restoration and Roadside Reclamation: A Shift Towards Culturally Important Species?

Historically, restoration has attempted to “... return an ecosystem to its historic trajectory” (Society for Ecological Restoration International Science and Policy Working Group, 2004, p. 1), wherein, restoration goals commonly aim to re-establish ecosystem functions to a degree that they can operate without further human intervention. Species deemed appropriate for restoration are often selected because they are considered characteristic of a reference ecosystem. However, while land restoration practices prioritise native species, these species are rarely selected with their cultural importance in mind and seldomly include Indigenous perspectives.

Involving Indigenous People and actively including culturally important species in Canadian land restoration practises has grown. Cultural keystone species – defined as species that have fundamentally shaped a culture due to their use in medicine, materials, or diet – have been recognised as a significant component of biocultural restoration (Garibaldi & Turner, 2004). These cultural keystone species have recently been a focus for planning several culturally sensitive restoration projects in Canada. For example, Uprety et al. (2017) collaborated with the Kitcisakik Algonquin community in

western Quebec to create a plan to restore the historical matrix of Eastern white pine (*Pinus strobus*) for community use in their traditional territory. In Alberta, community members of Fort McKay were consulted to determine which species should be prioritised for oil sand reclamation (Garibaldi, 2009). As a result of the project, seven cultural keystone species were presented to Albion Sands staff for restoration. Four of these were berry species (*Vaccinium spp.*).

Roadside reclamation in Canada has neither prioritised native species, nor included input from Indigenous People. Road rights-of-way across North America have conventionally been seeded with non-native seed mixes shortly after road construction as a form of erosion and invasive species control; the use of shrubs have generally been discouraged due to concerns of reduced driving visibility, safety, and increased roadside maintenance (Patriquin et al., 2021). Consequently, studies that have assessed roadside revegetation efforts have largely been focussed on graminoids or perennial forbs rather than shrubs (Hilvers et al., 2017; Mchaffie, 2020; T. Mitchell et al., 2022). Still, there have been a few notable projects aimed at using native plant species to revegetate roadside areas in Canada; Mallik and Karim (2008) used local transplant graminoid (*Juncus effusus*; *Eriophorum vaginatum*), perennial (*Iris versicolor*; *Clintonia borealis*; *Cornus canadensis*), and shrub species (*Kalmia angustifolia*) to revegetate sections of road rights-of-way in Terra Nova National Park, Newfoundland. On a larger scale, 100 hectares along the Rt. Hon. Herb Gray Parkway in Ontario was revegetated with the native herbs, shrubs, and trees found in Tallgrass Prairie habitat (Ontario Ministry of Transportation, 2016). Despite these efforts, revegetation in this context still has not been approached from an early-successional community standpoint, nor with a

goal of maintaining road rights-of-way in an herb/shrub stage. Furthermore, there has been no evident focus on culturally sensitive reclamation in a roadside context.

The use of culturally important berry species for land reclamation or restoration has notably increased due to the growth of Indigenous-led restoration initiatives. As mentioned in a previous section, berries are culturally important to Indigenous People across North America; thus, any Indigenous-led land restoration initiatives will likely involve berry species to some extent. In British Columbia, Indigenous-led habitat restoration has been supported by various funding agencies (e.g. Indigenous Watershed Initiative, BC Salmon Restoration and Innovation Fund, BC First Nations Caribou Recovery Implementation, etc.), making BC a hotspot for Indigenous-led Initiatives. For example, Katzie First Nation has used Saskatoon berry (*Amelanchier alnifolia*) and Red elderberry (*Sambucus racemosa*) in the restoration of riparian areas along the Alouette River (Leon et al., 2021). Additionally, K'ómoks First Nation in collaboration with the Comox Valley Project Watershed Society have included Black twinberry (*Lonicera involucrata*), Saskatoon berry, Salmonberry, and Red elderberry in the restoration of Kus-kus-sum, a site in the K'ómoks Estuary previously developed for a sawmill.

A shift towards collaborating with Indigenous communities and intentionally selecting culturally important species is a much-needed step forward in the field of restoration. This becomes essential when considering that both nationally and globally, Indigenous lands are threatened by industrial development and resource extraction (Anaya, 2015; Kennedy et al., 2023; Scheidel et al., 2023). Furthermore, using culturally important species is vital to reconnect people with landscapes and culture (Garibaldi &

Turner, 2004). Berry species may be the key to future eco-cultural land reclamation efforts given the wide geographic distributions among species, nutrition value of fruit, and the social implications of harvesting (Migicovsky et al., 2022). Additionally, some berry species are known to be valuable for restoring disturbed lands; MacKenzie and Renkema (2011) successfully revegetated post-mined areas in Alberta with local transplants of common blueberry (*Vaccinium myrtilloides*), mountain huckleberry (*Vaccinium membranaceum*), low-bush cranberry (*Viburnum edule*), and Canada buffaloberry (*Shepherdia canadensis*).

The Art of Transplanting: Reproductive Strategies, Propagation Methods, Traditional Indigenous Practises

Revegetating in the context of restoration can be done in several ways. Seeding, transplanting (whole seedlings/plants or cuttings), natural regeneration, or a mix of methods may be considered for revegetation depending on restoration goals and budget or time constraints (Steinfeld et al., 2007). Generally, the use of local plant stock for transplanting is encouraged and may be obtained through harvesting deciduous plant cuttings (Douglas, 2002). However, it is important to realise that the appropriateness of propagation methods can vary between species due their reproductive processes and life histories.

As previously alluded, life histories play an important role in the reproduction strategies, and therefore the best propagation methods, observed in plants. Fast-growing species like grasses and herbs that are subjected to intense competition are generally smaller in size, shape, and have reduced architectural complexity compared

to plants such as shrubs and trees that grow slower and outcompete other species in early succession (Waller, 1988). Thus, these differences in life history and morphology influence how plants extract resources from their environment and how they allocate these resources into vegetative growth, growth for reproductive purposes, and when plants switch their resource allocation strategies. In climates where the growing season is limited, plant species generally invest in a mix of vegetative growth and reproduction that reflect the community composition, habitat characteristics, and the competitive nature of the growing space (Waller, 1988).

Consequently, growth and reproductive strategies often differ between annual and perennial plants. Grasses and certain herbaceous species that are characteristic of early successional stages generally rely on sexual reproduction, as it is both energetically costly and ineffective to overly invest in vegetative growth or vegetative reproduction during a restricted growing season and life cycle. Instead, annuals allocate resources to reproductive strategies that maximize their persistence across seasons, primarily through the rapid production of seeds which provide a greater likelihood of successful reproduction and long-term population continuity in newly disturbed habitat. Conversely, perennial plants that persist across multiple growing seasons benefit from allocating resources to vegetative growth rather than immediate sexual reproduction. This allows them to increase in size, acquire resources more effectively, and ultimately outcompete early-successional species. As a result, perennial species frequently exhibit seasons of enhanced reproductive investment followed by periods of reduced vegetative growth due to energy costs associated with reproduction (Waller, 1988).

Since sexual reproduction is a resource-intensive process that requires substantial investment in the production of flowers, fruits, and seeds, many perennial species have the capacity to reproduce vegetatively through clonal growth. This strategy is particularly advantageous for perennial species that persist across multiple successional stages and a wide range of habitats, as the relative benefits of sexual and clonal reproduction often depend on local site characteristics. In habitats where resources are limited, such as shaded understories, plants may be unable to acquire sufficient resources to support the energetic costs of sexual reproduction. Under these conditions, plants that allocate more resources to clonal growth may maximize their fitness over those that do not, as clonal expansion can facilitate access to additional light, water and nutrients while simultaneously increasing the spread of the parent plant (Waller, 1988). In this sense, clonal reproduction can provide a less energy intensive and more reliable means of reproduction that does not depend on pollinators, dispersal, or seedling establishment. Plants produced through clonal reproduction generally exhibit greater survival rates compared to seed-derived seedlings because clones remain connected to the parent plant, allowing for resource sharing and reducing their dependence on highly specific environmental conditions during establishment (Barrett, 2015).

However, clonal reproduction also has its disadvantages. Since clonal plants are genetically identical to their parent plant, populations that rely heavily on vegetative reproduction generally exhibit lower levels of genetic diversity than populations developed through sexual reproduction and seedling establishment. This reduced genetic variation can increase the population's vulnerability to diseases, pests, and environmental fluctuations (Lei, 2010). Additionally, clonal dispersal is constrained by

the vegetative growth of rhizomes, resulting in clonal plants remaining relatively close to the parent plant. Over time, further clonal expansion may increase the competition among genetically related individuals for space and resources. In contrast, seeds can be dispersed across greater distances by a variety of mechanisms, allowing for the establishment of new sites and reducing competition with the parent plant (Lei, 2010). Furthermore, a significant limitation of clonal reproduction is that it does not contribute to the formation of a persistent seed bank. Dormant seeds can survive unfavorable environmental conditions, enabling populations to recover after major disturbances and providing a long-term security for the persistence of the population (Wakshum et al., 2018). Generally, predominantly clonal perennial species exhibit lower reproductive output in terms of reduced seed production and smaller seed size compared to non-clonal perennials, suggesting that clonal growth may come at the expense of sexual reproduction (Herben et al., 2015). This indicates that excessive reliance on vegetative reproduction may limit a species' capacity for dispersal, adaptation, and long-term persistence. To balance the advantages and disadvantages of each reproductive strategy, many perennial shrubs simultaneously employ both sexual and clonal reproduction (Vallejo-Marín et al., 2010) which enhances long-term survival under changing environmental conditions and future disturbance scenarios.

Replicating these diverse and complex reproductive strategies in restoration and land management can be challenging, particularly when attempting to establish plant communities at the early successional stage. Graminoids and many herbaceous species primarily reproduce by seed, making them easy to incorporate into restoration projects by seeding them directly onto disturbed soils (Steinfeld et al., 2007). In

contrast, Steinfeld et al. (2007) note that shrub species are often difficult or time consuming to germinate from seed, and may be outcompeted during establishment when sown alongside faster-growing graminoids and herbs. Consequently, the use of shrub cuttings may provide a competitive advantage and improve establishment success on disturbed sites and should therefore be considered in revegetation planning. At the same time, some temperate perennial herb species such as fireweed (*Chamaenerion angustifolium*) rely heavily on clonal spread as a reproductive strategy (Pavek, 1992), which may complicate restoration efforts if their rhizome cuttings are planted alongside those of shrub species. This highlights the complexity of ecological dynamics in revegetation planning and underscores the importance of selecting propagation methods on a species and project-specific basis.

The reproductive processes for several berry species are well described given their use as commercial crops (e.g. *Rubus idaeus*, *Vaccinium corymbosum*, *V. angustifolium*, *Fragaria x ananassa*, etc.). Although berry shrubs are perennials that are capable of reproducing by both seed (sexually) and vegetatively (asexually), rhizomes are often preferred as a propagation method because they quickly facilitate growth and establishment while aligning with species tendencies toward clonal growth. For example, salmonberry (*Rubus spectabilis*) primarily reproduces vegetatively through rhizomes at undisturbed sites, when aerial stems have been killed, or during intermediate disturbance. In contrast, reproduction by seed is largely restricted to newly disturbed sites, where germination rates and seedling establishment are more successful under open environmental conditions (Zouhar, 2019). Furthermore, the seeds of many temperate shrub species exhibit dormancy and possess hard seed coats

which can delay germination and often require scarification or other pre-treatment methods to achieve successful germination (Bonner, 2008), ultimately making these species difficult to propagate from seed. While it is possible to collect and process fruits to extract seeds for revegetation purposes, the labour and time required for seed collection, extraction, and germination often make vegetative propagation the preferred method. Although there is no standard method for propagating rhizomes, suggestions for vegetative propagation methods of root cuttings include cutting rhizomes into sections several centimeters long that include at least one active node, and placing cuttings horizontally in shallow top soil (less than 2 cm) for growth (Landis & Barnett, 1999; Luna, 2009; MacKenzie & Renkema, 2011; McKechnie et al., 2012).

Many First Nations of the Pacific Northwest have used transplanting or translocation of culturally important species in their own traditional land management practises (Turner et al., 2021). Forest gardens historically maintained by some Tsimshian Nations (Kitsumkalum First Nation and Kitselas First Nation) include pacific crabapple (*Malus fusca*) and beaked hazelnut (*Corylus cornuta*); These two species found at historic village sites are well outside of their natural geographic ranges, indicating that these First Nations intentionally transplanted culturally important plants from coastal locations to their inland villages (Armstrong et al., 2021). In addition to trees and shrubs, the Kitsumkalum are also thought to have transplanted coastal herbs to their forest gardens, such as stinging nettle (**steti**; *Urtica dioica*) and northern riceroot (**miyuubmgye**; *Fritillaria camschatcensis*) (Turner et al., 2013). This illustrates the long-term use of transplanting in some Tsimshian cultures.

While transplanting is a widespread practise among Nations, the exact stocktype and transplant methods used for transplanting is variable, as transplant material may have included seeds, whole plants, or other propagules. However, there is extensive evidence that using vegetative stocktypes played an important role in maintaining traditional food systems. Nuxalkmc and Kwakwaka'wakw elders attest to transplanting rhizomes of springbank clover (*Trifolium wormskjoldii*) and pacific silverweed (*Potentilla anserina. ssp. pacifica*) in tidal flat gardens close to village sites (Deur, 2002). The Heiltsuk traditionally selected productive sites to transplant whole berry shrubs of salal, blueberries and huckleberries, effectively creating berry gardens that were further maintained and cared for (Turner & Peacock, 2005). One Gitga'at elder, Mildred Wilson, mentioned that someone should “adopt a root” from a yellow-fruited red elderberry (*Sambucus racemosa*) plant located in Prince Rupert, so that it could be planted in Hartley Bay (Turner et al., 2021)

Gitga'at First Nation: Research Done in Hartley Bay, BC

Gitga'at First Nation has been a long-time collaborator with various research projects. Research themes explored with the Gitga'at Nation and the community of Hartley Bay have mainly focussed on climate change perspectives (Lamontagne, 2016; Reid et al., 2014; Thompson & Ban, 2022), tourism (Turner, 2010; Wilson, 2003), conservation and ecological monitoring, (Keen et al., 2023; Thompson et al., 2020), and the impacts of industry (Gill & Ritchie, 2023; Johnson, 2013). Given the community's rich land-use history, there is an extensive literature documenting Gitga'at ethnobotany.

In this section, I provide a short summary of three ethnobotany studies that have heavily influenced my understanding of Gitga'at food systems and land relationships.

