RESTORATION AND ENHANCEMENT OF *VIOLA ADUNCA* AND ASSOCIATED PLANT SPECIES FOR LARVAL DEVELOPMENT OF *SPEYERIA ZERENE HIPPOLYTA* IN PACIFIC NORTHWEST COASTAL PRAIRIE ECOSYSTEMS USING COCONUT COIR MATS

by
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ABSTRACT

Restoration and enhancement of *Viola adunca* and associated plant species for larval development of *Speyeria zerene hippolyta* in Pacific Northwest coastal prairie ecosystems using coconut coir mats

Graham Klag

Across the coastal prairie grasslands of Washington, Oregon and Northern California, the decline, extirpation and potential extinction of Oregon silverspot butterfly populations, *Speyeria z. hippolyta,* are closely associated with the decline in abundance, density and extirpation of the butterfly's larval host plant the Early blue violet, (*Viola adunca*). Researchers cite the loss of open low nutrient soil conditions as the number one reason for the violet and butterfly's decline. The suppression of historic fire regimes, advancement of forest succession into the prairies, combined with the introduction of livestock and non-native invasive pasture grasses, play a role in the loss of interstitial space the violet and butterfly require. These factors occlude the light and space that *Viola adunca* needs to grow, establish and recruit, which subsequently outcompetes the plant. The density and abundance of *Viola adunca* must be increased to support the butterfly's survival and recovery. Utilizing the traditional botanical restoration technique of plug planting to enhance violet population sizes has proven to be difficult. This research took an innovative approach using coconut coir mats that provide a growing substrate that mimics the plants' historic conditions while also suppressing area non-native invasive plants. The research results, following a Two-way MANOVA test, indicate a statistically significant difference in native plant aerial cover between planting types (plugs and the vegetative mats) for October $F(3, 416) = 203.39$, $p \leq (0.001)$. The vegetative mats grew *Viola adunca*, the associated native plant species and maintained interstitial space more effectively than the control plug plots.

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Figure 1: Nestucca study site. Vegetative mat at Willapa. *Speyeria zerene hippolyta.*

INTRODUCTION

In order to properly introduce this environmental study and fully communicate the research project's aim and future implications, I must respect and acknowledge the Alsea, Tillamook, Chinook and Squaxin people. Without their lands and sovereign land-use practices, I would never have been able to craft and share this story. Without the gift of their time and territories, we might never have known the Oregon silverspot butterfly (*Speyeria zerene hippolyta*) and its once ubiquitous host plant the Early blue violet (*Viola adunca*) (see Figure 1). I myself am not indigenous, and through this work I can add to the growing gratitude for ancestral embeddedness in ecology. Our cultural landscape has been, can be, and will be either an incubator for collaboration, diversification and speciation, or the driver of monoculture, instability and extinction debt[1] (Dunn, 2005; Samways, 2020; Shuey et al., 2016). The loss of *Viola adunca* represents the loss of indigenous burning practices that held back the succession of Salal (*Gaulthoria shallon*), Red Alder (*Alnus rubra*), and Sitka Spruce (*Picea sitchensis*). *Speyeria z. hippolyta,* like other Speyeria zerene subspecies, has evolved a close host-plant relationship with *Viola adunca* (Hill et al., 2018; Sims, 2017). *Viola adunca* leaves have high concentrations of nutrients such as vitamin C that the caterpillar of the butterfly depends on for nutrition to complete its slow growing life cycle and history (Bierzychudek & Warner, 2015; Hill et al., 2018). In the best reaches and historic habitat that hosted *Speyeria z. hippolyta, Viola adunca* densities can be as much as 100 plants per square meter (McCorkle et al., 1980; Schaeffer, 1992; Kiser, 1993). Part of this life history depended on human intervention by the native prairie

[1] Extinction debt - In ecology, extinction debt is the future extinction of species due to events in the past. The phrases dead clade walking and survival without recovery express the same idea.

dwellers in time immemorial (Schultz et al., 2011; Walsh et al., 2010; Zald, 2009). The practice of periodically burning the prairies for vegetation management, hunting, trade and ceremonial purposes also facilitated the ecological needs of *Speyeria z. hippolyta* and *Viola adunca*. Today, the habitat needs of these two species is maintained largely by the passive environmental forces of slope, aspect, and wind-driven salt spray, and the active forces of concerned citizens who facilitate restoration ecology (Kaye et al., 2015). The pragmatic land use practices of indigenous people provide a logical relational framework by which to better visualize our cultural and ecological landscape: the concept of an ecosystem[2] (Tansley, 1935). The impacts humans can provide to biological proliferation from intermediate disturbance and productivity[3] can be observed in example keystone species[4] such as the Ochre Sea star (*Pisaster ochraceus*) (See Figure 2). Here the animal's predatory impacts on mussels in the dynamic intertidal area actually leads to greater biological diversity (Yong, 2013). Might we be able to see humans as a keystone species to the coastal prairie ecosystem, missing and now returning? Through this research, I planted and disturbed the earth to share an ancestral idea that can become renewed again as we'll look to the future: traditional ecological knowledge (Shelvey & Boyd, 2000; Wilkinson, 2010).

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[2] Ecosystem - The whole system (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome — the habitat factors in the widest sense. It is the systems so formed which, from the point of view of the ecologist, are the basic units of nature on the face of the earth. These ecosystems, as we may call them, are of the most various kinds and sizes. They form one category of the multi-tudinous physical systems of the universe, which range from the universe as a whole down to the atom (Tansley, 1935, p. 96).

[3] The intermediate disturbance hypothesis - which proposes that biodiversity peaks at intermediate levels of disturbance, is often extended to predict that productivity follows the same response pattern.

[4] Keystone species - a species on which other species in an ecosystem largely depend, such that if it were removed the ecosystem would change drastically.

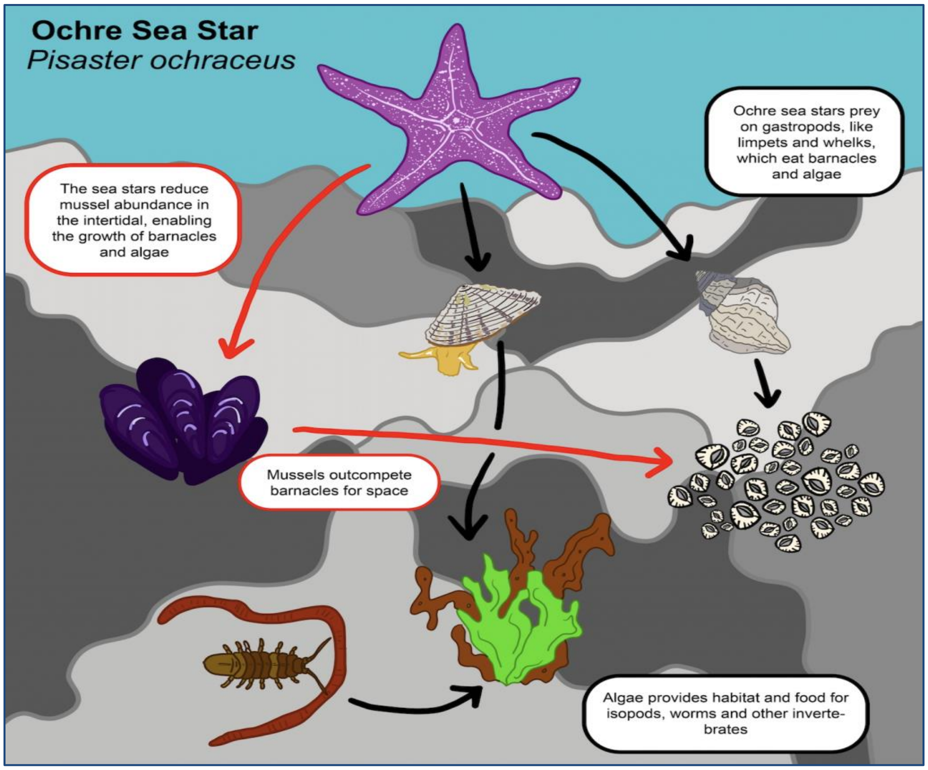


Figure 2: Keystone species concept visualized through the Ochre Sea Star. From: Mayne Island Conservancy, Ochre Sea Star (2020).

The proliferation of *Speyeria zerene spp*., such as *Speyeria z. hippolyta*, throughout the Pacific Northwest depended on a maintenance regime of fire, climatic and other environmental conditions that maintained an abundance of early seral stage prairies (Walsh et al., 2010; Zald, 2009). These dynamically disturbed environments allowed for an abundance of light and space that *Viola adunca*, *Speyeria z. hippolyta* and other plants and animals needed. The interspecies genocide of the 18^{th} and 19^{th} centuries in the Pacific Northwest followed the appropriation of land and subsequent invasion of settlers that left in its wake an extinction debt (Gould & Plew, 1996; Shelvey & Boyd, 2000; Wilkinson, 2010). The disappearance of the Alsea, Tillamook, Chinook and other indigenous denizens of the region removed the traditional dynamic disturbance regimes that led to creation of suitable habitat for *Viola adunca* and *Speyeria z. hippolyta*. In these traditional human habitats, tribes traveled the land they helped to shape in a collective and collaborative pragmatic land use regime, that may have been able to last into eternity (Hamman, Dunwiddie, Nuckols, & McKinley, 2011; Schultz et al., 2011; Shelvey & Boyd, 2000; Stanley et al., 2011; Walsh et al., 2010; Wilkinson, 2010; Zald, 2009). We have an opportunity to develop projects of reciprocity through restoration ecology for the rehabilitation of this habitat with the help of people, plants and a specie in rehabilitation (Kaye et al., 2015). To know and embrace the human gifts we still can give, to reform a relationship value of survival (Oren Lyons, Indigenous voice).

Significance

Grasslands are endangered ecosystems (Hughes et al., 2000; Kocher & Williams, 2000; Schultz et al., 2011; Sims, 2017). North American native grassland ecosystems have experienced species extirpation and decline in richness over the past century due to agricultural conversion, fire suppression and development, with the loss of these ecosystems as high as 99% (Noss et al., 1995; Hixon et al., 2010). Today, the coastal prairie grassland is rare and in rapid decline (Ceballos et al., 2010) (see Figures 3 and 4). Based on historic aerial photography from 1952 the map below highlights some of the modern losses of the coastal prairie of one of the butterfly's and violet's former strongholds the Oregon coastal headland; Cascade Head. In 2015, the Siuslaw National Forest contracted with me to conduct a series of community workshops with the help of area high school students to generate a restoration design solution for the recovery of *Speyeria z. hippolyta* within the Cascade Head Scenic Research Area: The Cascade Head Coastal

Prairie Charrette.[5] Following a summer of experience working with scientists, Forest Service biologists, and graduate students, the high school students gained an understanding of the coastal prairie ecosystem that was then shared back with the community through the workshop series. This research builds on the results of the workshop series and goals set by the community—to come up with a non-herbicidal solution for the restoration and enhancement of *Viola adunca* for the larval development of *Speyeria z. hippolyta*. This research represents some of the voices, ideas and experiences of the denizens of the Cascade Head Scenic Research Area and how they see the future of recovery for *Speyeria z. hippolyta* in their community.

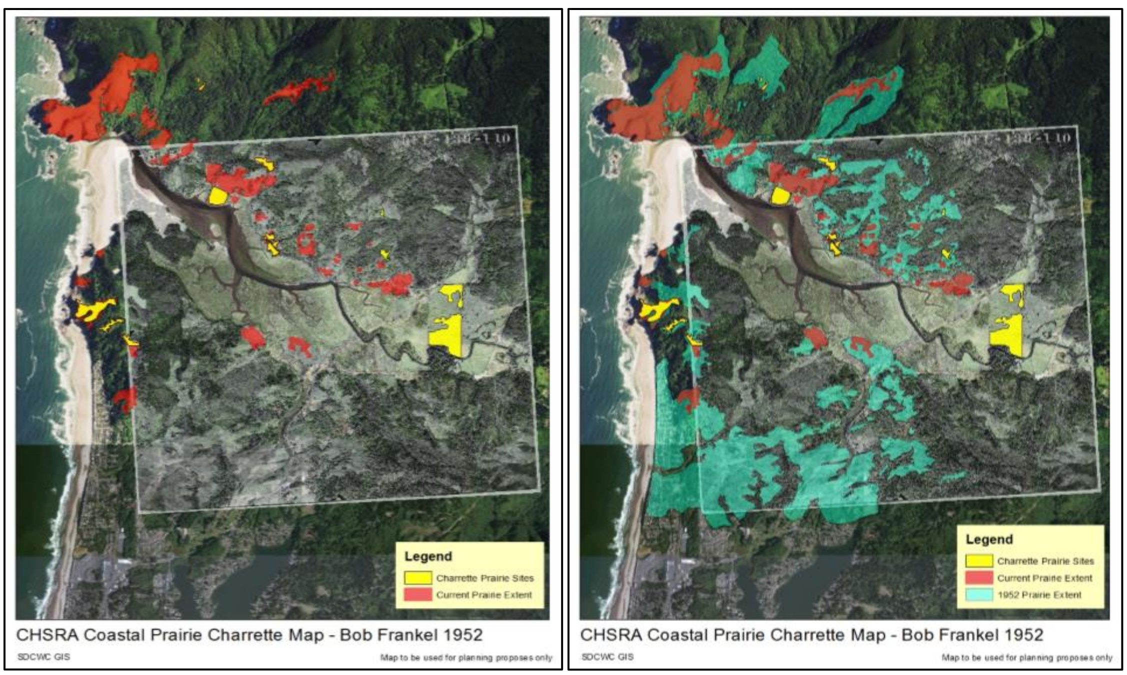
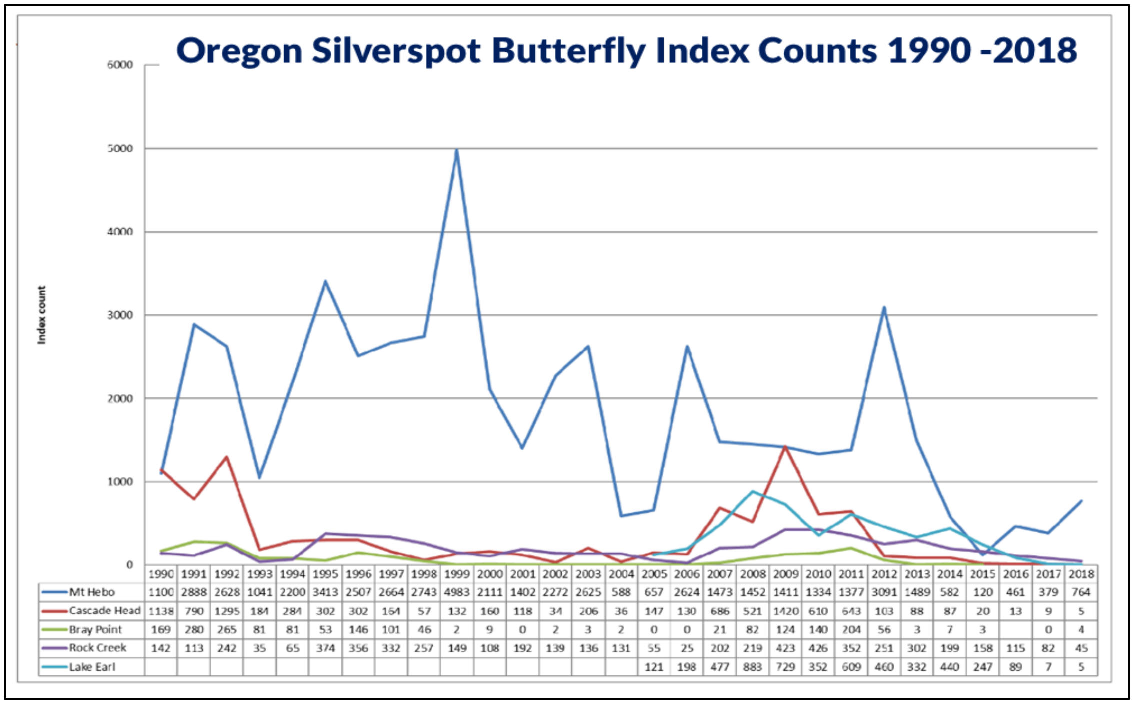