Turner & Clifton (2006) describe seaweed harvesting practises and use, highlighting the importance of seaweed as a traditional food and medicine. While there are several types of edible seaweed along the coast, a species of red laver (**la'ask**; *Porphyra abbottae*) is harvested by the Gitga'at in spring every year at Kiel, a traditional seaweed and halibut harvesting camp. **La'ask** is picked by hand directly from rocks on sunny days at low-tide, traditionally by women and older children while men fish for halibut. The **La'ask** is then sun-dried on rocks or square cedar trays and stacked to be cured with seawater. It is then chopped and stored after several drying phases, ready to eat as necessary. **La'ask** can also be used as an aid for heartburn and indigestion, or as an antiseptic. Similar to berry picking, seaweed harvesting and processing is very much a social activity that brings families and community together through collaboration and reciprocity.

Wyllie de Echeverria (2013) outlines the use of another culturally important plant for the Gitga'at, Pacific crabapple (**Moolks**; *Malus fusca*), as part of their master's thesis exploring crabapple morphological traits and identification. Five distinct varieties (also discussed in the Gitga'at Plant Guide (Turner & Thompson, 2005) are recognised by the Gitga'at based on differences in apple colour, shape, size, taste, and the location of the tree from which the fruit are picked. **Moolks** are primarily a food source, as no other wide-spread technical or medicinal uses have been documented within the community. Whole clusters are picked in the fall from locations designated for all community members, as well as from locations that are owned specifically by individuals.

Depending on variety, they are then preserved by eulachon grease or kept in sugar syrup, or made into jams or jellies. **Moolks** picked by the Gitga'at are prized for their taste and were historically traded with other nations. Thus, they hold a significant cultural role for ceremony, feasts, and gatherings.

Thompson (2004) provides a detailed exploration of Gitga'at First Nation's use of native terrestrial plants in their master's thesis. Using community action research, Thompson sought to improve the transmission of traditional ecological knowledge to younger generations through the Gitga'at Plant Project. This project enlisted Hartley Bay School students (grade 9-12) to interview community elders and plant informants on culturally important species. Overall, the project was deemed a success with students gaining new knowledge about Sm'algyax plant names, harvesting and preservation practises, and medicinal uses while furthering their connection with their elders and the local environment. The information gathered from the project in combination with published literature was used to create a Gitga'at Plant Guide, titled *'Nwana'a lax Yuup Plants of the Gitga'at People* (Turner & Thompson, 2005). This guide provides a list of culturally important plants and their use as food, technology, and healing in Gitga'at culture. Berries are a vital component of Gitga'at nutrition and are therefore described in detail, making the guide an invaluable resource that has helped shape my own research.

Chapter III: Methods

Overall Research Design

Study Area

This research was conducted on Gitga'at First Nation Territory in Tsalagiw (Hartley Bay), British Columbia. Hartley Bay is a small Tsimshian community with deep cultural connections to the lands and waters of their Traditional Territory. In recent years, the Nation has begun action to reduce their community's reliance on diesel power by constructing a new hydroelectric dam east of the community. To support the dam's construction, a 5.7-kilometre service road was built to facilitate the movement of equipment and building supplies to the new dam's location. While the service road will provide critical access to the dam and secure renewable energy for the community, the negative effects of road construction will persist. Consequently, this study focused on these newly formed roadside areas and how we might revegetate the area with local, native plant species.

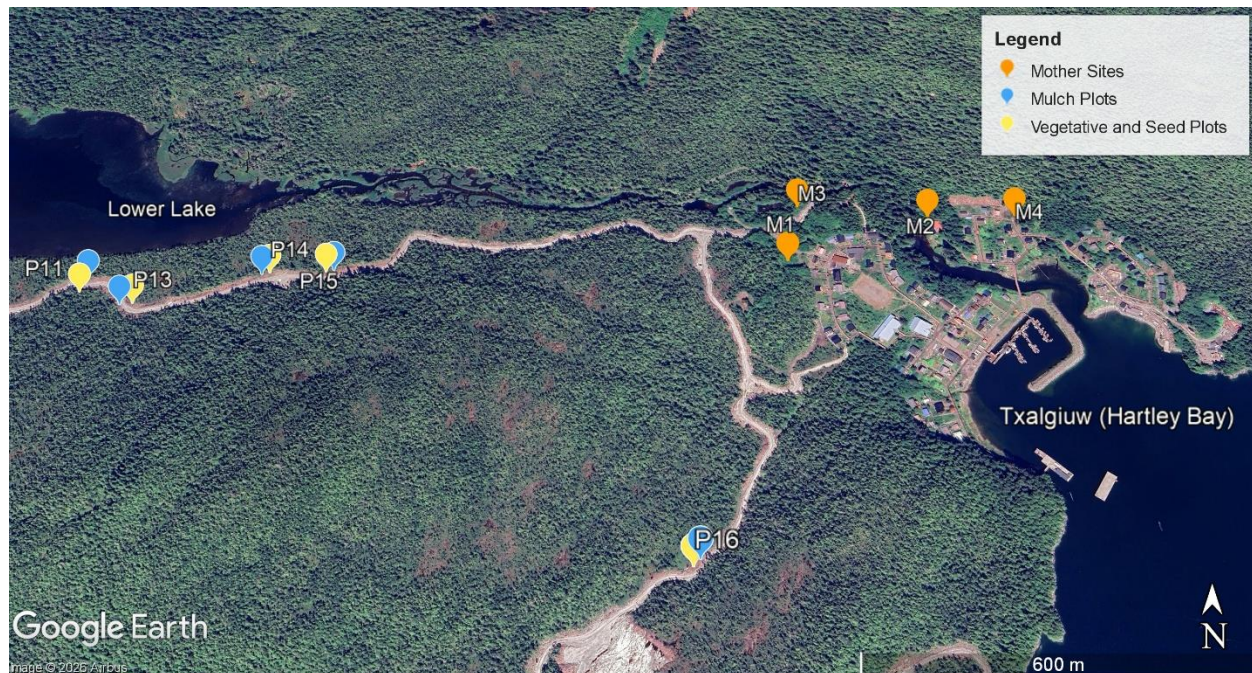
Experimental Site Selection

Five research sites were chosen along the road based on their size, slope, and debris cover. Large patches (at least 13 metres long by 4 metres wide) with minimal sloping and without woody debris and rock fragments were preferred. Minimal sloping was desirable to ensure easy access to patches by elders and children for future berry picking, while woody debris was avoided to ensure suitable planting substrate. Research sites were limited to the first four kilometres of road due to active road

construction. Roadside vegetative and seed trials were contained to these five sites, while mulch trials were conducted at additional sites located in close proximity due to spatial restrictions (Figure 1).

Figure 1

Map of Research Sites, Txalgiuw (Hartley Bay, BC)



Note. Yellow icons indicate the location of research sites that include vegetative and seed trial plots, while blue icons indicate the location of mulch trial plots conducted in 2025 in close proximity to the original research sites. Map data attributed to Google, Airbus (Google Earth, n.d.).

Species Selection

Species selection was carefully considered to promote culturally sensitive land reclamation. Revegetating patches with local transplants of culturally important plants to

the Gitga'at was essential for maintaining the connection between people and place, and to promote the future use of these patches for berry picking and material harvesting. As a result, '*Nwana'a lax Yuup: Plants of the Gitga'at People* (Turner & Thompson, 2005) was used to create a short-list of species that were culturally significant, and likely to succeed in harsh roadside conditions. Potential ecological benefits were also considered when selecting species for revegetation, as roadside soils would likely be degraded. Consequently, salmonberry (**mak'ooxs**; *Rubus spectabilis*), thimbleberry (**sgan k'oo**; *Rubus parviflorus*), fireweed (**haas**; *Chamaenerion angustifolium*), Alaskan bunchberry (**k'apk'oop**; *Cornus unalaschensis*) and broad-leaved plantain (**naaganaw**; *Plantago major*) were chosen as potential species for revegetation. This plant list was presented to community members at a community meeting at the beginning of the project in early May 2024. Following community feedback, the list was further narrowed to salmonberry, bunchberry, and fireweed.

Each of these selected species are culturally important to the Gitga'at and have the potential to bring ecological benefits to the roadside once established: Salmonberry plants readily grow in disturbed areas or roadsides and produce sought-after fruits, making them an excellent choice for land reclamation in our context (Zouhar, 2019); Fireweed is known to be an exceptional species for restoration across North America due to its fine roots and capacity for soil stabilization (Pavek, 1992), while the young inner shoots of fireweed were traditionally eaten by Gitga'at People (Turner & Thompson, 2005). Some community members have been using fireweed flowers to make jellies and drying the leaves and flowers to make teas with the Gitga'at Health

Department (Gitga'at Nation, M.B., personal communication, July 2026); Bunchberry may act as a barrier between the sun and soil once established as a ground cover, effectively allowing patches to retain moisture in an open-canopy environment.

Bunchberry is also known to inhabit all stages of succession in a wide range of habitats, soil moistures, and nutrient regimes (Gucker, 2012a), making it a good candidate for attempted roadside reclamation. Community members also harvest bunchberry fruits to eat (Turner & Thompson, 2005). Overall, the flowers, fruits, and soil stabilization provided by these species are expected to support the food and habitat needs of wildlife, while simultaneously creating a space where the Gitga'at community can harvest cultural foods and materials.

Species Collection

Salmonberry, fireweed, and bunchberry all readily reproduce through vegetative means (Gucker, 2012b, 2012a; Pavek, 1992; Zouhar, 2019), therefore rhizomes were prioritised for the propagation of these species directly to the roadside. Vegetative propagation was also chosen as the main propagation method, as it generally produces mature plants faster than attempting propagation by seed (Awotedu et al., 2021). All plant material was collected following the appropriate cultural protocols as well as with suggestions from community members to collect rhizomes away from known contaminated areas. As such, four mother sites were selected within the community to gather salmonberry and fireweed rhizomes, while bunchberry rhizomes were collected from the forest adjacent to sites 14 and 15 (Figure 1). Following the optimal rhizome cutting lengths for propagation and of other native berry species (MacKenzie &

Renkema, 2011; Sharma, 2005), root systems of mother plants were uncovered, and 10 cm rhizome segments were collected from all species. Salmonberry and fireweed rhizome segments were cut to include at least three nodes to encourage shoot emergence, and cuttings were generally kept between 1 and 1.5 cm in diameter. As it was difficult to count nodes on bunchberry rhizomes, these rhizomes were cut to include at least one ramet and two above-ground stems. Dates for rhizome collection are further described in the following sections.

Although vegetative propagation was the focus of this thesis, propagation by seed was pursued in small scale trials to explore the practicality of using this revegetation method within our context. Salmonberry and bunchberry fruits were collected within the community in July and August respectively, and processed in a blender with water to remove the fruit pulp from the seeds (Bonner, 2008). Afterwards, seeds were spread on paper towel and allowed to air dry before being stored at room temperature in glass containers. Three replicates of 100 seeds were counted and weighed to determine the average number of seeds per gram for each species. Using this mass ratio, seeds were weighed to estimate the sample size for each seed treatment. Fireweed seed was not collected due to time constraints, as fireweed plants within the community did not produce seed pods until late August.

Experimental Design of Objectives

Objective 1 – Roadside Vegetative Trials (2024-2025): Experimental Design, Rhizome Propagation, and Data Collection

To determine if target species were suitable for roadside revegetation through rhizome transplanting, a vegetative trial was conducted in 2024 at five sites. Each site was composed of four planting blocks (two metres by two metres) with at least one metre of buffer between treatments, the roadside, and the forest edge. These planting blocks were planted with varied species combinations (using salmonberry as the focal species) to control for any interactions between species that might occur as plants grew larger. Each planting block was quartered, and rhizomes were planted in patterns within each quadrant to ensure adequate spacing among species. Table 1 describes the species composition of each planting block and Figure 2 demonstrates the spacing configuration of each species. Spacing configurations of species were uniform across planting blocks.

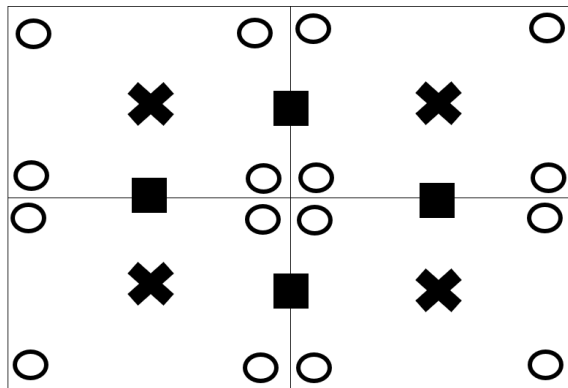
Table 1

Transplanted Species Included in Each Planting Block for 2024 Roadside Vegetative Trials

Planting Block	Species
1	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>)
2	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>) and fireweed (haas ; <i>Chamaenerion angustifolium</i>)
3	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>) and Alaskan bunchberry (k'apk'oop ; <i>Cornus unalaschensis</i>)
4	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>), fireweed (haas ; <i>Chamaenerion angustifolium</i>), and Alaskan bunchberry (k'apk'oop ; <i>Cornus unalaschensis</i>)

Figure 2

Spatial Configurations of Each Species within Roadside Planting Blocks



Note. A visual representation of treatment 4 with a quartered plot layout where X = salmonberry, ■ = fireweed, and O = Bunchberry.

Rhizomes were collected in early May 2024 (Salmonberry, $n = 80$; Fireweed, $n = 40$; Bunchberry, $n = 160$) and planted in treatment blocks at a depth of 5 cm.

Salmonberry rhizomes were randomly placed within each treatment with respect to origin, which was recorded for future analysis. Since bunchberry rhizomes ($n = 160$) were collected with ramets and stems attached, these rhizomes were transplanted at approximately 5 cm deep with aboveground foliage visible.

Salmonberry and fireweed rhizomes were monitored weekly for emergence from June 3 to August 28, 2024. Unemerged salmonberry rhizomes were excavated in late August 2024 to determine their viability, and were recorded as an emergence failure if they were rotted or moulded and were subsequently removed from the plot. Bunchberry success was assessed as shoot survival and new growth rather than “emergence” due to the presence of aboveground shoots when planted. The survival of shoots was monitored weekly, being counted as dead if the leaves desiccated and dropped from the

stem. New growth was documented if the bunchberry rhizome produced new shoots, and the number of those shoots were recorded. The survival of bunchberry rhizomes was not recorded at the end of the season, since many bunchberry rhizomes were still actively producing new shoots despite the absence of above-ground foliage. As a result, I did not want to falsely document rhizomes as dead when they may have gone on to produce new shoots in the following weeks. In May 2025, all sites and species were surveyed to determine the overwintering survival of planted rhizomes.

Each transplant treatment was surveyed to determine the percent cover of obstructions. Woody debris and coarse rock fragments that were at least 10 cm in size, along with an inventory of competitive vegetation was documented. Site characteristics for the roadside vegetative trials were reported (see Appendix A).

Objective 2 – Roadside Seed Trials (2024-2025): Experimental Design, Seed Propagation, and Data Collection

To assess the seed germination and establishment capacity of target species on the roadside, roadside seed trials were conducted at five sites for both salmonberry and bunchberry starting in August 2024. At each site, four experimental seed plots were established within the one-meter buffer space between the vegetative trial plots. These seed plots were placed within the buffer space between the vegetative trials due to a lack of available planting sites, as many roadside locations were being actively redressed with topsoil during the time of the experiment. Seed plots were randomly assigned a species and subjected to a mulched or controlled treatment (Table 2). Before

seeding, each plot was tilled and encircled with plastic fencing to reduce the erosion of any seeds or mulch outside of the research plot.

Table 2

Seed Trial Plot Layouts Per Site

Plot	Species	Treatment	Number of seeds
1	Salmonberry	Mulched	800
2	Salmonberry	Not mulched	800
3	Bunchberry	Mulched	500
4	Bunchberry	Not mulched	500

All seeds were pretreated with a 1% sodium hypochlorite solution for seven days to weaken the seed coat and enhance germination (Stevens & Darris, 2000). After seven days, seeds were carefully rinsed with water to remove traces of the pretreatment solution and broadcasted over their respective plots using a mesh screen in August 2024. Cedar bark mulch was added at a depth of 5 cm after seed was broadcasted. Mulch was made from western redcedar (**smgán**; *Thuja plicata*) bark locally sourced from the community's sawmill. The bark was soaked in water to be made pliable, then manually chopped into medium-sized pieces using an axe, since attempts at processing the bark through a woodchipper were unsuccessful.

Data collection involved determining seedling establishment rates of each plot, and digitally scanning salmonberry seedlings to calculate leaf surface areas. Seed plots were surveyed for seedling establishment on June 15, 2025 by grid-counts; mulch was temporarily removed from mulched treatments to ensure seedlings were not hidden, and counted seedlings were marked at the base of their stem using orange acrylic paint to reduce errors in counting. Sampling was completed in mid-June so that counts were

less influenced by seedling mortality from increasing summer temperatures. Since it is possible that seeds continued to germinate and establish in roadside soils after mid-June, it is important to note that the reported results of seedling establishment are with respect to the survey date. From August 7 to August 13, 20 salmonberry seedlings were removed from each plot by randomly selecting a grid square, then visually selecting the largest seedling in the grid square for analysis. Visually selecting the largest seedling was done to control for differences in seedling ages and the corresponding effects of seedling age on leaf surface area. Salmonberry seedlings were digitally scanned using a Xerox scanner and leaf surface area was calculated using ImageJ (Schneider et al., 2012).

Environmental variables recorded were soil moisture and bulk density; moisture readings were recorded weekly from June 3 to August 5, 2025. Weekly moisture readings consisted of three measurements taken at 5 cm and 10 cm depths from each seed plot. Average soil moisture was then calculated across the season for each seed plot at the specified depths for analysis. To measure bulk density, three soil samples were randomly taken from each seed plot at a depth of 0-5 cm and transported to the University of Northern British Columbia (UNBC) for kiln drying and weighing. The bulk density of each sample was determined, and average bulk density was calculated per treatment plot for analysis. Vegetation cover data was not collected because seedlings were the sole occupiers of the plot on the survey date.

Objective 3 – Greenhouse Vegetative Trial (2024): Experimental Design, Rhizome Propagation, and Data Collection

To assess the emergence capacity of target species in a greenhouse setting, a greenhouse trial was conducted. Due to limited greenhouse space and the importance of salmonberry as a cultural food, salmonberry was the only species pursued for a greenhouse trial. Roadside soil from Site 16 was manually homogenized with locally sourced sand to serve as a substrate for the greenhouse trial. Rhizomes were collected equally from four mother sites in May 2024 ($n = 60$) and planted in nursery pots at a depth of 5 cm. All propagates were watered as needed, and rhizomes were monitored weekly for emergence from May 13 to June 22, 2024.

Unemerged rhizomes were excavated on June 22 to assess their viability, with their status being recorded as viable if there were signs of node growth, or an emergence failure if they were rotted or moulded. Those with signs of node growth were wrapped in a moist paper towel and put into ventilated plastic bags to encourage further development, as emerged rhizomes would be used to conduct the natural fertilizer trial. Development was monitored regularly, and rhizomes were replanted in soil pots once they produced shoots longer than 1 cm. All rhizomes that failed during this process were recorded.

Objective 4 – Greenhouse Fertilizer Trial (2024): Experimental Design, fertilizer sourcing, and Data Collection

To determine the effects of natural fertilizers on greenhouse-grown salmonberry plants, a fertilizer trial was performed with the plants grown from the greenhouse trial.

Local materials that could be readily sourced within the community were selected to test the efficacy of natural fertilizers compared to commercially purchased fertilizers. As such, fish and seaweed were chosen for their widespread use as biofertilizers (Bhuimbar & Dandge, 2023; Zafar et al., 2022; Zodape, 2001). Fish, such as salmon, have been shown to support the productivity of salmonberry plants in the Pacific Northwest (Reimchen et al., 2002; Siemens et al., 2020; van den Top et al., 2018). Seeing that salmon fishing is a large part of Giga’at culture and diet, the community produces significant volumes of salmon fish scrap that could be made into biofertilizers and potentially used in large-scale applications if the results of the fertilizer trial were promising. Chinook salmon (**yee**: *Oncorhynchus tshawytscha*) was chosen as a natural fish fertilizer due to this rationale, in addition to its availability during the time of the experimental trials. Among the species of seaweed present in Gitga’at Territory, rockweed (**p’aatsah**; *Fucus distichus*) was chosen for its proximity to shore and high abundance. Other species from the *Fucus* genus have previously shown positive effects on plant growth (Latique et al., 2013; Michalak et al., 2016), making rockweed a good candidate for experimentation. Finally, Miracle-Gro® was selected as an inexpensive commercial alternative to natural biofertilizers for comparison. Since harvesting and processing natural materials for biofertilizer takes substantial time and effort, it was important to test the effectiveness of a commercial fertilizer that required minimal processing.

Four fertilizer treatments (rockweed, Chinook salmon, Miracle-Gro®, and a Control) were applied to the salmonberry plants following the first week of their emergence. Due to a limited timeframe, the unavailability of equipment within the

community, and the potential for the fertilizer-making process to become a bear attractant, liquid fertilizers were not pursued as an application method. Instead, natural materials were processed into fertilizer slurries that could be buried beneath the soil to reduce any potential odours.

To create these fertilizer slurries, rockweed was collected locally from Malsey Bay, and Chinook salmon was donated from a Hartley Bay community member. These materials were processed in a dehydrator at 65 °C from four to six hours until dry, ground into a fine powder, and made into slurries using distilled water. Slurries were mixed at a concentration of 2.5 g/10 mL and 4.0 g/10 mL of rockweed and fish respectively. Standard 20-20-20 Miracle-Gro® was mixed with distilled water according to outdoor application instructions to make a solution with the concentration of 0.26 g/500 mL.

Each week, slurry treatments were buried in the soil surrounding the salmonberry rhizome, while the liquid Miracle-Gro® was applied to the soil at the base of the plant. All plants were watered after fertilizers were applied. Salmonberry plants were measured weekly for stem height and stem diameter. Due to inconsistencies with weekly measurements, only final measurements for stem height and stem diameter were used for analysis. Final measurements were taken on August 28, 2024.

At the end of August, salmonberry plants and their pots were embedded within a raised flower bed inside the greenhouse. Plants were watered regularly until they entered dormancy and were subsequently mulched to provide an insulative barrier for overwintering, as the greenhouse did not operate year-round.

Objective 5 – Roadside Mulch Trials (2025): Experimental Design, Rhizome Propagation and Data Collection

During the first field season (2024), it was observed that roadside soils appeared to be forming a dense, dry crust. Since it was possible that this crust was inhibiting rhizome emergence, an additional roadside trial was designed in 2025 with mulch as a soil amendment to address this issue. Five roadside sites were established with two treatments (mulch and no mulch) per site. The size of each treatment block was 1 m². Due to spatial constraints, sites for the mulch trial were not necessarily the same as the sites used for the 2024 vegetative trials or seed plots. Salmonberry was pursued as the target species for this mulching experiment.

To assess if mulching would improve roadside salmonberry rhizome emergence and plant performance, rhizomes were collected in early May 2025 from two mother sites (M1, $n = 40$; M2, $n = 40$) since rhizome collecting was restricted due to active development and construction in the area. Rhizomes were planted on May 13, 2025 at a depth of 5 cm and arranged so that an equal number of rhizomes from both origins were planted under each treatment. Scotts Nature Scapes® Mulch Sierra Red was applied at a thickness of approximately 8 cm (3 inches) as a mulch treatment. Treatment plots were monitored weekly for salmonberry rhizome emergence from June 3 to August 8, 2025. Unemerged salmonberry rhizomes were excavated on August 8 to determine their viability. Rhizomes were recorded as an emergence failure if they were rotted or moulded, and were subsequently removed from the plot. Metrics of plant health including plant height, stem diameter, and average crown spread were measured for all salmonberry plants on August 6, 2025 using rulers and electric calipers. Average

crown spread was determined by first measuring the widest part of the plant, then measuring the second widest part of the plant perpendicular to the first (Faculty of Forestry & Environmental Stewardship, 2013). Plant height and average crown spread was measured to the nearest centimetre.

To capture soil temperature data, Thermochron iButton®s (DS1921G-F5#) were deployed within custom 3D-printed capsules at the centre of each treatment plot at a depth of 5 cm to record soil temperature (Note: iButtons were evaluated both with and without custom capsules prior to deployment to determine how capsules may impact temperature readings. Preliminary testing revealed that capsules did not significantly alter temperature readings, thus making them acceptable for deployment in this study. Capsules were required for deployment as Thermochron iButton®s are not waterproof, and were 3D-printed to specifications to reduce experimental costs); Onset HOBO UA-002-64 Pendants were deployed under mulch treatments to record surface soil temperatures beneath the mulch, and HOBO MX2202 Pendants were mounted between treatment plots approximately 30 cm off the ground to capture site-specific light intensity data. Due to issues with equipment availability, ambient temperature data was not collected until July 8, 2025, and therefore could not be used for emergence analysis. Surface soil temperatures, light intensity, and ambient temperature (from July 8 to August 10, 2025) is simply reported in the results section to provide additional detail for site characteristics.

Other environmental variables recorded were soil moisture, bulk density, and the percent cover of competing vegetation. Moisture readings were recorded weekly from June 3 to August 5, 2025. Weekly readings consisted of three measurements taken at 5

cm and 10 cm depths from each treatment plot. Average soil moisture was then calculated across the season for each treatment plot at the specified depths for analysis. To measure bulk density, three soil samples were randomly taken from each treatment plot at a depth of 0-5 cm at the end of the season and transported to the University of Northern British Columbia (UNBC) for kiln drying and weighing. The bulk density of each sample was determined, and average bulk density was calculated per plot for analysis. Vegetative percent cover surveys were taken at the beginning and the end of the season, however only end percent cover was included in salmonberry emergence and growth analysis models.

Objective 6 – Roadside Shrub Transplant Trial (2025): Experimental Design and Data Collection

Since salmonberry greenhouse plants from the previous season needed to be replanted to the roadside as part of the revegetation project, I planned a transplant trial in 2025 to compare the seasonal growth between greenhouse-grown ($n = 34$) and roadside-grown ($n = 21$) salmonberry plants in a roadside setting. Greenhouse-grown plants were re-located outside of the greenhouse for two weeks to allow plants to acclimate to an outdoor environment prior to roadside transplant. On May 30, 2025, greenhouse-grown plants were transplanted to the same plots used for the roadside vegetative trial. Greenhouse-grown plants were matched to the same plot quadrants as roadside-grown plants, and spaced at least 30 cm away to accommodate any growth over the season. Transplants were placed strategically to reduce any potential for greenhouse-grown plants to provide shade for smaller roadside-grown plants. Since

there were a greater number of greenhouse-grown plants, unmatched transplants were placed in other quadrants and evenly spread across sites. All plants were measured for stem height, stem diameter, and crown spread directly after transplanting, and on August 4, 2025 for end of the season measurements.

Statistical Analysis

R Programming and Statistical Packages

All statistical analyses were performed in R (R Core Team, 2024) using various packages; residual diagnostics were performed using DHARMA (Hartig, 2024) to assess model fit; linearity assumptions (including relationships and collinearity) were verified and ANCOVA tests were completed using the car package (Fox & Weisberg, 2019); Generalised Additive Models (GAMS) were performed with the mgcv package (Wood et al., 2016); viable models were compared using MuMIn R package (Bartoń, 2025); marginal effects for population estimates were made using marginaeffects (Arel-Bundock et al., 2024); and plots of significant effects were created using ggeffects (Lüdecke, 2018) unless otherwise stated. The following sections describe the model selection process for each objective, and Table 3 provides a summary of all models selected for analyses and reported in the results section.

Overview of Statistical Models

A variety of model types were used for data analysis given the diversity of the data collected (Table 3). The following table provides a summary of which models were used in correspondence to the thesis objectives and experimental components. A

detailed explanation for how each of these models were selected for analysis is provided in the following section.

Table 3

Summary of Statistical Models Used for Data Analysis

Objective	Response	Model Type	Model Structure	
			Fixed Effects	Random Effects
2. Roadside Seed Trials	Salmonberry germination and establishment	GLMER	Treatment (mulch/control) + Bulk density	Site
2. Roadside Seed Trials	Bunchberry germination and establishment	GAM	Treatment (mulch/control)*Bulk density	Site
2. Roadside Seed Trials	Salmonberry leaf surface area	GLMER with robust standard errors	Treatment (mulch/control)	Site
4. Greenhouse Fertilizer Trial	Salmonberry plant height	Weighted Regression	Treatment (Fertilizer type/control) + Days since emergence (plant age)	N/A
5. Roadside Mulch Trials	Salmonberry rhizome emergence	GLM	Treatment + Rhizome origin + Bulk density + Soil moisture + Percent cover + Maximum soil temperature recorded	N/A
5. Roadside Mulch Trials	Salmonberry plant height	LM	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent cover + Days since emergence (age)	N/A
5. Roadside Mulch Trials	Salmonberry stem diameter	LM	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent Cover + Days since emergence (age)	N/A
5. Roadside Mulch Trials	Salmonberry average crown spread	LM	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent cover + Days since emergence (age)	N/A
6. Shrub Transplant Trial	Salmonberry plant height	Wilcoxon rank-sum	N/A	N/A

Table 3*Summary of Statistical Models Used for Data Analysis (continued)*

Objective	Response	Model Type	Model Structure	
			Fixed Effects	Random Effects
6. Shrub Transplant Trial	Salmonberry plant height	Wilcoxon rank-sum	N/A	N/A
6. Shrub Transplant Trial	Salmonberry stem diameter	Wilcoxon rank-sum	N/A	N/A
6. Shrub Transplant Trial	Salmonberry average crown spread	Wilcoxon rank-sum	N/A	N/A

Note. The “ns” prior to soil moisture indicates that the variable was fit with a natural spline.