Figure 3: Cascade Head Scenic Research Area overlay of historic aerial photography. Maps with current satellite imagery used to delineate the historic prairie extent.

[5] Charrette - a meeting in which all stakeholders in a project attempt to resolve conflicts and map solutions.

Figure 4: Cascade Head Scenic Research Area fire. 1910 historic grass mountain fire, and 1930 forest growth. From: Tooze Family/Frank Boyden (2015)

The Cascade Head Coastal Prairie Charrette referenced some of the contemporary coastal prairie restoration in the Pacific Northwest that I will also explore through the literature review. Research points to many tested techniques that could provide valuable contributions to restoring these remnant prairie grassland ecosystems for species, such as *Viola adunca* and *Speyeria z. hippolyta*, by improving the size and quality of habitat at scale (Hughes et al., 2000; Petix et al., 2018). Topsoil removal, herbicide application and prescribed fire all have costs and benefits (Jones et al., 2010; Russell & Schultz, 2010; Sivakoff et al., 2016). In some cases, restoration treatments themselves can affect host plant quality or survival (Awmack & Leather, 2002). This research aims to tackle some of these restoration dilemmas and provide solutions for host plant quality and survival. The growing global body of research on insect conservation points increasingly to the precautionary principle and the need for the protection, restoration and enhancements of private and public lands still available to buffer the unknown and unforeseen variables of climate change (Bauerfeind & Fischer, 2013; Menéndez et al., 2007; Samways, 2020; Thorpe & Stanley, 2011). In 1980, the Oregon silverspot butterfly (*Speyeria zerene hippolyta*), was federally listed as a threatened species due to the loss of the butterfly's host plant *Viola adunca* (*Speyeria zerene hippolyta* W.H. Edwards; USFWS 2001) (see Figure 5). Today, the caterpillar of the butterfly still depends on the leaves of *Viola adunca* as its staple food source during its 6 stages of larval development (Crone et al., 2007) (see Figure 6). However, after decades of *Viola adunca* depletion and difficulties with plant reestablishment and quality, innovation is needed to address the index counts of this increasingly threatened and likely to now be endangered species (USFWS staff discussion). In fact, according to the Oregon silverspot butterfly recovery plan, "the butterfly has only four populations left in the world, with three in Oregon and a small disjunct population in northern California" (See Figure 7) (*Speyeria zerene hippolyta* W.H. Edwards; USFWS 2001). Coastal prairie ecosystems like Mt. Hebo and Rock Creek, which still provide habitat for both the violet and the butterfly include shallow and rocky soils, that support assemblages of sparse, low growing native plants adapted to low nutrient growing conditions (McCorkle et al, 1980). These are the ideal conditions for *Viola adunca* germination, establishment and recruitment (Almasi & Kollmann, 2007), as well as for other nectar source species preferred by *Speyeria z. hippolyta*, like Canadian goldernrod (*Solidago elongate*). Sadly, most of the prairies along the coast have lost these qualities, due to landscape level conversion to non-native pasture grasses for and by livestock (Petix et al., 2018). In order to address these issues and add to the ecological restoration toolkit, there is a need for research that explores horticultural methodology and restoration techniques that achieve rapid restoration targets at less cost while also taking into account micro and macro site conditions including roads and other obstacles to insects (Littlejohn, 2012; Petix et al., 2018; Shuey et al., 2016; Stanley et al., 2008).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Mt Hebo	1100	2888	2628	1041	2200	3413	2507	2664	2743	4983	2111	1402	2272	2625
Cascade Head	1138	790	1295	184	284	302	302	164	57	132	160	118	34	206
Bray Point	169	280	265	81	81	53	146	101	46	2	9	0	2	3
Rock Creek	142	113	242	35	65	374	356	332	257	149	108	192	139	136
Lake Earl														

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Mt Hebo	588	657	2624	1473	1452	1411	1334	1377	3091	1489	582	120	461	379	764
Cascade Head	36	147	130	686	521	1420	610	643	103	88	87	20	13	9	5
Bray Point	2	0	0	21	82	124	140	204	56	3	7	3		0	4
Rock Creek	131	55	25	202	219	423	426	352	251	302	199	158	115	82	45
Lake Earl		121	198	477	883	729	352	609	460	332	440	247	89	7	5

Figure 5: Oregon silverspot butterfly abundance index at extant sites in Oregon and California 1990 to 2018. From A. Walker, pers. comm. (2018).

Figure 6: Oregon silverspot butterfly larva being released into suitable *Viola adunca* habitat. Saddle Mountain, Oregon. From: Oregon Zoo (2018).

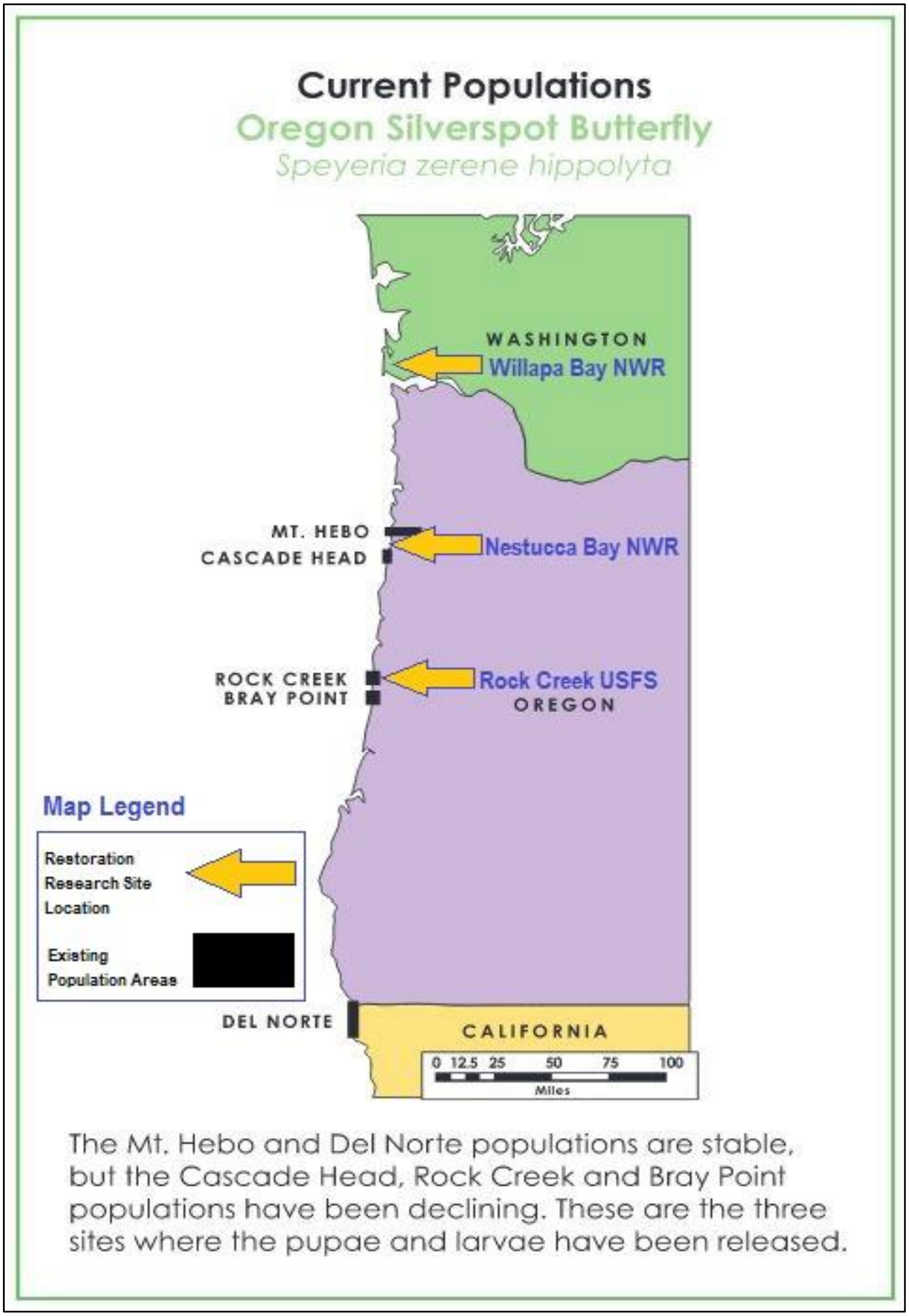


Figure 7: Map of Oregon silverspot populations and research site locations. Source map from: Andersen et al., (2010).

Practical and Theoretical Application

Federal, state and non-governmental organizations such as the Xerces Society agree that invertebrate and pollinator conservation is an important aspect for not only the agricultural production of the United States but also for understanding how invertebrates act as indicator species reflecting the health of our habitats, both human and non-human (Thorpe & Stanley 2011). This research will present a creative solution that addresses a specific species' life history needs, while also taking into account some of the structural diversity and ecosystem complexity required for functioning ecosystems (Haaland et al., 2011; Hughes et al., 2000; Petix et al., 2018; Thorpe & Stanley, 2011). By creating ecological functionality both structurally and biologically for *Viola adunca* and *Speyeria z. hippolyta* within coconut coir[6] mats, this research will showcase how restoration ecology can work to make localized structural changes which can lead towards larger global conservation goals (Foster et al., 2007; Glaeser & Schultz, 2014; Samways, 2020). The enhancement of new and former habitat areas can build on this work (Maiti & Maiti, 2015). In areas where habitat does not exist—rooftop gardens, roadsides, plazas—the mats can create habitats for insects and humans, proximal to places of development and busy human existence and activity (Haaland et al., 2011; Littlejohn, 2012). These plant building products can also lead to the growth of industries in restoration ecology and emerging markets such as land systems architecture (Systems & Interdisciplinary, 2007).

[6] Coconut coir - coir, or coconut fibre, is a natural fibre extracted from the outer husk of coconut.

Research Question

Will out-grown and out-planted vegetative mats of *Viola adunca*, *Festuca romeri,* and *Fragaria chiloensis* made from coconut coir and *Alnus rubra* chips promote *Viola adunca* and associated plant species ability to establish and maintain interstitial spacing within the mat more effectively than the traditional plug planting techniques?

Hypothesis

This research project will take an innovative non-herbicidal approach to ecological restoration by utilizing a common environmental engineering and soil conservation tool - coconut coir mats (Abad et al., 2002; Maiti & Maiti, 2015). I hypothesize that using the mats as a medium to grow the *Viola adunca* will create an environment suitable to the violet's historical habitat, while inhospitable to non-native invasive plants and their seed above and within the soil. If the vegetative mats are more effective than traditional plug planting, they will provide a new restoration tool to support the threatened *Speyeria z. hippolyta* larval development by suppressing non-native invasive plants, retaining soil moisture and creating a low nutrient growing media and recruitment substrate for *Violas.*

Roadmap of Thesis

My thesis research problem will explore the primary literature available to frame my research question within the contemporary context of restoration ecology and the known historic ecological conditions of the *Viola adunca* and the *Speyeria z. hippolyta* ecosystem. This thesis begins by exploring the global-to-local implications of insect conservation and the invaluable role it can play in shaping a human value system of true sustainability the concept of the ecosystem (Tansley, 1935). It will then explore the Cascade Head Biosphere Reserve and how the Biosphere Reserve concept and designation can help to communicate and achieve habitat for insects and human conservation efforts. After an exploration of the future of the concept of sustainability, the discussion will turn back to the ecological baseline of the historic coastal prairie--what it must have looked like and how indigenous peoples saw their land through the lens of traditional ecological knowledge. The concept of sustainability was once known by the indigenous and their territories, it is up to this thesis and future research to continue the eclipsing of western science with this knowledge. This thesis taps into this knowledge, exploring the biology and ecology of *Speyeria z. hippolyta* and its once abundant host plant *Viola adunca* while confronting some of the hurdles, limitations and successes for the restoration of the coastal prairie and the recovery of *Speyeria z. hippolyta* (Crone et al., 2007; Petix et al., 2018; Russell & Schultz, 2010; Service, 2013; Stanley et al., 2008). Based on insect conservation work, this thesis engages with research on a larval level to model the exploration and herbivory of the caterpillar's early instars and what a meter square of high-quality habitat could and should look like. This project builds off prior research ideas and professional experiences in restoration ecology and horticulture, growing emergent vegetative mats of various native *Carex* and *Juncus* species, with coconut coir in an aquaponics[7] system with the Sustainability in Prisons Project (SPP) for the Oregon Spotted Frog (*Rana pretiosa*) at Stafford Creek Corrections Center in Aberdeen, Washington. This thesis aims to achieve this high-quality

[7] Aquaponics - is a combination of aquaculture, which is growing fish and other aquatic animals, and hydroponics which is growing plants without soil.

low growing larval habitat in the coconut coir mats to add a new tool into the coastal prairie restoration toolkit (Glaeser & Schultz, 2014; Petix et al., 2018; Stanley et al., 2011).