Objective 2 – Roadside Seed Trials (2024-2025)

Germination was modelled separately for each species starting with logistic regression, while salmonberry seedling leaf area was modelled with a linear mixed-effects model. Predictor variables considered in analyses were treatment and average bulk density. Soil texture was not included in analyses as it was partially confounded with site, and a texture effect could therefore not be separated from a site-level effect. The process of selecting models is described below.

Salmonberry Germination and Establishment

An interaction between treatment and bulk density was explored but was not significant and did not improve model fit. As a result, the model without an interaction was selected for interpretation and odds ratio calculations.

Bunchberry Germination and Establishment

A weak nonlinear relationship between bulk density and bunchberry germination was detected. To improve model fit, bunchberry germination was modelled using a Generalised Additive Model (GAM), with bulk density incorporated as a smooth parameter. A model without interactions indicated significant concavity between bulk density and site as a random effect (concurvity = 1). Subsequently, an interaction between treatment and bulk density was found to be significant and substantially improved model fit (concurvity = 0.5). The final model selected for analysis was a GAM with a binomial family and logit link function that included an interaction between treatment and bulk density, and site as a random effect.

Salmonberry Seedling Health – Leaf Surface Area

When leaf surface area was modelled with bulk density, residuals exhibited extreme heteroskedasticity indicating poor model fit. Interactions between bulk density and treatment, and log transformations of the response variable did not improve model fit. Exploratory gam models found bulk density to be concave with site despite interactions (concurvity = 1), so bulk density was subsequently dropped from the model. The final model selected for analysis was a linear mixed-effect model with a log-transformed response, treatment as the predictor variable, and site as a random effect.

A Levene Test for homogeneity of variance was significant, so this model is reported with robust standard errors.

Objective 4 – Greenhouse Fertilizer Trial (2024)

To determine the effects of natural fertilizers on greenhouse-grown salmonberry plants, both final plant height and final stem diameter were analysed. A Type II ANCOVA was performed with final stem height as the response, fertilizer treatment as a predictor, and the number of days since emergence as the covariate. Diagnostic plots of residuals vs. fitted values indicated there was some unequal variance, although DHARMA did not detect any significant issues. To improve model fit, a weighted regression was performed and compared with the ANCOVA model (Table 4). Since the weighted model (model 2) had lower deviance and standard error while also improving model fit, the weighted model was selected for analysis and interpretation.

Table 4

Comparisons Between Fertilizer Effects Candidate Models

Model	<i>Model Structure</i>		<i>Model Summary</i>			
	Model Type	Fixed Effects	<i>df</i>	SE	Deviance	Adjusted r-squared
1	ANCOVA	Treatment + Days since emergence	29	2.86	237.8	0.30
2	Weighted Regression	Treatment + Days since emergence	29	1.24	44.65	0.40

Final stem diameter was also assessed using an ANCOVA model with fertilizer treatment as a predictor and number of days since emergence as a covariate. Residual

diagnostic plots did not indicate that a weighted regression analysis was necessary for this model. Consequently, results are reported using the ANCOVA model.

Objective 5 – Roadside Mulch Trial (2025)

Salmonberry Rhizome Emergence

Emergence was modelled using multivariate logistic regression with the proportions of emerged salmonberry rhizomes represented as binary outcomes. Site was initially trialed as a random effect in candidate models, but provided a singular fit and was subsequently dropped from all models. While all other variables satisfied linearity assumptions, maximum soil temperature recorded and average daily maximum soil temperature were found to be collinear. To determine which soil temperature variable should be included in prediction modelling, I modelled both variables separately while testing for their collinearity with other variables. Each model exhibited moderate collinearity between the temperature variable and average soil moisture (model 1, VIFs: average daily maximum temperature = 6.85 and average soil moisture = 7.17; model 2, VIFs: maximum temperature recorded = 6.72 and average soil moisture = 9.11), but otherwise provided good model fit. As a result, two models were compared, each fitted with a soil temperature variable (Table 5). Since the model with maximum soil temperature was strongly supported (model 1, delta AIC = 0.00, weight = 0.77), the model with maximum soil temperature (model 1) was selected to explore possible interactions. However, none of the interactions were statistically significant or improved model fit. Maximum temperature, average soil moisture, and vegetative percent cover (VIF = 5.59) variables were centered to improve model stability in the face of moderate

collinearity. Emergence probabilities were predicted and plotted to visualise the relationships between statistically significant variables and salmonberry rhizome emergence.

Table 5

Comparisons Between Rhizome Emergence Candidate Models

Fixed Effects	Model	
	1	2
Treatment (mulch or control)	+	+
Rhizome origin (M1 or M2)	+	+
Bulk density	+	+
Soil moisture (seasonal average)	+	+
Percent Cover (end of season)	+	+
Daily maximum temperature (seasonal average)	-	+
Maximum soil temperature recorded	+	-
Model Selection Summary		
Delta AIC	0.00	2.45
Weight	0.77	0.227

Salmonberry Plant Health: Plant Height, Stem Diameter, and Average Crown Spread

Plant height, stem diameter, and the average crown spread of emerged rhizomes were modelled using linear mixed-effects model with environmental predictor variables, time since emergence as a covariate, and site as a random effect. However, the random effects structure was dropped for all models, as it provided a singular fit. Maximum soil temperature recorded was not used as a variable in plant health models, as maximum recorded temperature was unlikely to cause long-term effects on plant growth. While testing model assumptions, average soil moisture and average daily maximum soil

temperature were found to be collinear (VIFs > 10). Consequently, average daily maximum soil temperature was dropped from all models since soil moisture would likely have a greater impact on plant growth. Average soil moisture was fitted with a natural spline (df = 2) in all models to capture the nonlinear relationship between moisture and plant health parameters, and a natural spline (df = 2, df = 3) was explored in candidate models for stem diameter and average crown spread respectively. Interactions were tested to improve model fit and to identify nonadditive effects, however no significant interactions were reported. Models with good fit for each plant health parameter were compared (Table 6). Models chosen for analyses of plant height, stem diameter, and average crown spread were models one, two, and five respectively.

Table 6*Comparisons Between Candidate Plant Health Effects Models*

Response	Model Type	Model	Model Structure	Model Selection Summary	
			Fixed Effects	Delta AIC	Weight
Plant Height	LM	1	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent cover + Days since emergence	N/A	N/A
		2	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent cover + Days since emergence	0.00	0.958
Stem Diameter	LM	3	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + ns(Percent cover, df = 3) + Days since emergence	6.28	0.042
		4	Treatment + Rhizome origin + Bulk density + Soil moisture + ns(Percent cover, df = 3) + Days since emergence	19.41	0.00
Average Crown Spread	LM	5	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + Percent cover + Days since emergence	0.00	0.876
		6	Treatment + Rhizome origin + Bulk density + ns(Soil moisture, df = 2) + ns(Percent cover, df = 2) + Days since emergence	3.91	0.124

Objective 6 – Roadside Shrub Transplant Trial (2025)

To compare the roadside growth between greenhouse-grown and roadside-grown salmonberry plants, final seasonal measurements of stem height, stem diameter, and crown spread were tested separately. Data exploration indicated that growth parameters were not normally distributed, but data transformations were unsuccessful and an appropriate distribution could not be specified for a generalized linear model.

Consequently, nonparametric Wilcoxon rank-sum tests were used to compare growth parameters between groups due to unbalanced pairings of plants from each group.

Chapter IV: Results

Objective 1 – Roadside Vegetative Trials (2024-2025)

Rhizome Emergence and Overwintering Survival

Rhizome emergence on the roadside differed across species, with salmonberry emergence (32.5%) being less than that of fireweed (75%). All emerged rhizomes survived the summer growing season; however, some overwintering mortality was reported (Table 7). Bunchberry had the greatest overwintering mortality rate, with more than half of transplanted rhizomes dying off.

Table 7

Rhizome Emergence and Overwintering Survival Across All Transplanted Species

	Species		
	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>)	Fireweed (haas ; <i>Chamaenerion angustifolium</i>)	Bunchberry (k'apk'oop ; <i>Cornus unalaschensis</i>)
<i>n</i>	80	40	160
Rhizome emergence rate (%)	32.5 %	75.0%	-
Proportion of emerged rhizomes by rhizome origin			
<i>M1</i>	0.55	1.0	-
<i>M2</i>	0.15	-	-
<i>M3</i>	0.35	-	-
<i>M4</i>	0.25	-	-
Overwintering survival rate of rhizomes (%)	80.8%	93.3%	40%

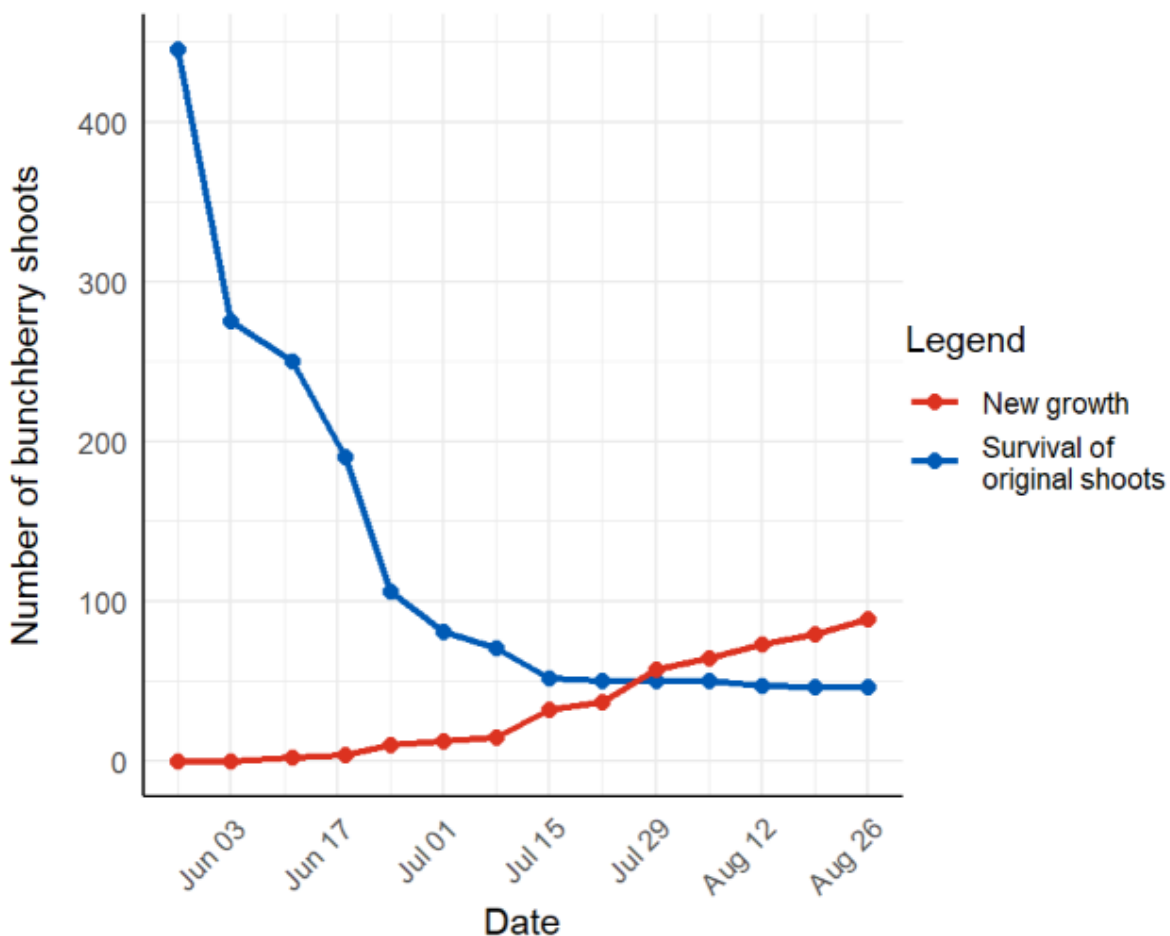
Note. Bunchberry rhizomes did not have a reported emergence rate, as shoots existing before transplant were monitored for survival throughout the growing season.

Bunchberry Shoot Survival and Rhizome Overwintering Survival

Bunchberry shoots saw a steady decline in survival as the growing season progressed (Figure 3). Following a 38.2% decrease in shoots from the planting date to June 3, many of the shoots from transplanted rhizomes desiccated within the first month of planting. Despite this, new shoot growth was reported by mid-June and steadily increased throughout the rest of the monitoring period.

Figure 3

Original Bunchberry Shoot Survival and New Growth Trends Across All Sites During the 2024 Monitoring Period



Objective 2 – Roadside Seed Trials (2024-2025)

Germination and Establishment Across Species

Overall, salmonberry seeds exhibited a greater capacity for germination and establishment in a roadside setting compared to bunchberry seeds, with 50.0% of salmonberry seeds germinating compared to 26.5% of bunchberry seeds germinating by mid-June, 2025 (Table 8).

Table 8

Roadside Seed Germination Rates Across Species and Treatments

	Species	
	Salmonberry (mak'ooxs ; <i>Rubus spectabilis</i>)	Bunchberry (k'apk'oop ; <i>Cornus unalaschensis</i>)
Seeds/m ²	800	250
Percent germinated and established by treatment		
<i>No mulch</i>	67.2 %	33.7 %
<i>Mulch</i>	32.8 %	19.2 %
Total seeds sown (<i>n</i>)	8,000	5,000
Total germinated	50.0 %	26.5 %

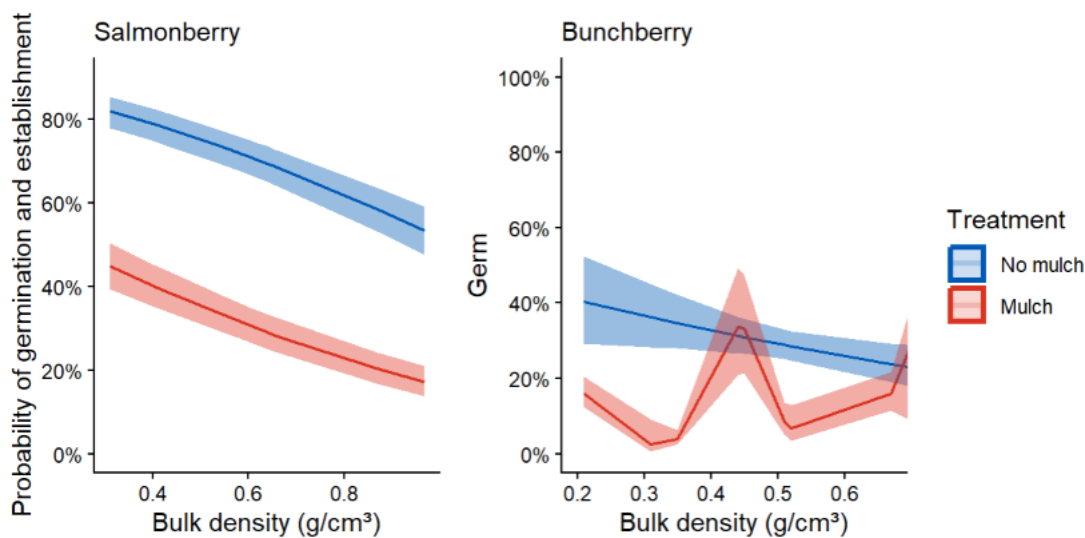
Salmonberry Seeds

Mulching had a significant negative effect on the germination and establishment of salmonberry seeds (Figure 4), with outcomes decreasing by 31.8% under mulch at average bulk density (Odds Ratio, *OR* = 0.682, 95% CI [0.668, 0.696], *p* < 0.001). Soil bulk density was also found to have a significant negative effect on salmonberry germination and establishment, with outcomes decreasing by 29.7% per every unit

increase of bulk density across treatments ($OR = 0.703$, 95% CI $[0.673, 0.735]$, $p < 0.001$). Model predictions indicated that salmonberry seed germination and establishment would be highest in areas of low bulk density, and when treated without mulch; the highest germination rates were estimated to be between 79-82% in soils with bulk densities under 0.4 g/cm^3 , with germination dropping below 60% once bulk density approached 1 g/cm^3 .