LITERATURE REVIEW

Insect Conservation

> Insects along with other invertebrates, play a vital role in many terrestrial ecosystem processes. Conserving insects is conserving what they do as much as conserving them for their own sakes, yet the task is vast and fraught with both challenges and opportunities we will explore here. (Samways, 2020, p. Half title).

Undoubtably, we face dilemmas in assigning value to the conservation of insects, while solitary insects such as *Speyeria z. hippolyta* are aesthetically beautiful and visually elusive, ants invade our homes and eat food while displaying elaborate behavioral cooperation (Pearce & Wilson, 1990). Specialized plant feeding insects have faced habitat loss from logging, agriculture, infrastructure development and an increasingly urbanizing environment for too long (Dunn, 2005). This puts insects at a particularly high risk of extinction globally (Samways, 2020). Our landscape is fragmented (Schtickzelle et al., 2007). As habitat corridors continue to shrink in volume and increase in perimeter, it will continue to drive invasive species movement, and further threatened endemic species (Dunn, 2005; Littlejohn, 2012; Zielin et al., 2016). Still, researchers debate how much loss has occurred, as the baseline of ecosystems have shifted rapidly and in some cases without proper observation or documentation (Samways, 2020). The silent vector forces of exotic and invasive plants continue to increase pressure on species resources and the habitat structure that buffers extinction debt (Stanley et al., 2011; Samways, 2020). The idea of land sharing and the concept of biosphere reserves provide one of these global-to-local opportunities to advance our land systems knowledge and architecture in a way that protects the animals and insects dwelling there through best management and restoration practices directed by science (Systems & Interdisciplinary, 2007).

Biosphere Reserves - Cascade Head

The United Nations Educational Scientific and Cultural Organization, UNESCO, developed the concept of biosphere reserves to bring together ideas of conservation of species and sustainability. In this global initiative, 714 active biosphere reserves around the world have been designed around three major areas: 1. Conservation of biodiversity and cultural diversity; 2. Socio-culturally and environmentally sustainable economic development; and 3. Logistical support and development through research, monitoring, education and training (UNESCO 2020, Biosphere Reserves, about). The support structure of a biosphere reserve helps to facilitate the graded intensity of the land-sharing-land-sparing spectrum (Samways, 2020; Van Cuong et al., 2017).

This begins with the core area of a biosphere, focused on conservation of the landscape, ecosystems, species and humans within by preserving genetic variation within species (Ishwaran et al., 2008). Unlike early attempts at creating reserves, the biosphere reserves do not take people out of the picture—humans, plants, and animals live and work together, not at odds with one another (Bridgewater, 2002). Designated in 1971, The Cascade Head Biosphere Reserve (see Figure 8) hosts ample opportunities to work with this community ecosystem concept, in an area that through human activities could potentially restore the resources and habitat for *Speyeria z. hippolyta* (*Speyeria zerene hippolyta* W.H. Edwards; USFWS 2001). Biosphere Reserves offer populations one of the best methods to critically calibrate value, resources and economic development through a proactive conservation lens for insects and the humans they serve (Bridgewater, 2002; Samways, 2020).

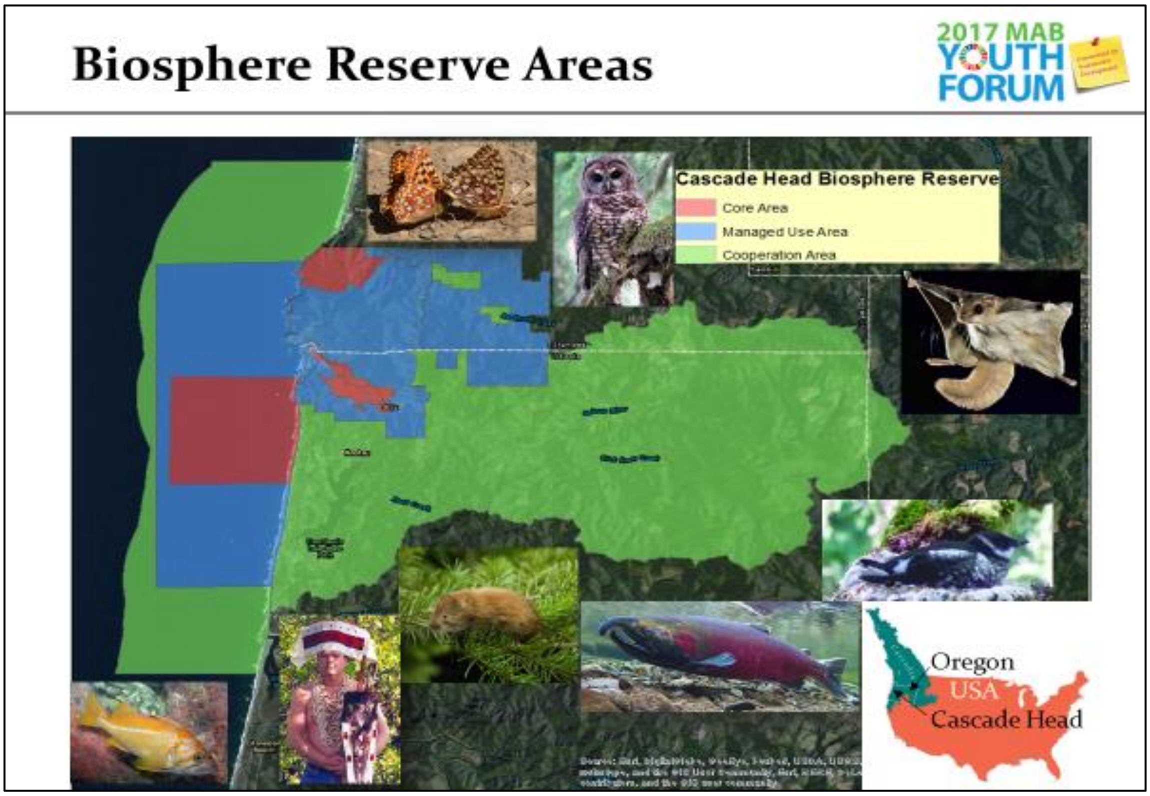


Figure 8: Map of the Cascade Head Biosphere Reserve and its endangered animals

The growing body of research on coastal prairie restoration in the Pacific Northwest points to many tested techniques that could provide valuable contributions to restoring these prairie grassland ecosystems for species such as *Speyeria z. hippolyta* (Bennett, Thomsen, & Strauss, 2011; Petix et al., 2018; Russell & Schultz, 2010). By improving the size and quality of habitat we might begin to see the role we can play and did historically (Awmack

& Leather, 2002; Hughes et al., 2000; Zald, 2009). However, many of these tested techniques have drawbacks. For example, while topsoil removal appears to be one of the most successful techniques in reestablishing native forb and grass cover, the cost and feasibility of soil removal continues to be a hurdle for large scale and site-specific restoration (Petix et al., 2018; Russell & Schultz, 2010; Schultz & Ferguson, 2020; Sims, 2017; Thorpe & Stanley, 2011). Moreover, the most adopted landscape level alterative—the use of herbicide—has significant stakeholder push back and growing animal and human health concerns (Gillam, 2017). To address these concerns and add to ecological function during restoration there is a need for research into treatment combinations and the innovation of novel techniques. But first, we must understand the dramatic changes to these coastal prairie ecosystems over time (Schultz et al., 2011; Stanley et al., 2011). These changes have informed our understanding of the role geographic variability and disturbance regimes play in the maintenance of plant communities and indicator species (Foster et al., 2007; Jermy, 1984; Sims, 2017). These include *Viola adunca* and the subspecies of *Speyeria zerene*, whose larva depend on the leaves of the violet. This review will explore the role of micro and macro site conditions in combination with historic and modern land use practices that aid in maintaining a seral stage of herbivory for the butterfly in coastal prairie ecosystems. Framed within the contemporary context of restoration ecology and the known historic ecological conditions of *Viola adunca* and *Speyeria z. hippolyta*, this literature review will provide the foundation for research into the question: Will planted native vegetative mats growing *Viola adunca*, made from coconut coir and *Alnus rubra* chips promote *Viola adunca's* ability to establish and maintain interstitial spacing within the mat more effectively than traditional plug planting techniques?

Historic Coastal Prairie Environment

To understand how to establish and maintain density and abundances of *Viola adunca* and other plant species native to Pacific Northwest coastal prairies, we must first understand the mechanisms and conditions, both biotic and abiotic, that created the historic prairie and caused its decline. “One of the most important conservation issues in ecology is the imperiled state of grassland ecosystems worldwide due to land conversion, desertification, and the loss of native populations and species” (Ceballos et al., 2010, p. 2). Across the globe, temperate grasslands and meadows have sharply declined in spatial extent relative to other grassland types such as savannahs and tropical grasslands (Kruess & Tscharntke, 2002; Sims, 2017; Zald, 2009). Temperate grasslands create hotbeds of primary production, biodiversity, and carbon storage comparable to that of tropical rainforest, and can even assist with climate change mitigation by affecting the earth's surface albedo, deflecting some of the sun's energy which darker colored forests absorb (Foster et al., 2007; Van Geel et al., 1999; Walsh et al., 2010). In addition to providing ecosystem services like those just mentioned, these coastal prairies contain rare endemic plant species and disjunct populations of relict botanical communities (Zald, 2009). Ultimately, the limited availability and the high level of speciation and numbers of rare species present in prairies contribute to their societal and ecological importance (Dunn, 2005; Hughes et al., 2000). Zald (2009) recounts that the current extent and spatial distribution of coastal prairies relates largely to tree encroachment. Over the past hundred years, in locations such as Mt. Hebo where the last population of *Speyeria z. hippolyta* currently thrives, as much as (96%) of the historic coastal prairie extent has been lost to forest encroachment (Bachelet et al., 2011; Zald, 2009).

Indigenous Prairie Practitioners

> Fire severity is a measure of the effects of fire on the environment—both in damage to vegetation and impacts on the soil. Fire severity is driven by weather conditions, the topography of the landscape, and the fuels that are present. Of these, weather is the overriding factor (OSU Extension Service, 2012. Fire severity).

The large and high severity wildfires that created the important disturbance agents in the coastal prairie environment became considerably disconnected over time. The earth's last major climatic change occurred approximately 2770 years ago (Van Geel et al., 1999). During this time the coastal prairies experienced stand replacing fire regimes every 140 to 170 years. The last 2770 years has been what is referred to as the "Little Ice Age" and saw the frequency of these fire regimes shift to every 240 to 270 years. Indigenous people thrived as active users shaping their landscape to maintain the coastal prairies by lighting more frequent and less severe fires (Hamman et al., 2011; Zald, 2009). Indigenous people incorporated fire as part of ceremonial practice, burning blankets to welcome the salmon home, to drive game into the open for hunting, as well as to maintain open prairies for ease of hunting and gathering activities (Walsh et al., 2010). Additionally, these burning practices helped to maintain prairie plant assemblages such as camas and other species which served as sources of food and medicine (Gould & Plew, 1996). Over time, the intermediate disturbance regimes of the indigenous prairie practitioners created an ecosystem of high biodiversity and abundance. It was an ecosystem where human land use management and biodiversity co-evolved (Gould & Plew, 1996; Shelvey & Boyd, 2000). However, this ecosystem ended beginning in the 1860's when European settlement led to the proliferation of disease and the subsequent genocide of the region's indigenous people and their land use practices (Zald, 2009). European immigrates settled along the coast to survive by agrarian and natural resource extraction to find stability in a land fraught with wind, weather and waves.

Figure 9: Viola adunca biological illustration.

Viola adunca - Evolution and Biology

Viola adunca is a perennial angiosperm forb[8], with slender rhizomes[9] that evolved out of one of the largest orders of flowering plants; Malpighiales with over 36 families (Judd et al., 1999).

[8] Forb - a herbaceous flowering plant other than a grass.
[9] Rhizomes - a continuously growing horizontal underground stem which puts out lateral shoots and adventitious roots at intervals.

> Usually stemless in the early part of the season, later developing aerial stems up to 10 cm tall. Starts to flower early in the growing season. Leaves generally oval to heart-shaped, hairy to hairless, blades to 3 cm long with fine round-toothed margins. Stipules reddish-brown or with reddish-brown flecks, narrowly lance-shaped margins slender-toothed or somewhat ragged. Flowers to 1.5 cm long, with a slender spur half as long as the lowest petal, petals blue to deep violet, the lower three often white at base and purple-penciled, the lateral pair white-bearded (MacKinnon et al., 2004, p. 201) (see Figure 9).

Viola adunca's habitat includes dry to moist meadows, open woods, grasslands and open, disturbed ground from lowlands to near timberline (Johnston et al., 1974). Its blue flower primarily attracts bees and flies; once pollinated it produces a capsule of seeds. The primary mechanism for seed dispersal is during the late summer when the fruit's small capsules open and three valves explosively propel the seed outward from the capsules as it dries. This dispersal can broadcast seed up to approximately 50 feet and into new areas where the seeds can lie dormant for years or can germinate after approximately 100 days of cool wet weather if conditions are optimal to initiate germination of the seed (Almasi & Kollmann, 2007; American & Aug, 2016). *Viola adunca* can flower multiple times per year, when punctuated events of moisture and sun coincide (American & Aug, 2016; Freitas & Sazima, 2003). The evolution of the physical, biological and cultural environmental influences of Pacific Northwest coastal prairies shaped the ecology that we witness today (Gould & Plew, 1996; Walsh et al., 2010). The presence and absence of *Speyeria z. hippolyta* and *Viola adunca* offer a clear indicator of the current state of the ecosystem function of the coastal prairie (Hughes et al., 2000; Jermy, 1984; Kruess &

Tscharntke, 2002; Schultz et al., 2011; Sims, 2017; Sivakoff et al., 2016). Together these two species help us visualize the influence of ecological forces on biological form and function that has disappeared in many areas today (Freitas & Sazima, 2003; Hill et al., 2018; Shuey et al., 2016). An animal emblematic and intermediary to the plant and animal community it co-evolved to. While restoration ecology has often focused on the reintroduction of a single species, little work has been done to examine the ecology of restoration itself and its overall effect on plant quality (Almasi & Kollmann, 2007). To better understand the biological needs of the butterfly and its ability to move into new habitats, we must examine the life and evolutionary history of *Viola adunca* (Botanical & Press, 2016).