Figure 4

Effect of Soil Bulk Density and Mulching on the Probability of Roadside Seed Germination Across Species



Note. Bunchberry predictions were limited to bulk density values ranging from 0.20 g/cm^3 to 0.67 g/cm^3 since predictions beyond this point were heavily extrapolated and result in large confidence intervals that should not be biologically interpreted. This is likely due to the limited overlap in bulk density values between the mulch and no-mulch treatments above 0.7 g/cm^3 .

Bunchberry Seeds

Bulk density had varying effects on bunchberry germination under different treatments (Figure 4). Bulk density had a negative linear effect on germination under no mulch (Effective Degrees of Freedom, $\text{edf} = 1$, $p < 0.03$), but had a non-linear effect on germination under mulched conditions ($\text{edf} = 3.91$, $p < 0.001$), with an edf above 1 indicating increasing non-linearity and a more complex response across bulk density values. Site was also found to have a significant effect ($\text{edf} = 2.84$, $p < 0.001$), indicating that sites differed in baseline germination. Sites 13 and 15 showed above-average germination rates while sites 11 and 16 tended to be below-average, although confidence intervals overlapped zero. Outcomes were predicted to be highest without mulch at 43%, with germination and establishment decreasing when approaching a bulk density of 1 g/cm^3 . Under mulch, bunchberry germination and establishment changed drastically across bulk density ranges, spiking above non-mulched rates at 0.45 g/cm^3 before dropping again at 0.525 g/cm^3 . Bunchberry germination and establishment increased past bulk density value of 0.55 and converged with the probabilities predicted for the no-mulch treatment.

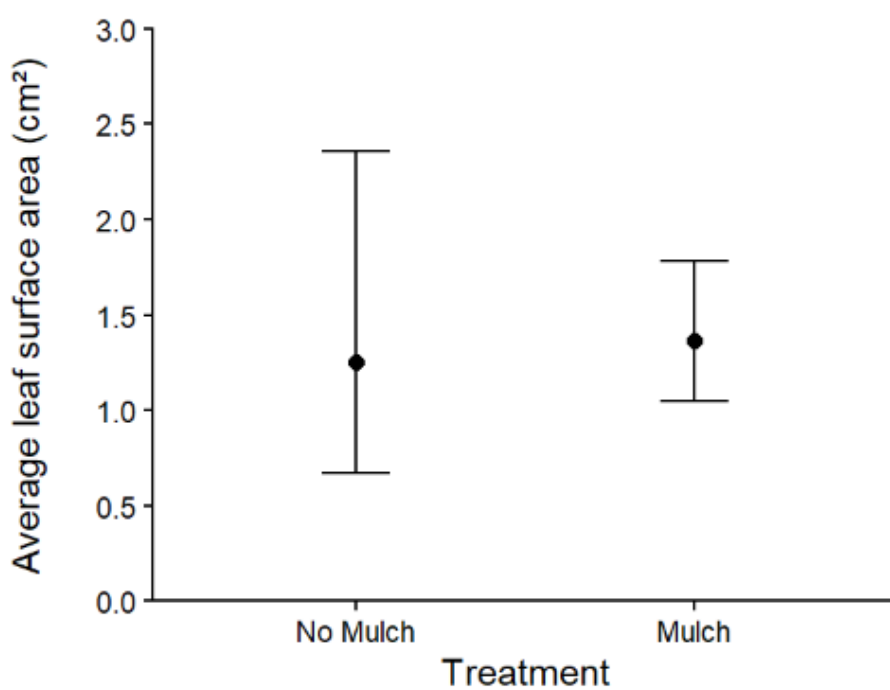
Salmonberry Seedling Health

On average, seedling leaf surface area was 1.37 cm^2 under mulch treatment, and 1.26 cm^2 under no mulch treatment when accounting for site variation (Figure 5). Mulching did not significantly enhance the total leaf surface area of salmonberry seedlings despite mulched seedlings having a 9% greater leaf surface area on average ($\beta = 1.09$, 95% CI $[0.49\text{--}2.42]$, $p > 0.8$).

Figure 5

Predicted Effect of Mulch Treatment on Average Salmonberry Seedling Leaf Surface Area

Area



Objective 3 – Greenhouse Vegetative Trial (2024)

The results indicated that 35% ($n = 60$) of salmonberry rhizomes emerged under greenhouse conditions without human intervention (Table 9). While 21 rhizomes emerged without intervention, another 21 rhizomes failed immediately as they showed signs of moulding. From the unemerged rhizomes, 18 showed evidence of node growth and were subsequently wrapped in moist paper towel to encourage faster development, as salmonberry plants from the emerged rhizomes would be used in the fertilizer trial. From these 18 wrapped rhizomes, eight were replanted and successfully emerged,

while 10 ultimately failed. Consequently, we are reporting the total emergence potential of rhizomes under greenhouse conditions and human care to be 65%, which is the sum of rhizomes that emerged, and rhizomes that showed node growth upon excavation.

Table 9

Salmonberry Rhizome Emergence in Greenhouse Trial

Viability Status	Number of Rhizomes
<i>n</i>	60
Immediate emergence (soil)	21
Immediate failure (soil)	21
Total with node growth (paper towel)	18
<i>Emerged</i>	8
<i>Failed</i>	10

Objective 4 – Greenhouse Fertilizer Trial (2024)

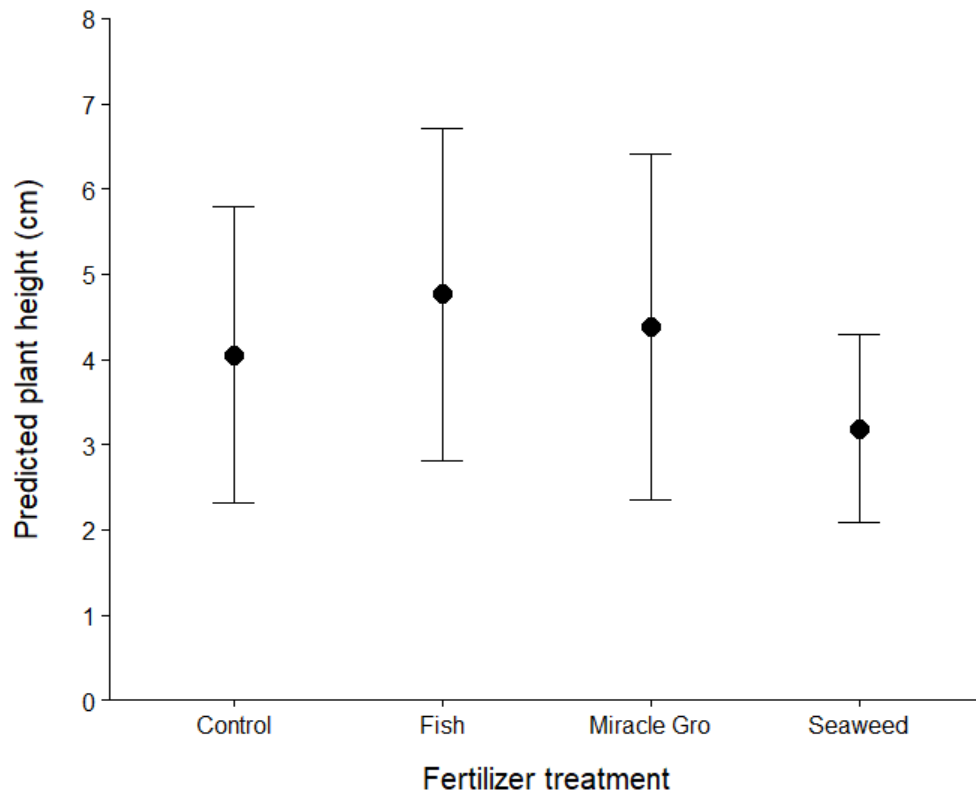
Fertilizer Effects on Salmonberry Stem Height

Fish fertilizer was predicted to produce the tallest plants at 4.76 cm, while seaweed fertilizer was predicted to produce the shortest plants at 3.18 cm (Figure 6). However, the ANCOVA adjusted for plant age indicated that fertilizers did not have a significant effect on salmonberry plant height in the greenhouse ($F(3, 0.8073) = 0.8579, p > 0.47$).

Figure 6

Predicted Heights of Salmonberry Plants with Respect to Greenhouse Fertilizer

Treatments



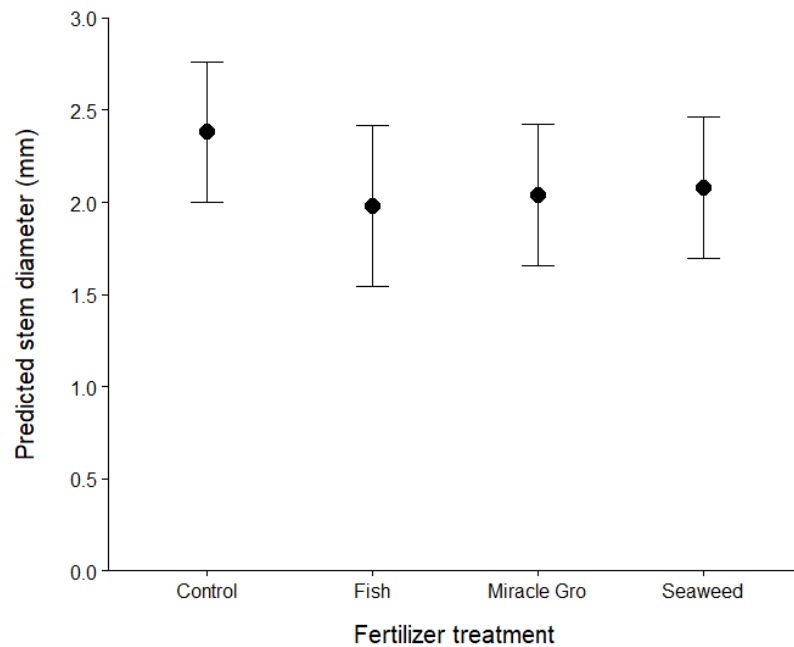
Fertilizer Effects on Salmonberry Stem Diameter

Salmonberry plants were predicted to have the largest stem diameter under the control fertilizer treatments at 2.38 mm, while plants given fish fertilizer were predicted to have the smallest stem diameter at 1.98 mm (Figure 7). After adjusting for plant age, the ANCOVA indicated that fertilizer did not have a significant effect on salmonberry stem diameter in the greenhouse ($F(3, 0.8073) = 0.8579, p > 0.47$).

Figure 7

Predicted Stem Diameter of Salmonberry Plants with Respect to Greenhouse Fertilizer

Treatments



Objective 5 – Roadside Mulch Trials (2025)

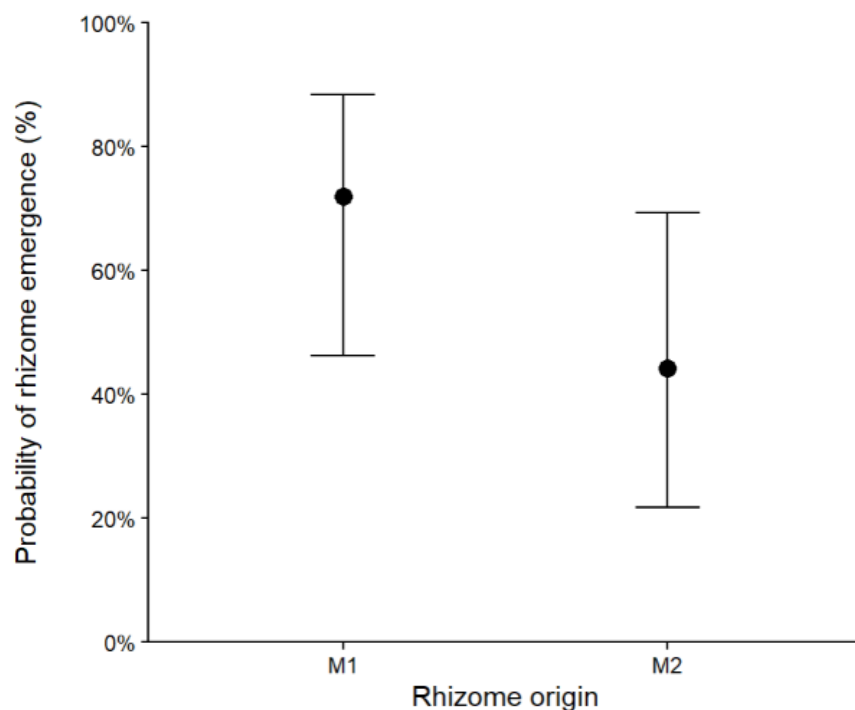
Salmonberry Rhizome Emergence

Rhizome origin ($p < 0.02$) (Figure 8), average seasonal soil moisture ($p < 0.02$), and maximum recorded temperature ($p < 0.04$) (Figure 9) were found to significantly affect salmonberry rhizome emergence in a roadside setting. Odds of rhizome emergence increased by 28% in average environmental conditions when rhizomes originated from Mother Site 1 compared to Mother Site 2 ($OR = 1.28$; 95% CI [1.05, 1.57], $p < 0.02$). Soil moisture had a negative effect on rhizome emergence, as a 1% increase above the average soil moisture conditions decreased the odds of emergence by 3.6% ($OR = 0.964$; 95% CI [0.940, 0.990], $p < 0.01$). Maximum soil temperature also had a negative

influence on rhizome emergence, with a 1 °C increase above the average maximum temperature decreasing the odds of germination by about 7.6% ($OR = 0.924$; 95% CI $[0.864, 0.987]$, $p < 0.02$).