Violas have evolved to have three different types of pollination syndromes: sternotribic (where an insect's stomach pollinates the flower), nototribic (where an insect's back pollinates the flower), and self-pollination (where no insect pollinates the flower, but the violet reproduces asexually). While yellow violets represent the most ancient of violet species, blue violets evolved more recently. Eighty-nine percent of *Viola adunca* pollination is sternotribic; it is pollinated almost exclusively seventy-two percent by solitary bees *Osmia Andrena*, also known as mason bees (Botanical & Press, 2016).

This co-evolution between ecosystem conditions, and a single insect genus is mirrored in other aspects of *Viola adunca's* life history. Research into the germination requirements of the violet has pointed to soil type and temperature regime as important factors in the germination success of the species (Almasi & Kollmann, 2007). Other research has shown that the violet responds well to inadvertent fluctuations in temperature, light, and high soil pH levels (James, 2008). Moreover, *Viola adunca* sown in soil medias of coarser substrate, greater structural diversity, and cooler temperatures appear to have the greatest influence on seed germination (Almasi & Kollmann, 2007; Dunwiddie & Martin, 2016; Sparling, 2020). This points to the applicability of this coconut coir research, focusing on the role that coconut coir mats and alder chips can play in providing a soil/substrate that mimics disturbed areas with these microsite conditions. This research can begin to examine the role of soil structure in the violet's ability to establish, maintain and recruit in the wild through mat mimicry. An examination of the role of site soils hosting the plant will address one of the important gaps that exists in developing a greater understanding of the *Viola adunca's* life history (Kubitzki, 2014).

Viola adunca - Microsite Conditions

Within the realm of soil structure, pH and other substrate variables, research within the inland prairies of the Salish lowlands and Willamette Valley has pointed to the role of microsite conditions at valley prairie sites like Mima Mounds, where geological history and topographic variation are associated with promoting the germination and establishment of a variety of plants including *Viola adunca* and the Golden Indian paintbrush (*Castilleja levisecta*), (Dunwiddie & Martin, 2016). The Dunwiddie and Martin (2016) paper entitled "Microsites Matter*:* Improving the Success of Rare Species Reintroductions" examined the inland prairie sites of Washington and Oregon at different stages of habitat suitability, restoration and geologic condition. Research into the role of these different variables on species presence or absence identified certain microsite conditions, such as loamy soil types and steeper localized topography, as strong indicators of Golden paintbrush

(*Castilleja levisecta*), *Viola adunca* and *Festuca roemeri* (Dunwiddie & Martin, 2016). Areas in the Salish lowlands, such as at Mima Mounds, presented the greatest abundance of *Castilleja levisecta*, *Viola adunca* and *Festuca roemeri* with the plant species growing in close association at the base of mounds.

The three plants' ability to maintain and recruit themselves within these microsites was associated with low nutrient and mid-disturbance regimes[10] due to the angle of repose[11] of mounds and other topography. Moreover, the authors believe the presence of these microsite conditions in combination with sub surface nutrient rich soils, such as the Nisqually loams below the low nutrient surface, was beneficial in promoting plant growth and survival. The findings of the study also point to the importance of the interaction of site and topography in affecting the survival and recruitment of *Castilleja levisecta*, *Viola adunca* and *Festuca roemeri* (Dunwiddie & Martin, 2016; Lawrence & Kaye, 2011; Sparling, 2020). Turning to this thesis research, the microsite conditions of the prairie may be mirrored in the conditions of the coconut coir mat planted with the *Viola adunca* and *Festuca roemeri* (Almasi & Kollmann, 2007; Dunwiddie & Martin, 2016; Sparling, 2020). The vegetative mats' ability to give these slower growing plants such as *Viola adunca* and *Festuca roemeri* a head start to the existing weed community by providing a low nutrient surface substrate with access to richer soils below, could provide insights into restoration succession and greater plant establishment success (Dunwiddie & Martin, 2016; Glaeser & Schultz, 2014; Hill et al., 2018; Stiling & Moon, 2005).

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[10] Disturbance regimes - Any of various modes of widespread floral replacement, e.g., flood, fire, disease or wind.
[11] Angle of repose - the steepest angle at which a sloping surface formed of a loose material is stable.

Speyeria zerene hippolyta- Biology

Coastal conditions such as fog and wind helped to create a darker smaller *Speyeria z. hippolyta* along the coast, also informing a smaller body surface area and a faster ability to thermoregulate in the early morning light along the forest edge (*Speyeria zerene hippolyta* W.H. Edwards; USFWS 2001). Darker wings also help absorb the sunshine the butterfly needs for thermoregulation in the cool summer temperatures of the coastal prairie were the butterfly thrives. Both *Speyeria z. hippolyta* and *Viola adunca* can often be found in locations where temperatures from the sun's energy fluctuates (McCorkle et al., 1980; Schaeffer, 1992; Kiser, 1993). The Northwest coast's ambient and often strong winds shaped the wing dimensions of the coastal *Speyeria z. hippolyta* that are stout and like their alpine *Speyeria* cousins. Persistent northwest summer winds are believed to have played a role for populations of the butterfly moving between the Clatsop Planes and Saddle Mountain where coast range meadows provide amble *Viola adunca* habitat today suitable for larval release (Petix et al., 2018; Service, 2017). This population migration and gene flow may have also occurred between Mt. Hebo and proximal historic coastal prairie sites like Nestucca, Netarts and Cape Mears (see Figure 13).

Speyeria z. hippolyta is a highly localize endemic[12] which makes it well adapted to r-selection[13] and disturbance associations (Sims, 2017; Sivakoff et al., 2016). *Viola adunca* population sizes can help provide an estimate of the carrying capacity available for the

[12] Endemic - native and restricted to a certain place.
[13] R- Selection - species are those that emphasize high growth rates, typically exploit less-crowded ecological niches, and produce many offspring, each of which has a relatively low probability of surviving to adulthood.

Speyeria z. hippolyta selection and movement into new habitats in combination with adequate nectar sources for adults (Bierzychudek & Warner, 2015; Hill et al., 2018; Hughes et al., 2000; Jermy, 1984; Sims, 2017). While male butterflies use the open coastal meadows for courtship, fertile females are seekers of low vegetation height where *Viola adunca* patches can persist for oviposition[14] on the violet leaves. Once the females' eggs have been laid, the first instar[15] of the butterfly typically hatches after approximately 22 days when the larva then eats its egg case, typically between June and July (Kiser, 1993, Schaeffer, 1992) (see Figure 11).

Figure 10: Oregon silverspot pupae being released on Cascade Head 2015. Charrette students visit Mt. Hebo to learn about pollinators.

[14] Oviposition - means expulsion of the egg from the oviduct to the external environment and is a common phenomenon in invertebrates, vertebrates and other than eutherian mammals.
[15] Instar - a phase between two periods of molting in the development of an insect larva or other invertebrate animal.

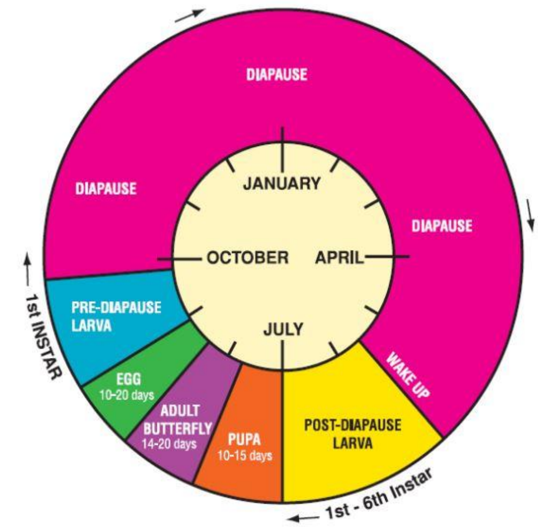


Figure 11: Speyeria z. hippolyta's slow growing life cycle. From: Andersen et al., (2010).

The timing of *Speyeria z. hippolyta's* life cycle and history are closely linked to the climatic and elevational conditions along the coast where localized weather patterns, moisture and temperature are greatly associated with coastal proximity (McCorkle et al., 1980). The herbicidal effect of salt spray from summer winds seem to have the greatest effect on these proximal plant communities, stunting the vertical growth of the plant community. Factors such as vegetation height, effects adult flight behavior, migration and host plant availability. Additionally, the phenology[16] of the plant community that host the butterfly's nectar is closely associate with the coastal prairie summer (Kiser, 1993). Key features to the habitat needs of *Speyeria z. hippolyta* is in abundance of late-season nectar sources such as Canadian goldenrod (*Solidago elongate*), Pearly Everlasting (*Anaphalis margaritacea*), and Pacific aster (*Symphyotrichum chilense*) (*Speyeria zerene hippolyta* W.H. Edwards; USFWS 2001). While the butterfly is currently listed as threatened, an

[16] Phenology - the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life.

endangered classification is now warranted, for the specie based on a lack of funding available to monitor the species population (Discussions with USFWS).

The caterpillars' dependence on the leaves of the plant to complete its slow growing life cycle evolved out of the plant's once nationwide dispersal and nutritional value (Bierzychudek & Warner, 2015; Hill et al., 2018). *Speyeria z. hippolyta* was first described from three males and one female taken in Oregon with an additional male from Northern California in 1879. These individuals constitute the classification of the subspecie that we know today to be true *Speyeria z. hippolyta*. It is important to note that some biologists believe the Northern California population represents a convergent subspecie that evolved through a convergent ecotype derived from adjacent inland *Speyeria zerene behrensii or gloriosa* (McCorkle et al., 1980). Alternatively, some hypothesize that the population represents a divergent relict form of *hippolyta* now separated from the parent population by an extensive and dynamic dune complex of the Central Oregon coast (see Figure 13). As McCorkle (1980) describes in ecological detail; it is important to understand that there are other *Speyeria zerene* or Oregon silverspot subspecies that live in Oregon, including *Speyeria z. gloriosa* of the Illinois River Valley, and the–now extinct from Oregon– the Valley silverspot *Speyeria z. bremnerii*, last observed in the 1970s at Mary's Peak. Another more widespread and non-endangered member of the *Syperia* genus can also be found within the habitats of *Speyeria z. hippolyta*; *Speyeria hydaspe* has cream colored spots under its wings in contrast to the metallic silver spots of *Speyeria z. hippolyta*.

> The subspecies of *zerene Fritillaries* once radiated throughout the Pacific Northwest and into California and illustrated the principles of geographic variability and subspeciation across the region, with six or more Cascadian

subspecies currently or formerly occupying localized habitats as distinct as the subspecies (Pyle, 2002, p.268) (see Figure 14).

Speyeria zerene hippolyta - occupies the coastal and dune prairies of Washington Oregon and Northern California. *Speyeria zerene zerene (or conchyliatus)* - occupies the Southern Oregon Cascades, the Warner, Klamath, Coast Range Mountains of Northern California and the Sierra Nevada Mountains extending into Southern California. *Speyeria zerene gloriosa* - occupies the riparian areas of the Illinois River, the Siskiyou Mountains, the Southern Oregon Coast from Coos Bay to Gold Beach and continuing in through the Northern California coast from Arcata and into the Kings Mountain Range. *Speyeria zerene behrensii* - occupies the Mendocino range in Northern California. *Speyeria zerene bremnerii* - occupies the Sunshine Coast of British Columbia, the Salish Lowlands of Washington west to Port Angeles east to the Cascades and historically south throughout the Willamette Valley. *Speyeria zerene* unnamed subspecies - occupies the north and northeast subalpine habitats of the Olympic Mountains in Washington (McCorkle et al., 1980; Pyle, 2002, p. 268).

Speyeria z. *hippolyta's* biology is deeply related to its ecology, which is why there are other animals that can be used as stand indicators of ecological conditions associated with *Viola adunca* and *Speyeria z. hippolyta*. Animals such as the Pacific jumping mouse (*Zapus trinotatus*) and other small mammals can be used as stand-level indicators for ecological health, in absence of the butterfly. In areas such as Cascade Head, where today the butterfly has been expatriated, its indication is related to the complex variety of interactions that it benefits from based on the plants, animals and ecological structure present. In contrast, at

Cascade Head, insectivorous Vagrant shrews (*Sorex vagrans*) have been documented in small mammal research as having a possible association with mowing regimes on present pasture grasses as they can still hide in the low vegetation, while larger mammals such as the jumping mouse are vulnerable to predators (Unpublished research, Wilson 2015). The Deer mouse (*Peromyscus maniculatus*) is not an insectivore and thus not a predator of the *Speyeria z. hippolyta* larvae, but is a predator of *Viola adunca* seed (Cor& Bury, 1991; Wilson & Forsman, 2013).

Figure 12: Pacific jumping mouse (*Zapus trinotatus*). Vagrant shrew with ticks (*Sorex vagrans*). Deer mouse (*Peromyscus maniculatus*). Cascade Head small mammal trapping 2016.

Figure 13: Current and historic habitat map of *Speyeria z. hippolyta* with locational status.

Figure 14: Habitat map of *Speyeria zenrene spp*. Current and historic in the Pacific Northwest and California.

Modern Habitat Restoration Ecology Techniques

A wealth of research has been conducted on the California coastal prairie complex (Bennett et al., 2011; Thorpe & Stanley, 2011). While climatically and geologically different than the coastal prairie ecosystems of Oregon and Washington, there is much we can learn from this regional research. For example, researchers have examined the interaction between a native California forb, Seaside fleabane (*Erigeron glaucus*), and a non-native invasive grass, Velvet grass (*Holcus lanatus*), a species that is also of non-native invasive concern in Pacific Northwest coastal prairie ecosystems. Bennett et al. (2011) found the weeding of plots to have the most competitive interaction effect on *Holcus lanatus*, while also increasing seed bank germination of *Erigeron glaucus*. The research examined how the presence and persistence of *Holcus lanatus* changes the soil community over time, while also directly competing with the native plant community and the effects of herbivory[17] on the plants (Bennett et al., 2011). They also explored *Holcus lanatus* competition via allelopathy.[18] Weeded areas led to high rates of germination success for *Erigeron glaucus*. Germination rates increased up to (815%) as compared to unweeded plots. Direct competition of *Holcus lanatus* and *Erigeron glaucus* influenced the total survival of *Erigeron glaucus.* Mammalian herbivory also played a role in the reduction of *Erigeron glaucus* plant size by (71%). Perhaps the most important finding from the study was that the removal of competitors without the alteration of seed bank resulted in the failure of native species to re-establish. This points to the role that soil scraping in combination with

[17] Herbivory - the state or condition of feeding on plants.
[18] Allelopathy - the chemical inhibition of one plant (or other organism) by another, due to the release into the environment of substances acting as germination or growth inhibitors.

vegetative (coconut coir) mats may play in altering the seed legacy of soil monocultures following degradation and non-native invasion (Bennett, Thomsen, & Strauss, 2011). The results of the research illustrate the multitude of mechanisms that drive native and non-native invasive plant interactions in the coastal prairie ecosystem.

In Buisson et al. (2006), research dealing with the California coastal prairies explored the most appropriate combination of treatments for reintroducing the coastal prairie bunchgrass California oatgrass (*Danthonia californica*). In complement to the *Holcus lanatus* and *Erigeron glaucus* study, this research examined the impact of local versus non-local seed sources on the long-term survivability of the native bunch grass (Buisson et al., 2006). The study also examined the misleading nature of short-term plant establishment studies (research that occurs with the monitoring of one growing season) and the value of genetically localized seed sources. Plant genetics were of value to the study to trace the success of local seed sources while also examining restoration treatments, determining that topsoil removal greatly enhanced both transplanted and seeded *Danthonia californica*. Even longer-term research has examined the role of continual disturbance regimes such as of grazing on *Danthonia californica* biomass. Grazing was noted to increase the root growth of *Danthonia californica* the but also a decrease in the overall plant biomass, which has also been identified in the Pacific Northwest and other conservation areas (Kruess & Tscharntke, 2002; Schultz et al., 2011; Dunwiddie et al., 2008). From this California study, one can conclude that future studies should take a long-term approach to monitoring to account for restoration success, even in the dynamic and rapidly changing forb communities of the coastal prairie. The study highlights the beneficial role of local seed sources, transplanting versus seeding and most importantly the role soil scraping can play in the success of establishing other native species found in the coastal prairie complex with species such as *Viola adunca* (Buisson et al., 2006, Thorpe & Stanley, 2011).

Northward to the Pacific Northwest coastal prairie, the most recent restoration efforts for the violet and butterfly reflect a variety of projects designed to try to re-establish quality habitat for *Speyeria z. hippolyta*. Of great significance to this coastal prairie restoration research is a series of research projects conducted in the Clatsop Plains on the northern Oregon and southern Washington coast through partnerships with the Institute for Applied Ecology and the United States Fish and Wildlife Service, which focused on the effect of scraping and topsoil removal in the restoration treatments of coastal prairie plant communities at Tarlatt, Willapa (incorporated into this research project) and the Clatsop Plaines (Petix et al., 2018; Service, 2017) (see Figures 16 & 17). Pertix et al. (2018) research on the use of grazing, soil impoverishment, and applications of organic herbicide and heat treatments to sterilize soil of non-native plant seed provides an understanding of other restoration tools available. These treatments helped to reduce the abundance of specific groups of non-native invasive plants, they also increased the abundance of seeded native plant species that continue to outcompete *Viola adunca* for light (Dover & Settele, 2009; Petix et al., 2018). Ultimately, the study discovered that topsoil removal was most effective in reestablishing low growing native vegetation in the foredune coastal prairies of the Clatsop Plains. The field research conducted at the Clatsop Plains in Oregon points to the current most effective restoration treatments in the Pacific Northwest coastal prairie complex and suggest that a vegetative mat growing *Viola adunca* might aid the plant by suppressing local non-native and even native vegetation from light and topsoil access (Bennett et al., 2011; Buisson et al., 2006; Jones, Norman, & Rhind, 2010; Jutila & Grace, 2002; Petix et al., 2018; Service, 2017). This treatment had the greatest success in native seeded forb and grass establishment as well as the lowest cover of non-native forbs and grasses due to removal of a portion of the existing seedbank and exposure of bare soil (Petix et al., 2018). The research corresponds to the larger study of the role of topsoil removal in prairies (Buisson et al., 2006; Dunwiddie & Martin, 2016; Jones et al., 2010). Petix et al. (2018) provides a very site-specific set of tools to consider for restoration treatments associated with the coastal prairie mat research at Willapa and suggests a role vegetative mats could play in cutting down on the cost of soil removal and maintaining interstitial spacing for plants like *Viola adunca* to grow and possibly recruit.

Speyeria zerene hippolyta - Larval Survival

The paper, "Modeling caterpillar movement to guide habitat enhancement for *Speyeria zerene hippolyta*, the Oregon silverspot butterfly", examines the biology and life history of the butterfly in relation to *Viola adunca* density, abundance and location. Bierzychudek & Warner's (2015) work highlights the last 20 years of insect conservation research related to the *Speyeria z. hippolyta* (Bierzychudek, Warner, McHugh, & Thomas, 2009; Hill et al., 2018; James, 2008). The article explains the relationship between habitat spatial structure and the butterfly's occurrence and abundance as related to the presence of its host plant *Viola adunca*. In addition, to identifying the other variables at play related to the butterfly's survival; particularly other predators, the article addresses the connection between human-caused landscape alteration and the decline of *Viola adunca* populations and biodiversity within regions such as Cascade Head. Using a combination of in the field observations and computer modeling, the authors explore the role of the butterfly's larval caterpillar stage in relation to foraging behavior and movement, finding that during the caterpillar's first instar phase of development, the insect's movement is limited to an area of about one meter square. As the caterpillar develops into its second, third and fourth instar phases, the insect's movement based on foraging increased outside of the meter square area in a random pattern till a *Viola adunca* plant was reached. Moreover, the research proposes that with a *Viola adunca* density of at least four plants per square meter, the butterfly will see a 10% increase in survivorship from caterpillar to adulthood (Bierzychudek & Warner, 2015). Insect conservation behavior research in this study, provides a clear research connection for my hypothesis; the role of the vegetative mats in hosting both biological and structural elements that may help foster the larval development for *Speyeria z. hippolyta*, and new *Viola* mat metrics for measuring survival.

METHODS

Overview

The methods used in this research look to measure the effectiveness of out growing and out planting experimental coastal prairie vegetative mats as compared to the traditional restoration planting methods of dibble stick or shovel and plug planting (see Figures 31 & 32). The base substrate of the vegetative mat was made from coconut coir and a coating of latex for increased durability. The coconut coir was sourced from Sri Lanka and the company Rolanka^{tm}, a layer of Red Alder (*Alnus rubra*) chips was also placed on top of the seed sown and coconut coir to retain soil moisture in the mat for sown germinated seed. Additionally, during the summer, shade cloth was used to cover the hoop house growing the mats and plugs. In contrast to the mats, an equal seed quantity was sown into the traditional planting plugs filled with soil and topped with a thin layer of granulated granite. All plant material associated with the mats was sourced from areas in Oregon and Washington that represent the same genetic region and integrity as the restoration sites. The project utilized three plant species associated with the life history of *Speyeria z. hippolyta* based on ecological field data associated with *Speyeria z. hippolyta*'s habitat usage at Mt. Hebo and Rock Creek Siuslaw National Forest, Oregon (Unpublished research, Glavich 2019). The plant species tested are *Viola adunca*, *Festuca romeri*, and *Fragaria chiloensis*. Restoration areas prioritized for the planting of plant material include three sites that spanned the historic geographic distribution of the insect and are currently undergoing various conservation actions as part the federal recovery plan for the specie (see Figures 16-21): Willapa Bay and Nestucca Bay National Wildlife Refuges and Rock Creek Siuslaw National Forest (*Speyeria zerene hippolyta* W.H. Edwards; USFWS 2001).

Figure 15: Mating pair of *Speyeria zerene hippolyta*.

Research Study Sites

Figure 16: Soil removal and *Viola adunca* planting for *Speyeria z. hippolyta* release at Willapa Refuge.

Chinook Territory - Tarlatt Slough on the US Fish & Wildlife Service's Willapa National Wildlife Refuge host habitat restoration opportunities for Washington's coastal prairie. The site is currently undergoing restoration conversion for *Speyeria z. hippolyta* from cow pasture dominated by the grass (*Agrostis gigantea*), False dandelion (*Hypochaeris radicata*), Birdsfoot trefoil (*Lotus corniculatus*), Lanceolate plantain (*Plantago lanceolate*) and other non-native invasive plant species. Large areas of topsoil removal have been out planted with thousands of *Viola* plugs (see Figures 16 & 17). Currently, these treatments and plantings are expanding within the site and are in combination with other treatments including herbicide, mowing and scraping to deplete the non-native seed bank. The only natives recorded at the site where those planted. The site is proximal to Sandbar Road. Based on research at Rock Creek, a hedge row of native shrubs has been planted to buffer butterflies from the road (Littlejohn, 2012; Zielin et al., 2016).

Figure 17: Map of Tarlatt at Willapa Restoration Area.

Figure 18: Restored and enhanced extant habitat for *Speyeria z. hippolyta* at Nestucca Bay Refuge.

Tillamook Territory - Cannery Hill (Area 3 South) on the US Fish & Wildlife Service's Nestucca Bay National Wildlife Refuge represents a unique habitat restoration opportunity for Oregon's coastal prairie (see Figures 18 & 19). In 2013, Cannery Hill was added to the Refuge. Shortly thereafter habitat restoration work began converting the 1,202 acres from Reed canary grass (*Phalaris arundinacea*) and other non-native pasture grasses to native coastal prairie grasses and forb species. A combination of techniques is still being experimented with on the grassland, including herbicide application, scraping, mowing and others (Service, 2013). The work at Nestucca provides case studies and insights into coastal prairie restoration best practices and techniques including invasive species control, native seeding proportions, seeding techniques and prescribed burning (Service, 2013). In the winter of 2014 *Viola adunca* seed was drilled into the site and in the summer of 2017 captively raised *Speyeria z. hippolyta* from Mt. Hebo were released to the site to establish a new population in the renewed habitat.

Figure 19: Map of Area 3 South and Nestucca Restoration Area.

Figure 20: Enhanced extant habitat for *Speyeria z. hippolyta*. Rock Creek Siuslaw National Forest.

Alsea Territory - Area 8 of the Rock Creek Site in the Siuslaw National Forest represents an intact habitat currently and historically harboring *Speyeria z. hippolyta*. Rock Creek is located on the east and westsides of highway 101 and is a long-term study site that has generated a wealth of data on the site-specific behavior of *Speyeria z. hippolyta* and the environmental history and impacts to the area, principally the impacts to the Rock Creek population from highway 101 (Kiser, 1993; Littlejohn, 2012; Zielin et al., 2016) Within the sandstone cliff road cuts of the highway one can observe an absence of roots and other historic vegetation preserve that would imply the area has long been prairie (McCorkle et al., 1980). In other areas of the site, restoration treatments such as soil removal, scraping, mowing and plug planting is occurring with species including *Viola adunca*, Yellow-eyed grass (*Sisyrinchium californicum*), Beach strawberry (*Fragaria chiloensis*) and other coastal prairie pollinator resources.

Figure 21: Map of Area 8 and Rock Creek Restoration Area.

Figure 22: First mat *Viola adunca* to flower in trial media test at SCCC.

Cold Stratified Germination and Sowing

At Stafford Creek Corrections Center (SCCC) the initial mat germination test of *Viola adunca* seed sown directly into the coconut coir mats and control plug trays with a soil and granulated gravel cover took place on December 13th, 2018, with ~108 seeds per meter square meter of mat and two seeds per individual c7 plug with 98 plugs per tray. This resulted in a (64 %) germination rate in the mat and (82 %) within the plugs respectively (see Appendix). In March 2019, to ensure consistent plant establishment in the mats and c7 control plugs, additional *Viola adunca,* seed was cold stratified in a refrigerator for 100 days at 40^{o} F; this resulted in a (90%) germination rate. The cold-stratified seed was then directly sown at a rate of ~108 seeds per m^2 and two seeds per plug on August 22, 2019. *Festuca romeri* was directly sown on August 22, 2019 at nine seeds per m^2 and two seeds per plug (both with an 80% germination rate), and *Fragaria chiloensis* was planted from cuttings at two per m^2 and one cutting per plug on September 24, 2019 (with a 95% survival rate). Below (see Figures 23-25) show the process.

Table 1

Seed weight and sowing rates for target plant species

Plant Species	Seed grams/ cuttings per plug tray	Total plug seed/ cuttings	Seed grams/ cuttings per $1m^2$ mat	Total mat seed/ cuttings	Sow dates
Viola adunca,	0.21 grams 98 plugs	5 grams 588 plugs	0.36 grams	13 grams 36 mats	12/13/18 8/22/2019*
Festuca romeri	0.4 grams 104 plugs	1.6 grams 416 plugs	0.2 grams	7.2 grams 36 mats	8/22/2019*
Fragaria chiloensis	1 cutting 98 plugs	1 cutting 72 plugs	2 cuttings	72 cuttings 36 mats	9/24/2019

Notes: Sowing details and dates for mat and plug sowing with * = 100-day wet cold stratification.

Figure 23: *Viola adunca* seed direct sow. December 13, 2018 at SCCC.

Figure 24: *Viola adunca* survival counts in trial media. March 23, 2019 at SCCC.

Figure 25: Cold stratified *Viola* seed, *Festuca* seed and *Fragaria* cuttings at SCCC.