Figure 8

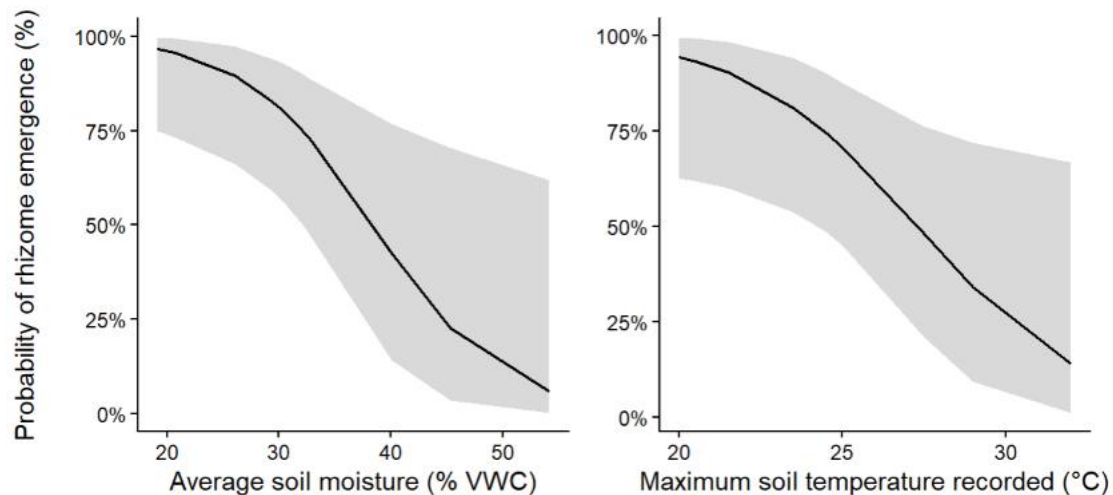
Predicted Roadside Emergence of Salmonberry Rhizomes with Respect to Rhizome Origin



Note. This figure was created using the R package *ggeffects*. This package calculates marginal predictions by holding categorical variables at their reference level, and numeric variables at their mean. Consequently, the effects of rhizome origin on emergence probability are displayed under no mulch conditions across average environmental conditions.

Figure 9

Predicted Roadside Emergence of Salmonberry Rhizomes with Respect to Average Soil Moisture (% VWC) and Maximum Recorded Soil Temperature (°C)



Note. This figure was created using the R package *ggeffects*. This package calculates marginal predictions by holding categorical variables at their reference level, and numeric variables at their mean. Consequently, the effects of average soil moisture and maximum soil temperature recorded on the probability of emergence are displayed under no mulch conditions across average environmental conditions.

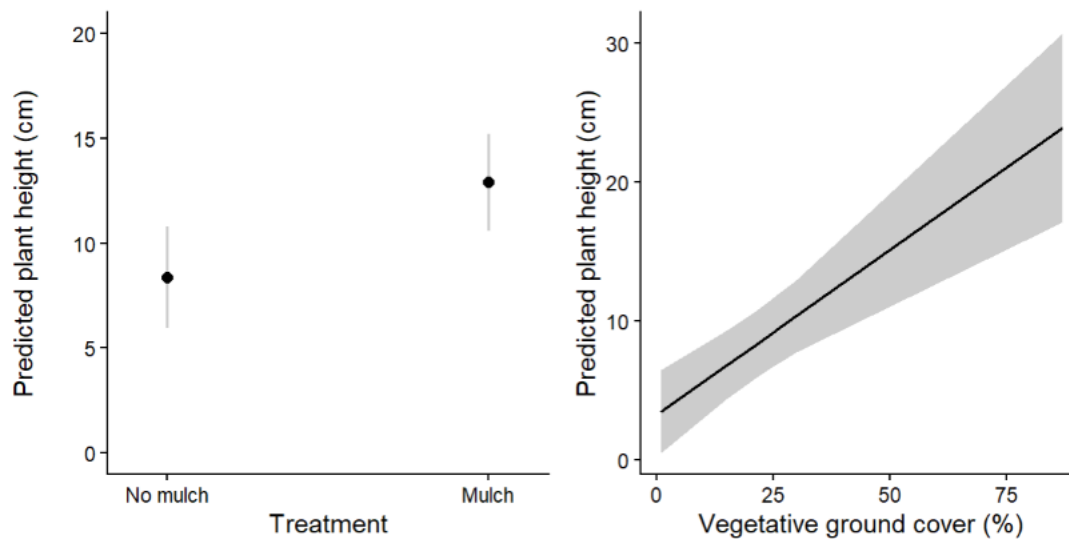
Salmonberry Plant Health: Plant Height, Stem Diameter, and Average Crown Spread

Salmonberry height was significantly influenced by treatment ($p < 0.01$) and vegetative ground cover ($p < 0.001$) (Figure 10). At average environmental conditions, mulch treatment produced taller salmonberry plants than plants grown without mulch (β : 4.51, 95% CI [1.69, 7.33], $p < 0.002$). Salmonberry plant height increased by

approximately 0.2 cm for every 1% increase in vegetation cover (β : 0.238, 95% CI [0.147, 0.328], $p < 0.001$).

Figure 10

Predicted Roadside Salmonberry Height by Treatment and Vegetative Percent Cover



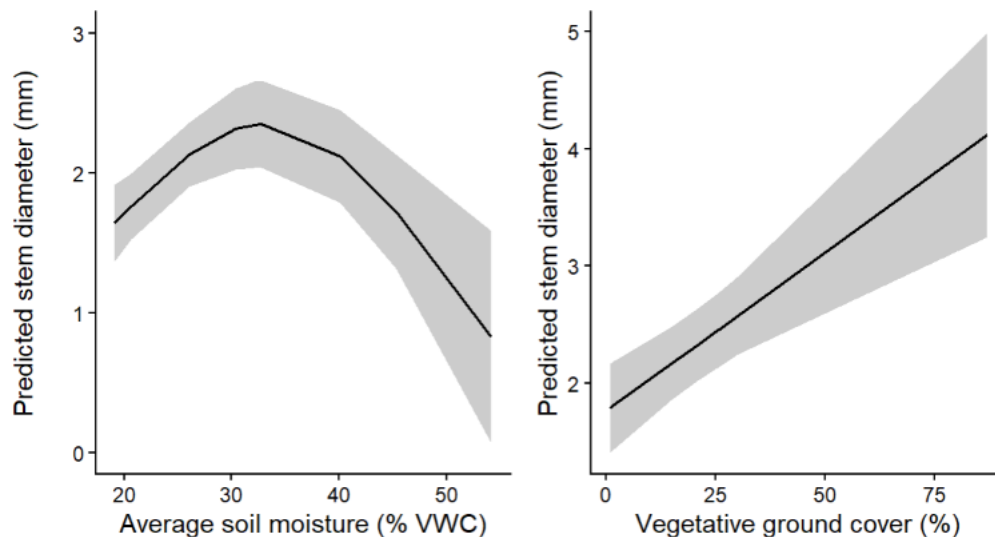
Note. This figure was created using the R package ggeffects. This package calculates marginal predictions by holding categorical variables at their reference level, and numeric variables at their mean. Consequently, the effects of treatment and vegetative ground cover on predicted plant height are displayed under rhizome origin M1 across average environmental conditions.

Both soil moisture and vegetative ground cover were found to have significant effects on salmonberry stem diameter ($p < 0.003$ and $p < 0.002$ respectively) (Figure 11); increasing soil moisture had a non-linear effect, with stem diameter increasing and peaking around 33% soil moisture around 2.5 mm before declining. As soil moisture

approached 60%, stem diameter was predicted to be smaller than diameters predicted under the lowest observed soil moisture value (approximately 20%). Increasing ground cover was associated with larger stem diameters (β : 0.027, 95% CI [0.0155, 0.0386], $p < 0.001$) across observed conditions. Analysis suggested that treatment may have had an impact on stem diameter ($p = 0.059$); however, this effect could not be confidently concluded since the p -value was close to the alpha (α) threshold of 0.05.

Figure 11

Effects of Average Soil Moisture and Ground Cover on Predicted Roadside Salmonberry Stem Diameter

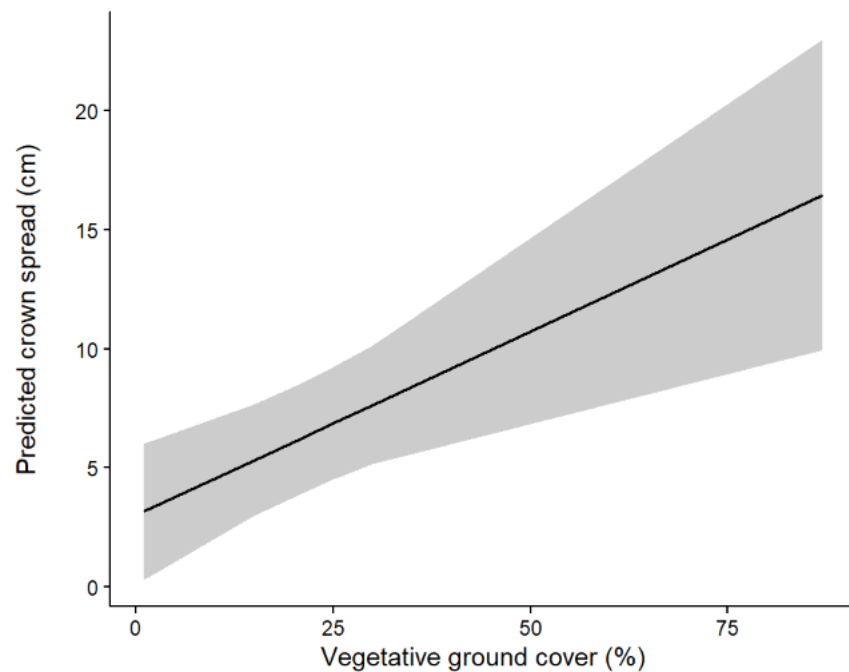


Note. This figure was created using the R package ggeffects. This package calculates marginal predictions by holding categorical variables at their reference level, and numeric variables at their mean. Consequently, the effects of soil moisture and ground cover are displayed under rhizome origin M1 and no mulch conditions across average environmental conditions.

Vegetative ground cover had a significant influence on average crown spread ($p < 0.002$), with increasing ground cover having a positive effect on predicted average crown spread ($\beta: 0.155$, 95% CI [0.068, 0.241], $p < 0.001$) (Figure 12). This relationship mimics the effects of ground cover on predicted salmonberry plant height and stem diameter. Analysis suggested that treatment may have had an impact on average crown spread ($p = 0.07$); however, this effect could not be confidently concluded since the p -value was close to the alpha (α) threshold of 0.05.

Figure 12

Effects of Vegetative Ground Cover on Predicted Average Crown Spread of Roadside Salmonberry



Note. This figure was created using the R package ggeffects. This package calculates marginal predictions by holding categorical variables at their reference level, and numeric variables at their mean. Consequently, the effects of ground cover are

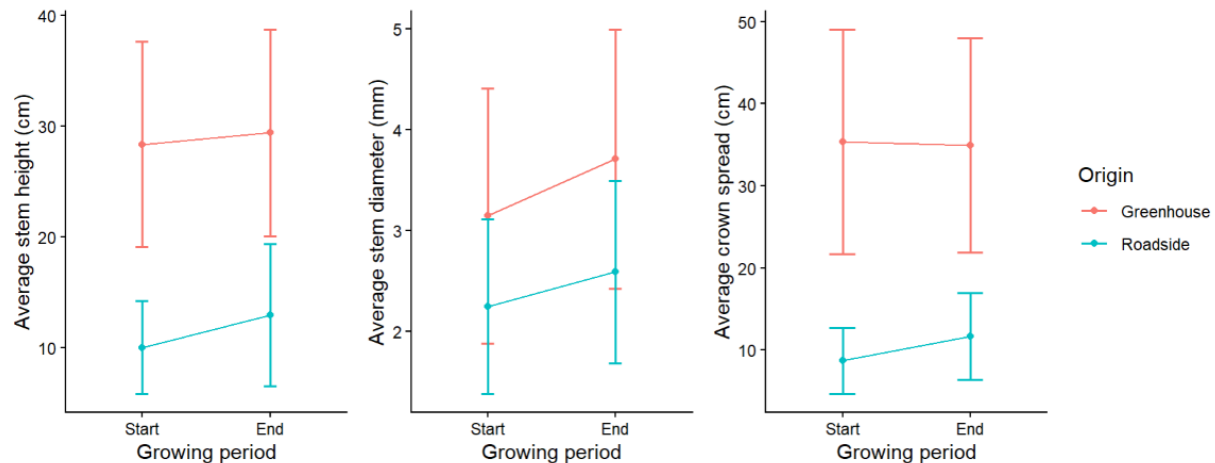
displayed under rhizome origin M1 and no mulch conditions across average environmental conditions.

Objective 6 – Roadside Shrub Transplant Trial (2025)

On average, greenhouse-grown plants were larger in all measured aspects of plant growth when compared to roadside-grown plants both before and after roadside transplanting; the average change in salmonberry height, stem diameter, and crown spread differed significantly by plant origin ($W = 181, p < 0.02$; $W = 478.5, p < 0.04$; $W = 92.5, p < 0.001$). Salmonberry plants from the greenhouse had a slower seasonal growth rate in height, but had a faster seasonal growth rate in stem diameter compared to roadside-grown plants. However, roadside-grown plants had greater increases to average crown spread while the average crown spread of greenhouse-grown plants appeared to decrease over the season (Figure 13).

Figure 13

Average Seasonal Roadside Growth of Both Greenhouse-Grown and Roadside-Grown Salmonberry Plants from the Shrub Transplant Trial



Note. Plant growth data was averaged and plotted to graphically showcase the average growth rates of stem height, stem diameter, and crown spread between groups (greenhouse-grown or roadside-grown plants) at the start and end of the growing season. Standard deviations were plotted to indicate the observed variation in plant height, stem diameter, and average crown spread within groups.

Chapter V: Discussion

Overview

Across two field seasons, this study aimed to assess the propagation methods and transplant capacity of culturally important plants for revegetating roadside locations in Tsalgiuw, Gitga'at Lax Yuup (Hartley Bay, British Columbia). To do this, we utilised vegetative transplant trials on the roadside and in the greenhouse (objectives one and three respectively), seed trials on the roadside (objective two), a mulch amendment trial with salmonberry rhizomes (objective five), a biofertilizer trial with local natural materials (objective four), and a salmonberry shrub transplant trial (objective six). Vegetative trials indicated that revegetating through rhizomes would provide positive results, as the emergence rates of target species were quite successful (salmonberry: 32.5%, fireweed: 75.0%) with moderate to high overwintering survival rates (salmonberry: 80.8%, fireweed: 93.3%, bunchberry: 40.0%). Additionally, seeding directly to the roadside showed promise as a revegetation method in that salmonberry and bunchberry exhibited relatively high germination and establishment rates (50.0% and 26.5% respectively). While mulching did not improve the growth of seedlings in this study, it is possible that providing mulch at later growth stages may be beneficial.