Experiment Design and Site Treatments

Each of the study sites received two types of restoration treatments two weeks prior to the planting of the plant plugs and vegetative mats—scraping and mowing. The plugs grown were then out planted randomly within the 12 1 x 1-meter control plots. The vegetative mats spacing, and planting mirrored the control plots within both treatment types. These treatments and planting types are summarized in Tables 2 and 3 below (see Appendix for vegetative mat plant survival table).

Table 2

Explanatory and response variables of research

Explanatory Variables	***Response Variables***
Scraping	Percent aerial cover and height of *Viola adunca, Festuca romeri*, *Fragaria chiloensis*
Mowing	Percent aerial cover, height and phenology of native plant species
Control Plugs	Percent aerial cover, height and phenology of non-native plant species
Vegetative Mats	Percent aerial cover of bare ground and vegetative mat

Table 3

Treatment and planting area size and dates

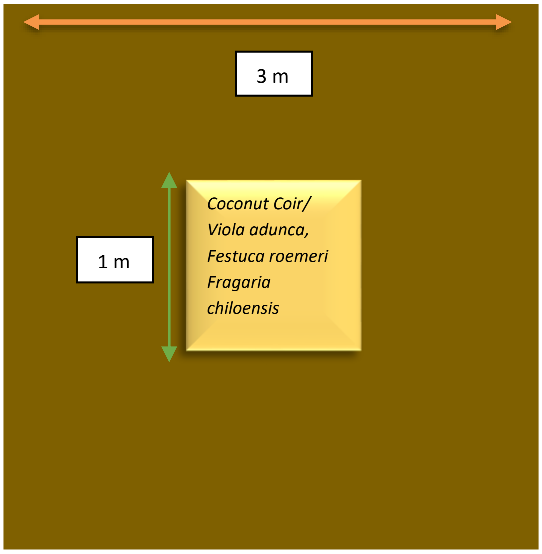
Site	***Total Treatment Areas***	***Total Planted Area***	***Date Planted***
Willapa Bay National Wildlife Refuge	Scraped Area 88 m^2 Mowed Area 88 m^2	Mats 36 m^2 Plugs 36 m^2	12/16/19 12/16/19
Nestucca National Wildlife Refuge	Scraped area 88 m^2 Mowed Area 88 m^2	Mats 36 m^2 Plugs 36 m^2	1/24/20 1/20/20
Rock Creek Siuslaw National Forest	Scraped area 88 m^2 Mowed Area 88 m^2	Mats 36 m^2 Plugs 36 m^2	1/24/20 1/19/20

Experiment Design of Study Plots

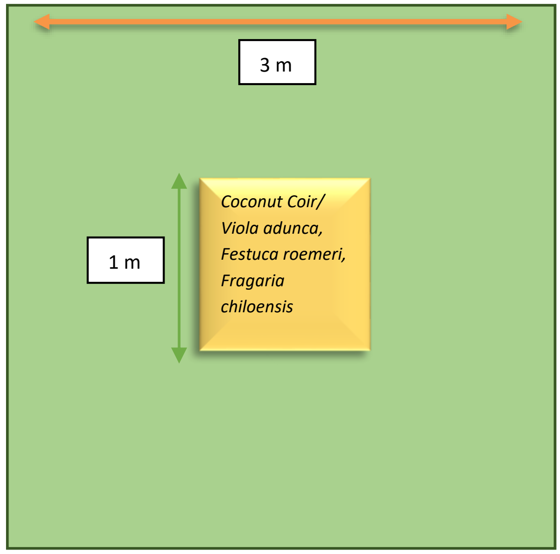
Illustration of study area for each vegetative mat and control plug planting area.

Vegetative Mats

Scraped treatment

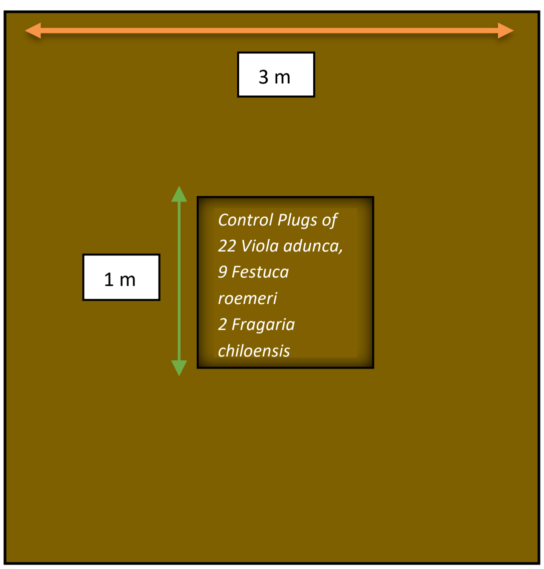


Mowed treatment



Control Plugs

Scraped treatment



Mowed treatment

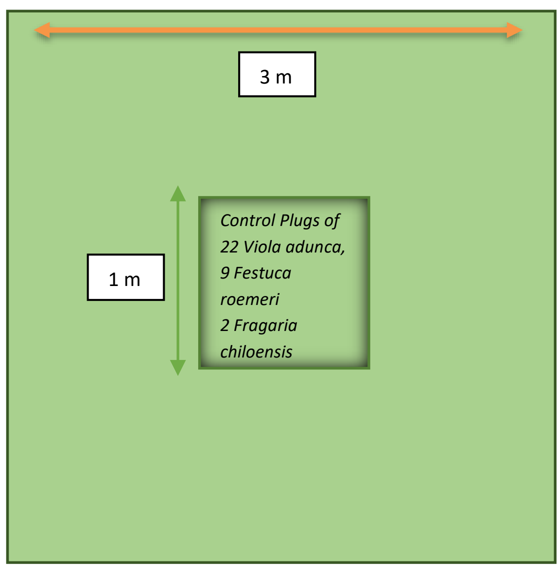
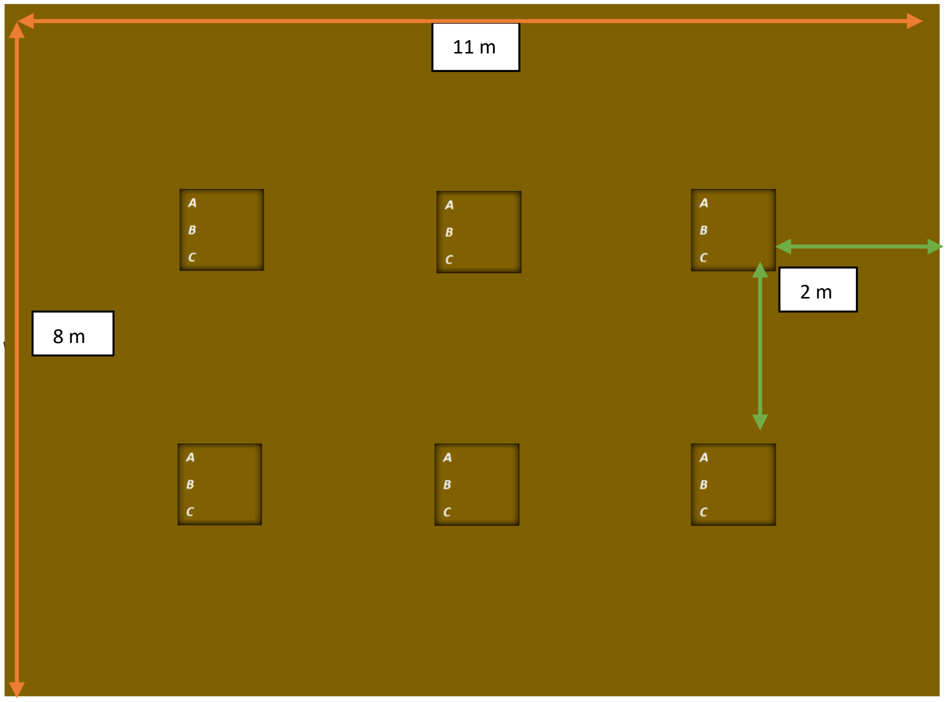


*Figure 26***:** Study area for vegetative coastal prairie mats plant plug control installation design within treatment types.

Experimental Design of Treatment / Planting Areas

Scraping with Plugs and Mat



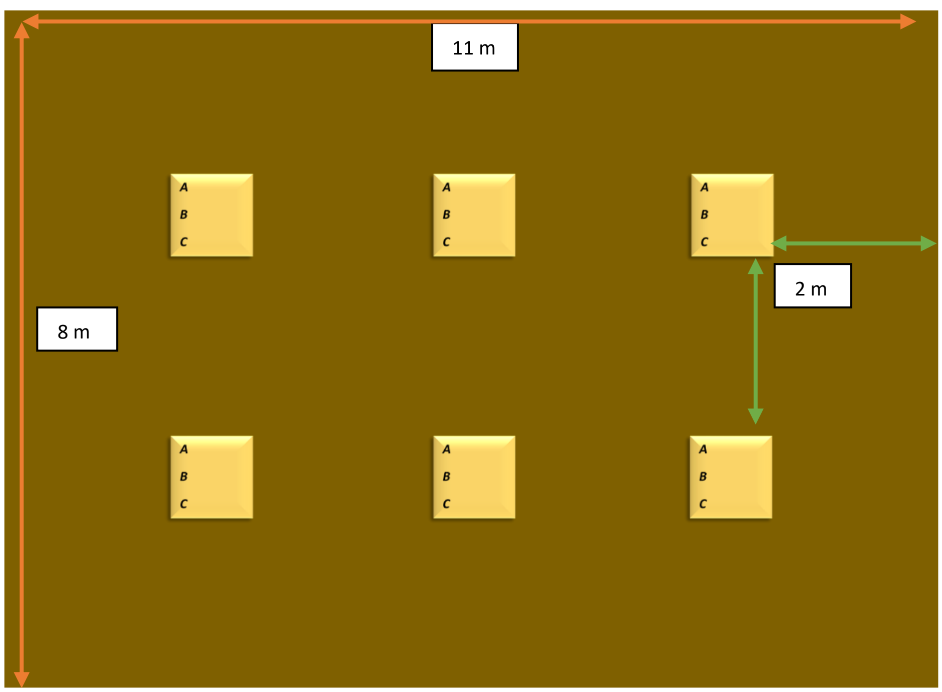
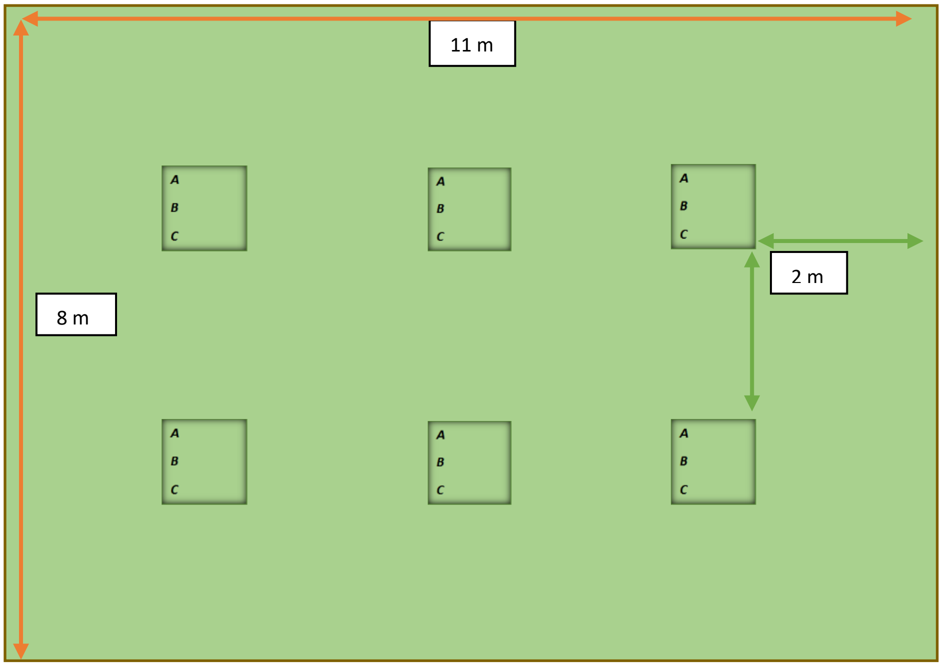


Figure 27: Scraped treatment out planting designs for control plugs and vegetative mats. (A = *Viola adunca*, B = *Festuca roemeri*, C = *Fragaria chiloensis*).

Mowing with Plugs and Mat



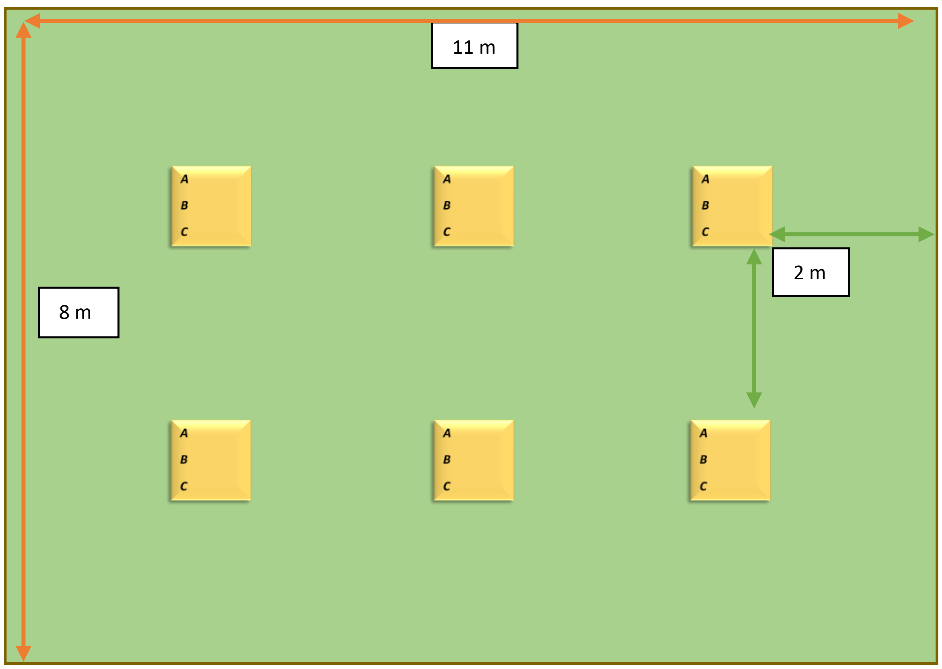


Figure 28: Mowed treatment out planting designs for control plugs and vegetative mats. (A = *Viola adunca* B = *Festuca roemeri*, C = *Fragaria chiloensis*).