Mulch as a roadside soil amendment did not directly influence the emergence of salmonberry rhizomes. However, results of the mulch trial indicated that rhizome origin, soil moisture, and soil temperature play important roles in salmonberry rhizome emergence, leading me to speculate that rhizomes may have higher emergence rates when their habitat of origin is more similar to their transplant habitat. Interestingly,

increasing soil moisture negatively impacted salmonberry rhizome emergence, revealing that salmonberry rhizomes are sensitive to moderate moisture when being used as transplant propagules. While mulch had no direct effect on rhizome emergence, mulch likely influenced rhizome emergence indirectly by influencing soil conditions such as soil moisture and soil temperature. Mulch was found to have a positive effect on salmonberry plant health (plant height) at average site conditions.

Both the fertilizer and shrub transplant trials yielded inconclusive results. The fertilizer trial indicated that neither natural biofertilizers nor commercial fertilizers had an effect on salmonberry growth. However, this may have been due to the age of the plants and the lack of established root systems. Future trials could be undertaken to better determine the effects of local biofertilizers once root systems are more developed. Shrubs transplanted to the roadside from the greenhouse had slower seasonal growth rates in height and decreases in average crown spread compared to roadside-grown plants. However, these results were mostly attributed to the initial size of plants at the start of the season, as well as herbivory.

Objective 1 – Roadside Vegetative Trials (2024-2025)

Overall, salmonberry and fireweed showed great potential as species for roadside revegetation within our context despite differences in rhizome emergence rates. I hypothesise that these differences are due to the variable growth strategies of each species. Although salmonberry and fireweed are both perennials that spread extensively through rhizomes, fireweed is a fast-growing early seral-stage forb (Comeau et al., 1989; Cormack, 1953), while salmonberry is a woody shrub that often persists

past early-successional stages (Zouhar, 2019). Since herbaceous plants generally have higher root to shoot ratios compared to shrubs (Guo et al., 2021; Harris et al., 2023), the investment in root biomass for herbaceous species like fireweed could be interpreted as a strategy to competitively reproduce through rhizomes (Markgraf et al., 2023).

Consequently, differences in emergence between species may reflect species-specific clonal traits that are associated with their respective life-history strategies, with the vigorous rhizomatous growth habit of fireweed likely contributing to its greater success.

The general habitat preferences of salmonberry and fireweed might also play a role in rhizome emergence. Fireweed is most often found in open habitat with soil moisture ranging from moist to fairly dry, while salmonberry is largely an indicator of moist or wet areas (Pojar & MacKinnon, 2016). Consequently, roadside conditions matched the site characteristics of fireweed much more closely, and therefore its rhizomes may be better adapted to emerge under the fluctuating environmental pressures of the roadside.

Species phenology could also play a role in the propagation success of rhizomes collected during stages of early seasonal growth. Although both species have low rhizome carbohydrate storage during May in response to spring growth (van Andel, 1975; Zasada et al., 1994), salmonberry rhizomes may have comparatively limited energy storage since plants are producing significant aboveground biomass in addition to flowers for sexual reproduction. Furthermore, Martínková et al. (2025) found that young fireweed plants had increased rhizome carbohydrate contents, which may have contributed to the substantial propagation success of fireweed in our experimental trials.

Bunchberry showed moderate potential as a roadside revegetation species. Steep declines in bunchberry shoots can be largely attributed to regular transplant shock in addition to a heatwave in the days following transplant. The foliage of many bunchberry propagates produced anthocyanins before dropping, indicating stress in response to the high light and drought conditions of the roadside (Chalker-Scott, 1999; Li & Ahammed, 2023). However, the steady sprouting of new stems and above-ground foliage surpassed the survival of existing above-ground foliage by August 2024, revealing that transplanted bunchberry rhizomes can persist on roadsides despite above-ground dieback.

Although the overwintering capacity of bunchberry rhizomes was poor in comparison to salmonberry and fireweed, this may be due to unstable roadside soils or unintentional disturbance while establishing experimental seed plots; in some cases, bunchberry rhizomes transplanted in 2024 were observed in spring 2025 to be unearthed and displaced by soil erosion. Overall, the persistent new growth after top kill combined with moderate overwintering success suggests that bunchberry rhizomes are considerably resilient and can survive under harsh environmental stressors. This provides valuable insight into the transplant capacity of this species through rhizomes (which remains largely undocumented), and their value in land reclamation or restoration. My findings also suggest that bunchberry may have a greater transplant capacity than that of *C. canadensis* (Gucker, 2012a), a species similar in morphology, ecology, and geographic distribution. For future planting initiatives, we suggest that bunchberry rhizomes be collected from plants established under open canopies to potentially reduce the stress caused by drastic changes in light intensity. Transplanting

longer rhizome segments may improve roadside regrowth rates; however, this can only be confirmed through additional experimentation. Continued monitoring is needed to understand the growth rates of this species after roadside transplanting.

Objective 2 – Roadside Seed Trials (2024-2025)

Salmonberry Seeds

While it was hypothesized that mulching might improve salmonberry germination by regulating water availability and reducing surface soil crusting, there are a variety of factors that could have contributed to better yields under the no mulch treatment. Although salmonberry seeds do not require light to germinate, germination rates may improve when seeds are exposed to increased light levels (Luna & Wilkinson, 2009; Ruth, 1970). This response is well documented in other *Rubus* species (Zasada & Tappeiner II, 2008), as site disturbances and the subsequent increase in light availability often trigger germination (Oleskevich et al., 1995). Furthermore, light availability has also been documented as a critical factor in the successful establishment of salmonberry seedlings (Haeussler & Coates, 1986). It makes sense that, when covered by mulch, seeds must elongate their hypocotyls significantly while navigating the three-dimensional structure of mulch to reach surface sunlight. This would require significant energy, and it is possible that many germinated seeds do not have the energy stores required for this expenditure. Consequently, successful germination may have been reduced by low-light conditions, and establishment inhibited by the physical barrier created by the mulch. Although increased light levels may benefit initial germination and establishment, Ruth (1970) found that the long-term seasonal survival of salmonberry

seedlings was greater under shaded conditions compared to full sun. While we did not observe obvious signs of seedling mortality by August 2025, this may be because summer precipitation received at our study sites was abundant and adequately supported established seedlings. It is possible that future seeding attempts on bare roadside soil will have lower than expected seedling survival rates when precipitation is reduced and roadside soils are dryer.

The germination and establishment of salmonberry seeds were also negatively impacted by increasing bulk density. This is an expected outcome (Bassett et al., 2005; Menary & Kruger, 1966; Nasr & Selles, 1995) as soil compaction generally inhibits seed radicle penetration into the soil. Increasing bulk density is also associated with reduced soil moisture as there are fewer pore spaces to retain water. Consequently, soil textures correlated with higher bulk density, like sand, may have been more susceptible to surface drying on days without precipitation, leading to trouble with successful establishment.

Mulching did not significantly improve salmonberry seedling health by increasing total leaf surface area. However, these results may reflect the environmental conditions of 2025, as significant precipitation from April to June (Canada Weather Stats, 2026) may have provided substantial moisture for seedling growth regardless of treatment. Rather, mulching may have provided a regulatory function that reduces the variability of seedling growth (Chalker-Scott, 2007), as un-mulched seedlings had leaf surface areas that ranged from under 1 cm to over 2 cm, and mulched seedlings ranged from around 1 cm to about 1.75 cm. Since cedar mulching has been shown to have positive effects on plant growth and survival (Maggard et al., 2012b) and has not been found to

significantly suppress emergence through chemical influence alone (Maggard et al., 2012a), it is possible that mulching may be more important as seedlings grow larger and increase their water demands. Consequently, mulching may not be a suitable soil amendment for roadside revegetation with salmonberry seeds when considering its inhibition on germination and establishment, as well as its lack of benefits provided to small seedlings as seen in our study. However, it is possible that mulching may produce different results when tested under drier growing seasons.

Bunchberry Seeds

Bunchberry germination may have peaked at a bulk density of 0.45 g/cm^3 under mulch treatment due to a combination of sampling and design limitations rather than a true bulk density effect. For example, germination and establishment under mulch increased above that of no mulch around a bulk density of 0.45 g/cm^3 . While there were samples from both treatments that had similar bulk density values around 0.45 g/cm^3 , these bulk density samples were from different sites; the no-mulch bulk density sample was from site 16 and the mulched bulk density sample was from site 14. As a result, lower predicted germination and establishment under no-mulch (bulk density 0.45 g/cm^3) may be attributed to a texture effect where site 16 had higher clay content and experienced solar-induced soil surface-sealing that inhibited successful establishment. This idea is supported by the fact that sites significantly differed in baseline germination, indicating that soil texture may have an important effect on bunchberry germination and establishment that cannot be modelled due to partial confounding with site. Bulk density samples for no mulch ranged from 0.31 g/cm^3 to 0.90 g/cm^3 , while bulk density samples

for mulch ranged from 0.21 g/cm³ to 0.67 g/cm³. Since bulk density ranges are imbalanced across treatments, model predictions of interactions become uncertain and lead to large confidence intervals above 0.67 g/cm³.

Objective 3 – Greenhouse Vegetative Trial (2024)

Although I was unable to report the total percentage of rhizomes that would have emerged in the greenhouse without human intervention, 65% of rhizomes either immediately emerged or showed evidence of node growth before human intervention. This is 32.5% higher than the total number of rhizomes that emerged across roadside sites during the 2024 Roadside Vegetative Trial. Given the mixed results produced by the moist paper towel method, it is possible that human intervention and the use of paper towel was detrimental to successful emergence. Since rhizomes planted to the roadside continued to emerge into August, I recommend leaving rhizomes undisturbed when attempting to propagate salmonberry in the greenhouse, or exercise abundant caution when using paper towel to quicken node elongation. Consequently, greenhouse conditions likely increase the success rate of salmonberry rhizome emergence when rhizomes are left to emerge in soil without human intervention. Higher rates of combined emergence and node growth in the greenhouse in comparison to growing rhizomes directly on the roadside was possibly due to the superior environmental conditions provided by the greenhouse such as increased water availability and regulated temperatures. As a result, growing salmonberry rhizomes in a greenhouse setting for transplant stock seems to be a worthwhile effort, as greenhouse conditions may

improve salmonberry emergence by up to 50% when roadside soils are used as a substrate.

Objective 4 – Greenhouse Fertilizer Trial (2024)

Since none of the fertilizer treatments were found to influence salmonberry plant height, it is likely that the height of emerging plants from rhizomes are more strongly influenced by the properties of the rhizomes themselves. When rhizomes are separated from the parent plant and cut into propagules, shoot growth is heavily constrained by the energy stores available within the rhizome segment as is found in other herbaceous plants (Luo & Zhao, 2015). As a result, rhizome segments that contain larger energy stores would likely produce taller plants (Zhai et al., 2022). Although we attempted to select rhizomes that were uniform in diameter to account for potential differences in energy storage, diameter was not strictly controlled, and any fertilizer effects could have been made undetectable due to variations in plant height attributed to the energy capacity of individual rhizomes. Furthermore, salmonberry rhizomes were not observed to have developed adventitious roots during the fertilizer trial period; it is unlikely that propagates were actively absorbing nutrients from fertilizers and transferring it into shoot growth. As such, the effects of local natural fertilizers would be better studied on salmonberry plants in their second growth year, as plants had developed substantial roots systems by the spring of 2025. The presence of these root systems would likely allow better nutrient absorption, and fertilizers would have more tangible effects.

Fish slurry as a fertilizer may have a greater impact on young salmonberry plants than what is captured by analysis, as negative side-effects became apparent with its

use; two salmonberry plants being treated with fish slurry died before the end of the experiment, despite no other plant mortality being observed among fertilizer treatments. Maggots also became established in the fish slurry applied beneath the soil surface, with plants showing visible signs of stress like wilting and leaf discoloration. As a result, future trials should consider other application methods when using fish as a fertilizer. Incorporating the dry fish powder into the soil may still provide slow-releasing benefits to plants while reducing the likelihood of insect pests.

Objective 5 – Roadside Mulch Trials (2025)

Salmonberry Rhizome Emergence

Origin had a significant effect on salmonberry rhizome emergence, with rhizomes from M1 having a greater emergence rate than those from M2. The effects of rhizome origin on emergence may be due to a variety of factors, ranging from potential genetic differences between populations to the ecological characteristics of the roadside. The origin of plant material used for transplanting or propagation is often recorded during experimentation, as it is generally conceived that transplant or propagation capacity is specific to the individual (Luna, 2009). In this sense, genetics are thought to play an important role in the overall success of transplants, with individuals from different populations generally having genotypes that are better adapted to the environmental characteristics of their home site (Mackenzie, 1985). It is possible that the genetic makeup of plants from the two mother sites used in this study are different considering that these populations are located over 300 m away from each other and spatially

separated by a river. Consequently, rhizomes from M2 may have genotypic differences associated with wet riparian sites and are therefore less likely to emerge under stressful roadside conditions, whereas rhizomes from M1 were genetically adapted to comparatively dryer sites and may have emerged better because they were better suited to the conditions of the road. However, the effects of genotypes on the success of rhizome transplants in a terrestrial setting is largely unexplored, and genetic testing between mother site populations would be needed to confirm this theory.

Furthermore, there is widespread evidence that the success of transplanting is not influenced by genetics alone, but also by the home-site of the plant material. For example, the seeds of perennial herb *Aster amellus* germinated more successfully when the ecological characteristics of the transplant location were increasingly similar to those of their origin (Raabová et al., 2007). This relationship has also been found in various grassland species in that the performance of transplants decreased when there was a larger mismatch between climates of the site of origin and the transplant location (Bucharova et al., 2017). Furthermore, Midolo and Wellstein (2020) found that the performance of individuals in reciprocal transplant experiments was dependent on the origin of the individuals and the environmental characteristics of the transplanting site such as temperature and rainfall. Our study also seemed to exhibit this pattern, as M1 was much more similar to the roadside in that it had an open canopy, comparatively lower vegetation diversity and soil moisture, and a greater history of disturbance. Although none of the above studies assessed these effects on rhizome emergence, they highlight the importance of propagate origin on transplant success when translocating plant material to different locations. Future studies could focus on a

reciprocal transplant experiment of salmonberry rhizomes from additional mother sites, which could help disentangle the potential effects of genetics and home-site characteristics on rhizome emergence. These findings could provide valuable information as to which mother sites might produce the most viable propagules for other transplanting projects across habitat types in Gitga'at Territory.