Over the course of the research project's installation, the time to complete each treatment method was measured for a cost benefit analysis (see Appendix). For both Willapa and Nestucca Bay National Wildlife Refuge site treatment prep began on 12/7/19 and 12/17/19 respectively. Here, refuge staff employed the use of a tractor pulled flail mower to scrape, and mow both sites' 8 x 22-meter study areas on 1/18/20. At the Rock Creek Siuslaw National Forest, the site topography made it inaccessible to the tractor. In place of the flail mower Forest Service staff employed the use of a weed whacker, rakes and a Rototiller to implement scraping and mowing treatments. While the use of these tools took considerably longer, treatment results yielded similar outcomes.

Figure 29: Scraped and mowed treatment areas at Nestucca National Wildlife Refuge using a tractor flail mower 12/17/19.

Figure 30: Scraped and mowed treatment areas at Rock Creek Siuslaw National Forest using a weed whacker and Rototiller 1/18/20.

Control Plug and Mat Planting

The Sustainability in Prisons Project (SPP), a partnership between the Evergreen State College and the Washington Department of Corrections, grew a total of 36 1 x 1 meter mats and the study's control plant plugs within a hoop house at the controlled nursery environment of Stafford Creek Correctional Facility's Conservation Nursery in Aberdeen, Washington. Each vegetative mat was secured using 9 stainless-steel yard staples. All control plugs were installed using a dibble stick and bisecting hole edge scores by hand trowel to ensure soil and plug contact (see Figures 31 & 32).

Figure 31: Scraped treatment area at Nestucca National Wildlife Refuge with plug planting process with control *Viola adunca* plugs.

Figure 32: Vegetative mat and control plant plugs for Rock Creek Siuslaw National Forest.

Monitoring Data and Analysis

ArcGIS Survey123 Connect was used for XLS form design for electronic field data collection (see Figure 33). The project's data collection, storage and upload were all done through the Coastal Prairie Monitoring Application I developed. Data was collected into three groups (Native, Non-native and Site Details) with local and global IDs. A drop-down plant list with detailed photo identification for each plant was also created within the application to assure all plants were correctly identified. The plant list was composed of native and non-native plants provided by Willapa, Nestucca Bay National Wildlife Refuge, and the Siuslaw National Forest (see Appendix). Site data collected within the planting plots included site planting and restoration treatment type, the percent aerial cover and height of native plant species, the percent aerial cover and height of non-native plant species and the plants' phenology. For the purpose of the study, the percent aerial cover of bare ground and vegetative mats (coconut coir) were included in the native grouping, as both substrates constitute as interstitial space. Photos of each plot and subplot were also collected. To account for edge effect on the mats and plug plots, a buffer of two meters surrounding the plots was established; mats and plugs were planted two meters apart from each other. Subplot data was gathered from the northwestern 1 x 1-meter areas surrounding the plots, to understand the response of the existing plant community to the treatment types and its potential effect on the experiment's variables without planting. In June plant height was measured using a bisecting ruler that fit over the quadrate (see Figure 34). Microsoft Excel was used for data management, QA/QC and ArcGIS Insights was used for initial analysis, data visualization and mapping. October data was analyzed in R Studio with a Two-way MANOVA.

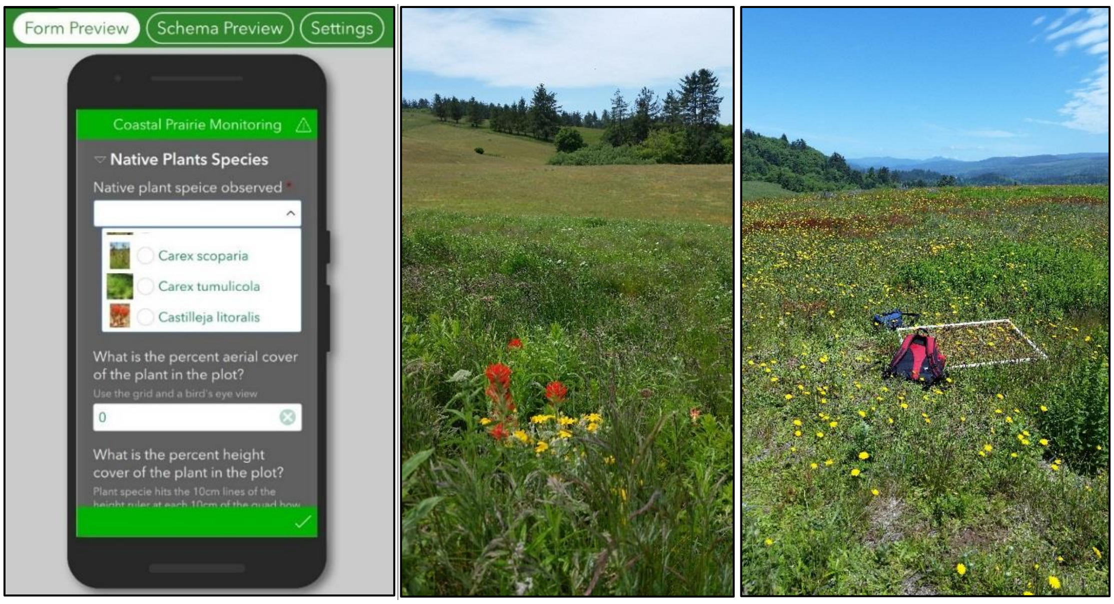


Figure 33: Coastal Prairie Monitoring application at Nestucca National Wildlife Refuge.

Figure 34: Monitoring quadrate and height ruler.

RESULTS

Following the treatments and plantings in December and January the first monitoring event began on June 6, 2020 and ended on October 25, 2020. Sites were monitored from south to north beginning at Rock Creek traveling northward to Nestucca and Willapa. Monitoring occurred over the course of two weeks. During this initial visit all the project variables were collected. Other research evidence collected included site, plot and subplot photo points (see Figures 40 - 43). Additional photo point data can be accessed upon request. Based on vegetative mat planting and scraping treatments, from June to October native plant aerial cover was dominated by 15 species observed across all, some or one of the sites (see Figure 36 and Appendix for plant codes). Based on vegetative mat planting and mowing treatments, June native plant aerial cover was dominated by 13 species observed across all, some or one of the sites (see Figure 37 and Appendix for plant codes). Comparison bar charts display June's percent native and non-native aerial cover based on treatment and planting types (see Figures 44 & 45). These comparison bar charts are repeated to show how June and Octobers' percent native and non-native aerial cover based on treatment and planting types changed throughout the projects' growing season (see Figures 52 & 53). Data collected during June provided the first opportunity to collect information on the interaction effect of these variables which can be seen in the link charts that reflect the top down hierarchical relationships of the treatments to the planting types on total native aerial plant cover for June and October (see Figures 47 & 48). The link chart can be understood as a data visualization tool to display data associations, with thicker chart lines displaying more association between variable points. With points such as planting or treatments type at the top of the chart having a greater association with a variable, in this case native aerial cover. Across all planting and treatment types Willapa saw the greatest increase in the sum of *Viola adunca* aerial cover over the project's duration from (68) in June to (128) in October. Between June and October, Nestucca saw a decrease in the sum of *Viola adunca* aerial cover from (57) to (51) while Rock Creek's cover changed from (38) to (31) by October (see Figures 49 & 50). Scraped areas at Nestucca with in subplots yielded *Viola adunca* germination and establishment (see Figure 35). As built photo points were established during the initial planting and visited in June and October to document the plant growth, phenology, and succession over the entire growing season (see Figures 56 - 73). These photo points included captures of the mowed treatment, scraped treatment and the full project area. Plot and subplot photos collected help to visually illustrate the plant communities' competition with the planting and treatment types (see Figures 40 - 43).

Figure 35: Field monitoring observations. *Viola adunca* in scraped area. *Solidago canadensis* and *Achillea millefolium* growing up through a mat at Nestucca. Mat *Violas* at Willapa.

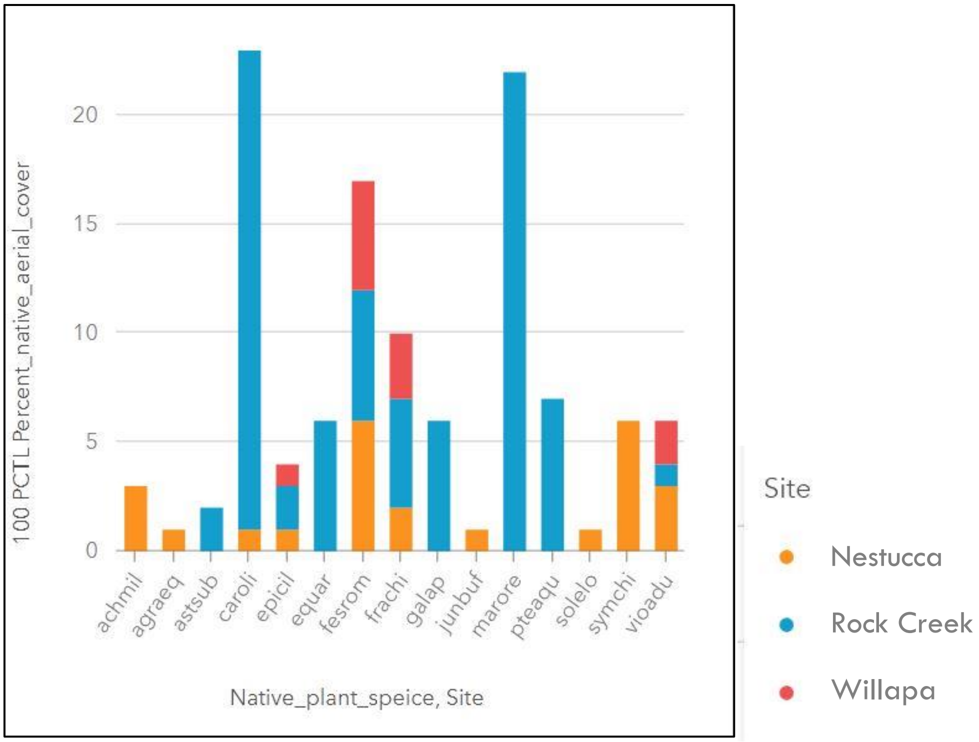


Figure 36: June 2020 native plant aerial cover by site and specie. Filtered by scraping and vegmat.

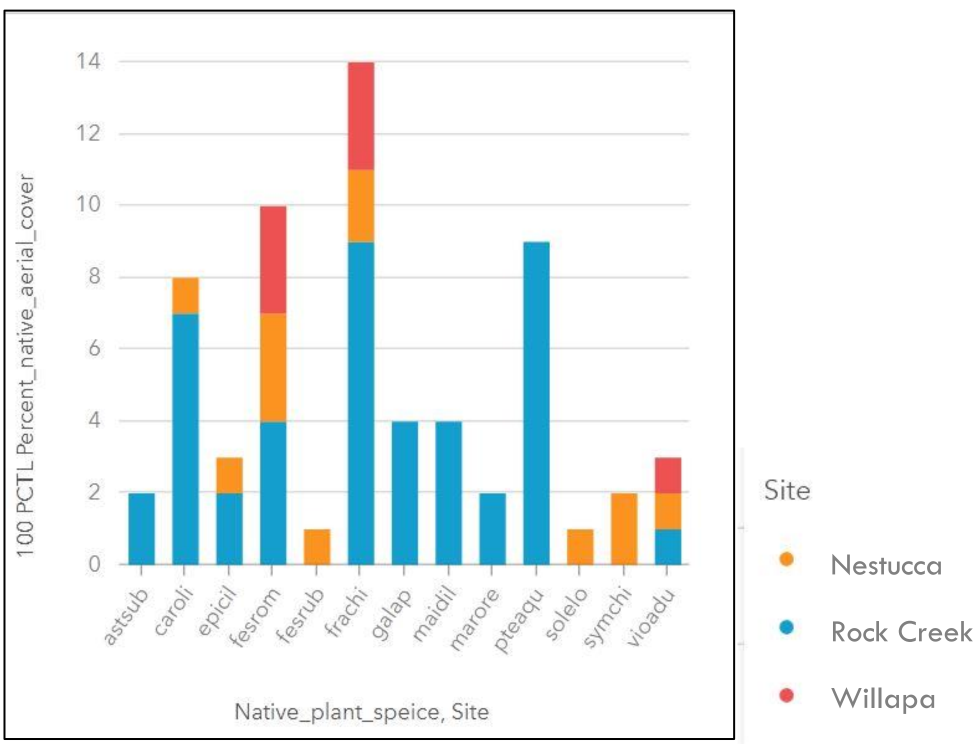


Figure 37: June 2020 native plant aerial cover by site and specie. Filtered by mowing and vegmat.