Soil moisture effects were slightly surprising in that increasing soil moisture reduced salmonberry rhizome emergence. While salmonberry is generally an indicator of moist sites (Pojar & MacKinnon, 2016), it is likely that these moisture preferences don't extend to rhizomes that have been separated from the parent plant and are more susceptible to rot. The high moisture conditions represented in the model were generally attributed to one site (site 13), whereas the other sites had moisture ranges that were more characteristic of their soil textures. Site 13 was located on the northern slope of the road and experienced significant water runoff from the forest above. This excess water likely inhibited rhizome emergence by producing soil conditions that were generally too wet and anaerobic. Considering that rhizome segments with node growth generally reacted poorly to being wrapped in paper towel during the greenhouse trial, these results indicate that salmonberry rhizomes may be somewhat sensitive to moderate moisture levels during the node elongation phase of emergence.

Maximum recorded temperature was negatively associated with rhizome emergence ($p < 0.04$), indicating that excessive heat can reduce rhizome viability or cause mortality. The absence of a significant interaction between origin and temperature suggests that rhizomes from different origins responded similarly to heat stress and did not exhibit meaningful differences in heat tolerance.

Salmonberry Plant Health: Plant Height, Stem Diameter, and Average Crown Spread

Salmonberry plant height was influenced by treatment and salmonberry plants grown with mulch were taller than those grown without mulch. This is likely due to the role mulch played in regulating soil moisture and moderating the microclimate. Mulch may have mitigated plant stress by reducing the fluctuations in soil moisture lost to evaporation between precipitation events, whereas treatments without mulch dried out much quicker in comparison. Although soil moisture was included as a variable in analysis, the average soil moisture variable calculated from weekly moisture surveys may not have been sensitive enough to capture ecologically relevant fluctuations in available water over the short-term. Future studies could employ soil moisture data loggers that collect continuous measurements that would allow for better assessments of how mulch influences soil moisture and plant height. It is also possible that mulch provided an insulative effect that reduced any potential heat stress to rhizomes. Farnsworth et al. (1995) found that some temperate woody shrub species had reduced leaf sizes when subjected to temperatures increased by 5 °C, suggesting that mulch in this study could benefit plant growth by buffering against temperature extremes and ultimately improve plant height. Considering that rhizome emergence was negatively impacted by increasing temperature, I speculate that salmonberry growth is also sensitive to elevated heat despite this species' ability to grow in disturbed, open soils. The effects of mulching on overwintering are yet to be determined, although mulching could provide an insulator layer that improves overwintering survival.

The growth of salmonberry stem diameter was influenced by both average soil moisture and vegetative ground cover. Increasing soil moisture had a nonlinear effect, with stem diameter increasing and peaking at around 35% soil moisture around 2.5 mm before declining. The positive change in stem diameter was likely a biological response to available water, with plants at moderately moist sites producing thicker stems due to the growth of xylem and phloem needed to facilitate increased water and nutrient transport (Pallardy, 2008). The steady decline in stem diameter after an average soil moisture of 35% suggests that excessively moist soil conditions may have inhibited growth, as prolonged periods of high soil moisture can limit oxygen availability to the rhizome.

Since vegetative ground cover was positively associated with all salmonberry plant health parameters, it suggests that plots with greater plant cover generally indicated favourable growing spaces. Rather than reflecting a single underlying mechanism, vegetative cover likely reflects multiple environmental variables that influence plant growth. Ground cover may have provided benefits to growing salmonberry plants by positively influencing soil and ambient conditions. This may be due to ground cover improving soil conditions by acting as an evaporation barrier between the sun and the soil regardless of treatment, or due to cover plants improving soil structure and oxygen through root growth. Ground cover could also create a microclimate that is more suitable for plants by reflecting ambient heat away from the soil, and improving ambient air moisture, all contributing to increases to plant height, stem diameter, and crown spread.

Furthermore, the positive effect of cover on salmonberry health parameters indicated that significant competition between the salmonberry and the ground cover for available moisture was unlikely, as the dominant ground cover observed were grasses (*Poaceae* sp.). Grasses would comparatively have much deeper and established root system compared to planted salmonberry rhizomes, suggesting they were not accessing same water in the soil profile. The lack of negative effects of ground cover across all plant health parameters indicates that ground cover is not harmful to young salmonberry plants.

Objective 6 – Roadside Shrub Transplant Trial (2025)

Roadside-grown plants having faster seasonal growth rates in height compared to greenhouse-grown plants is most explained by the disparity in average plant height between groups at the beginning of the season. Larger greenhouse-grown plants would naturally have slower growth rates due to their comparative size, as larger plants produce biomass more inefficiently than smaller plants since it takes more resources and energy to maintain larger plant structures (Hunt, 1982; Pommerening et al., 2023; Rees et al., 2010). The reduced growth rate of plant height in greenhouse-grown plants was likely further influenced by transplant shock from changes in water availability, higher roadside temperatures, and increased sun exposure (Close et al., 2005). Transplant shock was visibly evident in greenhouse-grown plants in the weeks following transplant, as chlorosis and leaf dropping were observed. Both stress responses largely inhibit photosynthetic capacity and therefore lead to reduced plant growth rates. Since roadside soil was used as substrate for the greenhouse trials, it is unlikely that

differences in nutrients availability were a major factor. While it was not anticipated that greenhouse-grown plants would have grown so dramatically between the end of the 2024 season and the start of the 2025 season in comparison to roadside-grown plants, this is likely due to the benefits of overwintering in the greenhouse.

Quicker stem diameter growth in greenhouse-grown plants may be a response to changes in plant access to soil moisture after transplant. When soil conditions are dry, root systems may elongate in an attempt to access moisture (Pearson, 1966; Voothuluru et al., 2024). Since stem diameter is positively correlated with root biomass (Mexal & Landis, 1990), stem thickening may have occurred as a result of expanding root systems that are being grown to compensate for comparatively dryer soil conditions. Furthermore, faster stem diameter growth of greenhouse-grown plants is likely related to their overall size, as larger plants generally need thicker stems to structurally support expanding foliage and new lateral growth.

The negative changes in average crown spread for greenhouse-grown plants was most attributed to leaf dropping and herbivory. Throughout the season, some greenhouse-grown plants were observed to have had the tops of their stems shredded, which is consistent with ungulate browsing. In contrast, deer generally did not browse on roadside-grown plants, as herbivory was not observed despite there being signs of deer being present. We speculate that salmonberry leaf quality or palatability may have differed between plant origins and that deer had a selective preference for greenhouse-grown plants, or that deer were simply more attracted to taller plants while browsing due to their visibility and accessibility.

Overall, plant performance parameters provided significant insight into the effects of transplanting greenhouse-grown salmonberry plants to the roadside. While roadside-grown plants generally outperformed greenhouse-grown plants relative to their size, continued monitoring over future growing seasons is necessary to understand the full advantages and disadvantages of planting salmonberry rhizomes directly to the roadside, or transplanting greenhouse-grown plants. It is possible that the height of roadside-grown plants will be stunted despite several growing seasons, which significantly impacts the project's purpose to provide patches for berry picking. On the other hand, greenhouse-grown transplants may have poor overwintering survival, which raises concerns over the benefits of having larger plants on the road with the time and resource commitment of growing them in the greenhouse. As a result, it is important that these plant performance parameters continue to be measured so that timelines and expectations for productive berry patches can be practically managed and adapted.

Chapter VI: Management Implications

Suggested Species and Roadside Revegetation Methods

Future revegetation plans in Hartley Bay should consider pursuing all three focal species for roadside revegetation, with a focus on salmonberry as the primary fruiting species and fireweed as a companion plant. Rhizomes of salmonberry and fireweed showed high transplant capacity in a roadside setting, while transplanting with bunchberry rhizomes showed moderate transplant capacity, but may be improved through collecting propagates from sunnier mother sites and using larger rhizome lengths. As a result, proceeding with bunchberry may prove to be labour intensive, which should be considered when developing future revegetation plans. Salmonberry rhizomes from mother site M1 (the patch located at the beginning of the road, before the water treatment plant) emerged best in roadside conditions, however rhizomes should still be collected and transplanted from other mother sites to encourage genetic variation in roadside populations.

Since seed is important for genetic diversity, revegetation plans should consider including local seeds of all three target species. Broadcasting local salmonberry seed directly to the roadside has been quite successful within our context (about 50%), and seeding with fireweed, while untested, could be effective due to the disturbance level of roadside soils and fireweed's reputation for rapid establishment (Broderick, 1990). While bunchberry seeds germinated less than salmonberry seeds, germination was still adequate at around 26%. As a result, adding local bunchberry seed to any seeding

mixtures should be considered if time and resources allow to help establish ground cover.

Greenhouse Versus Roadside

Continued monitoring of roadside-grown and greenhouse-grown transplants is necessary to understand if greenhouse efforts are necessary for project success since it is not yet known if greenhouse-grown transplants survived overwintering on the road. Ideally, we suggest doing both since growing salmonberry plants from rhizomes in the community greenhouse successfully produced viable transplant stock and produced significantly larger plants within the same growth period. Transplanting greenhouse-grown plants should be done in early spring when plants are dormant following their first growing season to reduce the negative effects of transplant shock and allow plants to have grown sufficient root systems prior to transplant. Consider fertilizing while transplanting to help give plants an added boost to growth.

Although salmonberry seeds exhibited exceptional germination on the roadside, seeds might alternatively be sown outdoors within the village to take advantage of natural stratification processes. Successfully germinated seedlings may then be dug up and transferred to the community greenhouse, where they can be grown until they reach a size and level of robustness that is suitable for roadside transplanting. Not only would this improve genetic variation in roadside patches, but it might promote faster revegetation timelines as seedlings would be larger and could be produced in larger quantities.

Fertilizers

Any fertilizer applications to plants grown from rhizomes should be provided in their second growth year after root systems have sufficiently developed for nutrient uptake. Since it is unclear which fertilizers may provide the best results, the type of fertilizer should be chosen based on application method and setting. Miracle-Gro® is a cost-effective and easy-to-use fertilizer to employ within the greenhouse. However, we suggest avoiding chemical fertilizers on the roadside that could have runoff effects due to proximity of the roadside to the nearby lake. Instead, consider using fish (while keeping in mind that fish may act as an animal attractant) or other local natural fertilizers that will have a more localised effect.

Other Soil Amendments

Mulching can be used to improve the overall growth of young salmonberry plants produced from vegetative transplants, as mulching was found to have a positive effect on plant height. Mulching should not be used when broadcasting seed, as it hinders salmonberry and bunchberry seed germination and does not have any observable effects on salmonberry growth within the first few months following germination. Soil fencing is suggested to be used alongside seed broadcasting to reduce the likelihood of seeds eroding from roadside soil or otherwise collecting within lower slopes during spring runoff.

If mulch is not an option, establishing a ground cover with native grasses and herb species will provide similar effects by improving soil structure, moisture, and nutrients depending on the species included in the seed mix. Ground cover will also

create a microclimate that is more suitable for berry transplants by reflecting heat away from the soil and improving air moisture. From this study, it has been determined that ground cover is unlikely to have a negative effect on the emergence and growth of salmonberry rhizomes. Consequently, rhizome transplanting can be done in conjunction with any seed mix broadcasting, as shrubs will naturally outcompete grasses or herbs through successional processes. Seeding before or during rhizome transplanting may be especially important considering that seed mixes broadcasted in previous years at other roadside locations in Hartley Bay were generally observed to be slow on the uptake. As a result, multiple seasons may be required before benefits to the soil are delivered through established ground cover. Native species should be selected for any seed mix to reduce any competitive pressures exacerbated by non-native or non-local species.

Broad Picture Implications

This study demonstrated that culturally significant plants could be practically and successfully integrated into a roadside revegetation project, ultimately exemplifying a strategy for land revegetation that is both informed by cultural priorities and ecologically effective. The successful establishment of salmonberry, fireweed, and bunchberry on the roadside illustrated that culturally appropriate revegetation practises are capable of meeting ecological objectives such as re-establishing native plant communities and initiating early-successional habitat recovery, while simultaneously supporting the cultural needs and values of the community. While native species are generally preferred for land restoration or reclamation, practical barriers such as propagation requirements, limited plant material availability, cost, and uncertainty about

establishment success can constrain their use in roadside revegetation projects. This study demonstrated that culturally important native plants can be propagated directly to the roadside and can establish successfully when matched to appropriate site conditions, indicating that their incorporation into revegetation projects may be more feasible and less resource intensive than previously perceived. Finally, this study highlighted the importance of intentionally selecting species based on their ecological fit and cultural relevance rather than using a pre-prescribed revegetation plan, reinforcing the value of approaching land reclamation at a site-specific and community-informed level.

Furthermore, the methods trialled in this project demonstrated that locally collecting and propagating plant material was an effective and low-cost way to implement a community-based revegetation initiative. This approach is especially important in remote communities, such as Hartley Bay, where there are significant costs or burdens associated with the purchase of nursery-grown plant stock, arranging the transport of plant stock to the community, and the deteriorated condition of plant stock upon arrival in the community. Harvesting local rhizomes and seeds using the methods documented in this study provides an accessible approach to revegetation that is feasible for community members to independently carry out, and is compatible with the Gitga'at ways of knowing. This also reduces the community's dependence on contracted workers who are often expensive and logistically difficult to support in remote settings, and instead locally builds the knowledge and skills required for ongoing land revegetation efforts.

Utilising local plants allows the knowledge generated through this study to be transferred to other projects in Gitga'at Territory. The rise in capital projects within the community (Robinson et al., 2025) have created new opportunities to apply these lessons to the revegetation of recently disturbed sites. Revegetation methods used in this study could also be applied to rehabilitating old logging roads or other culturally important sites across Gitga'at Territory, such as the traditional **moolks** (*Malus fusca*; Pacific crab apple) orchards in Laxgalts'ap (Old Town). The general principles behind this study – using local plant material, prioritising culturally important species, and trialing revegetation methods at the community-level – offer a transferable framework for other First Nations that share similar cultural plant uses in the Pacific Northwest and are seeking to rehabilitate disturbed lands in ways that align with their distinct cultural needs and values.

Finally, the propagation methods used in this study, particularly rhizome transplants and direct seeding, along with the species selected mirror the ecological processes that drive early-successional plant communities. Rhizomatous species such as salmonberry, fireweed, and bunchberry spread clonally and via seeds in the early stages of natural disturbance regimes. These same traits can be utilised to accelerate the establishment of early-stage successional habitats following anthropogenic disturbances. The rapid and successful establishment of all species observed in this study aligns with the ecological role these species play in naturally populating landscapes by quickly covering bare ground. This integrated approach provides a compelling model for how culturally sensitive land revegetation methods can support

early successional spaces, while reinforcing relationships between people, plants, and place.

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Appendix A

Environmental Site Characteristics: Vegetative Trials 2024

Site name	Latitude	Longitude	Elevation	Aspect	General slope
11	53.42566	-129.276711	26	NNW	Heavily sloped towards bottom
13	53.425142	-129.275263	24	NNW	Heavily sloped, flattens towards bottom
14	53.425753	-129.271384	23	NNW	Level
15	53.425765	-129.269909	26	NNW	Level
16	53.420780	-129.259961	40	WNW	Level