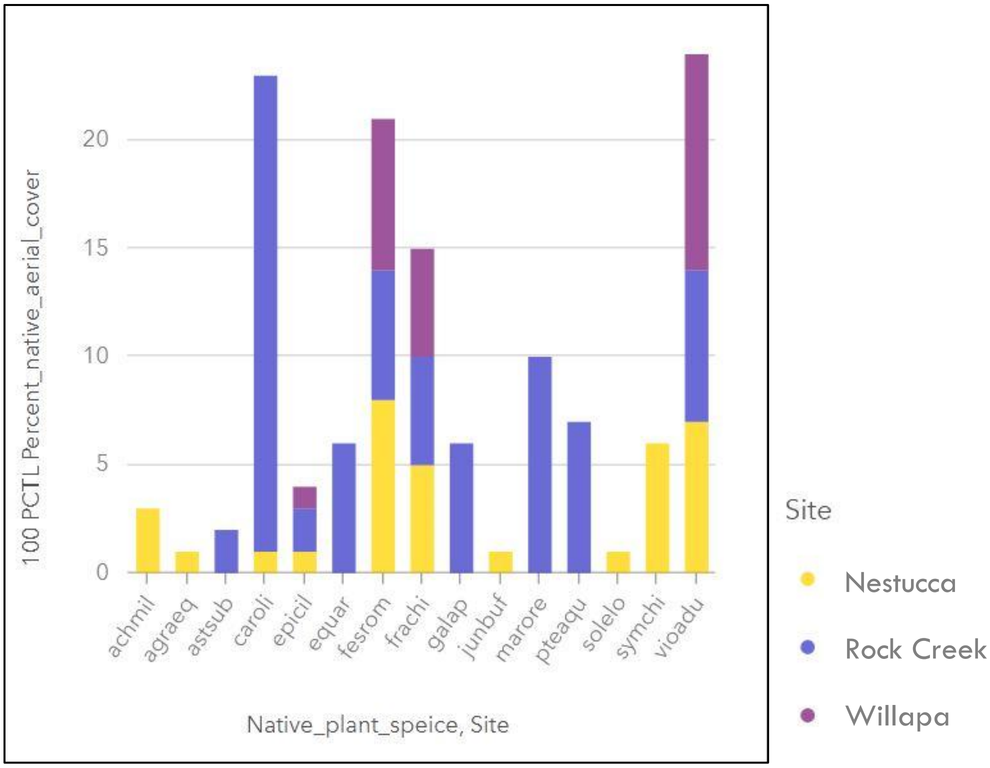


Figure 38: October 2020 native plant aerial cover by site and specie. Filtered by scraping and vegmat.

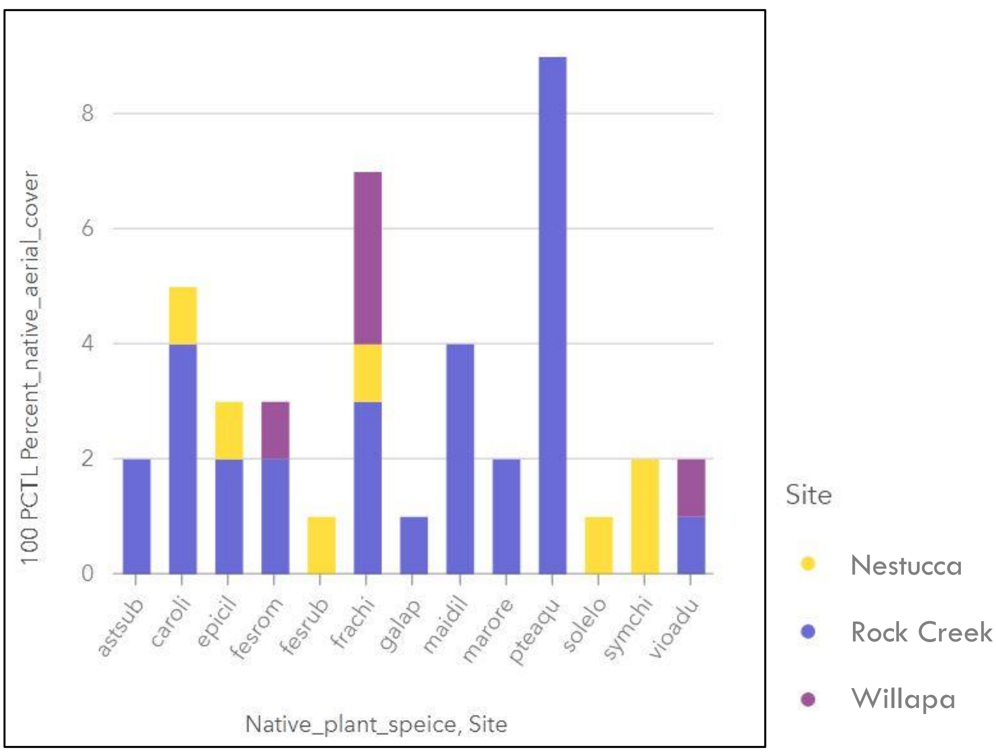


Figure 39: October 2020 native plant aerial cover by site and specie. Filtered by mowing and vegmat.

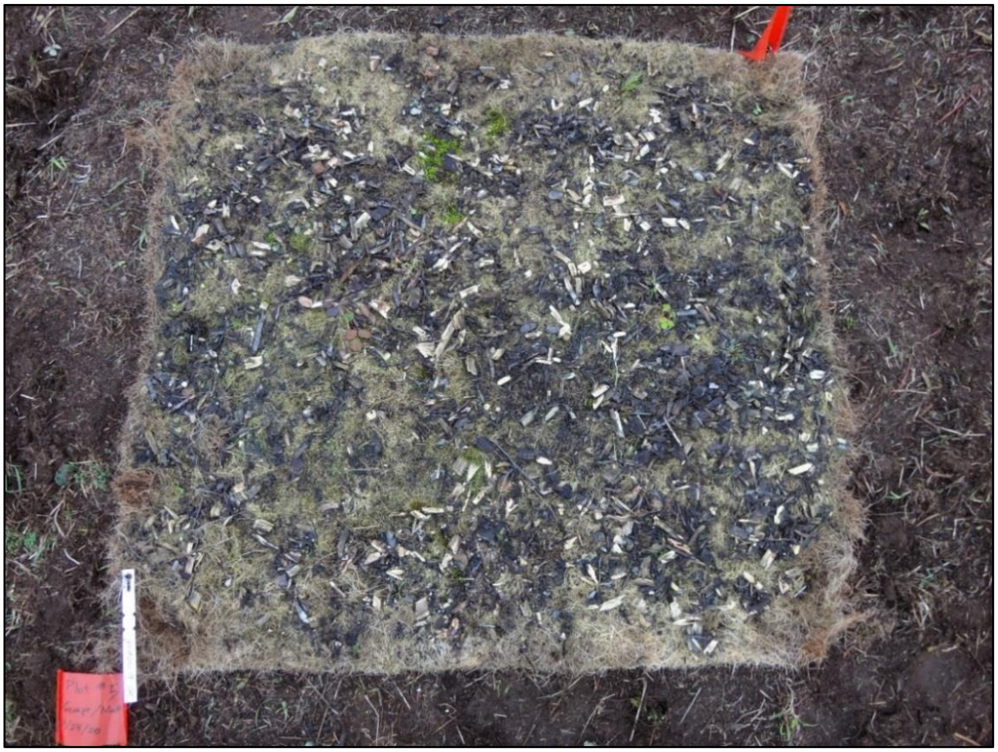


Figure 40: January 2020 plot 5 planted in scraped area with vegetative mat.

Figure 41: June 2020 plot 5 planted in scraped area with vegetative mat.

Figure 42: January 2020 plot 5 scraped area planted with plant plugs.

Figure 43: June 2020 plot 5 scraped area planted with plant plugs.

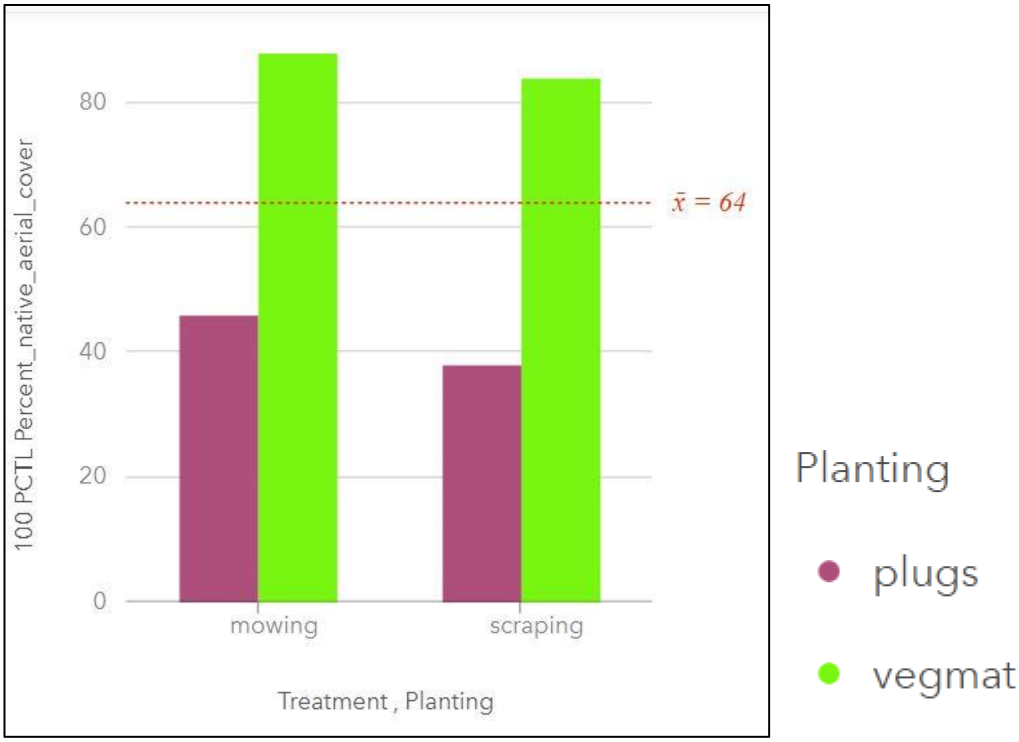


Figure 44: June 2020 percent native aerial cover based on treatment and planting type.

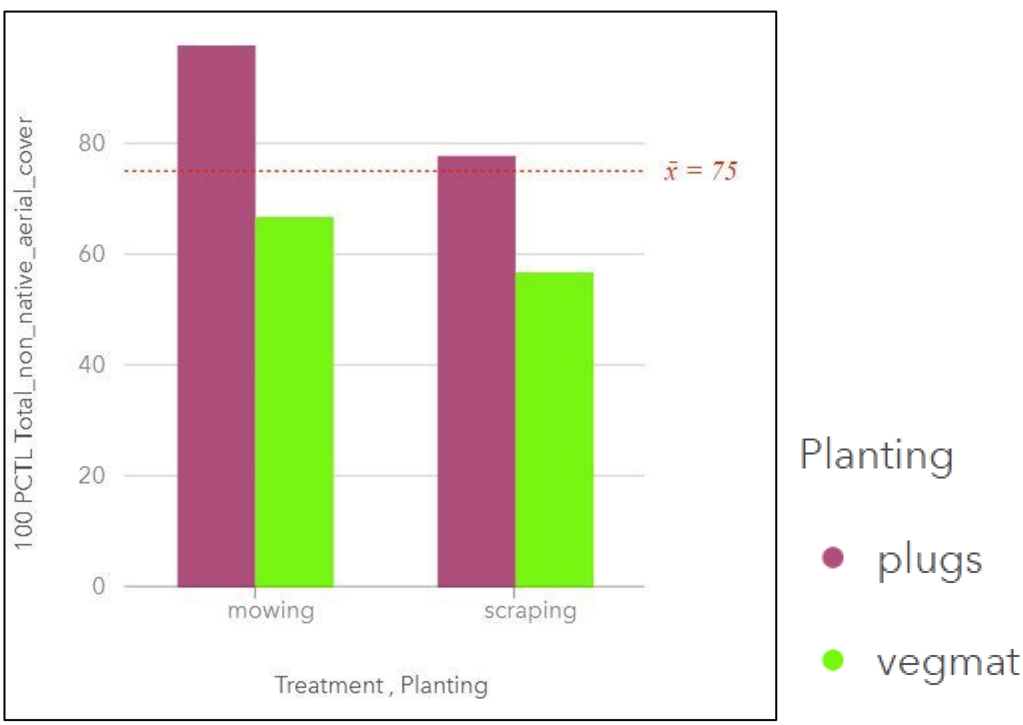


Figure 45: June 2020 percent non-native aerial cover based on treatment and planting type.

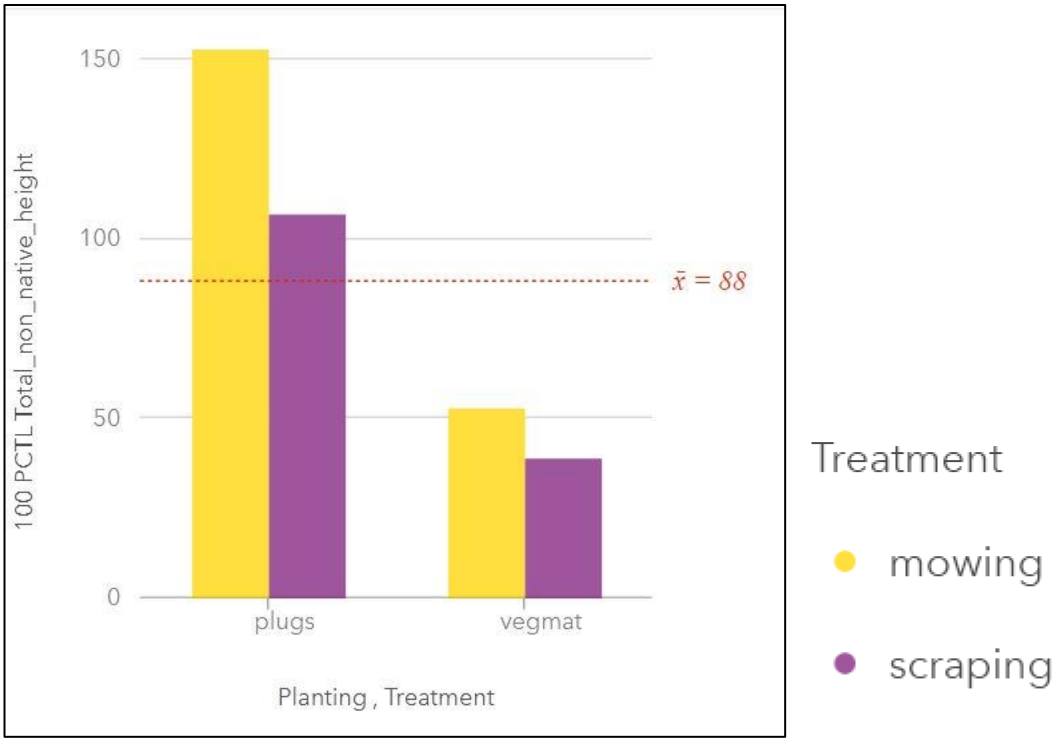


Figure 46: June 2020 non-native height based on treatment and planting type.

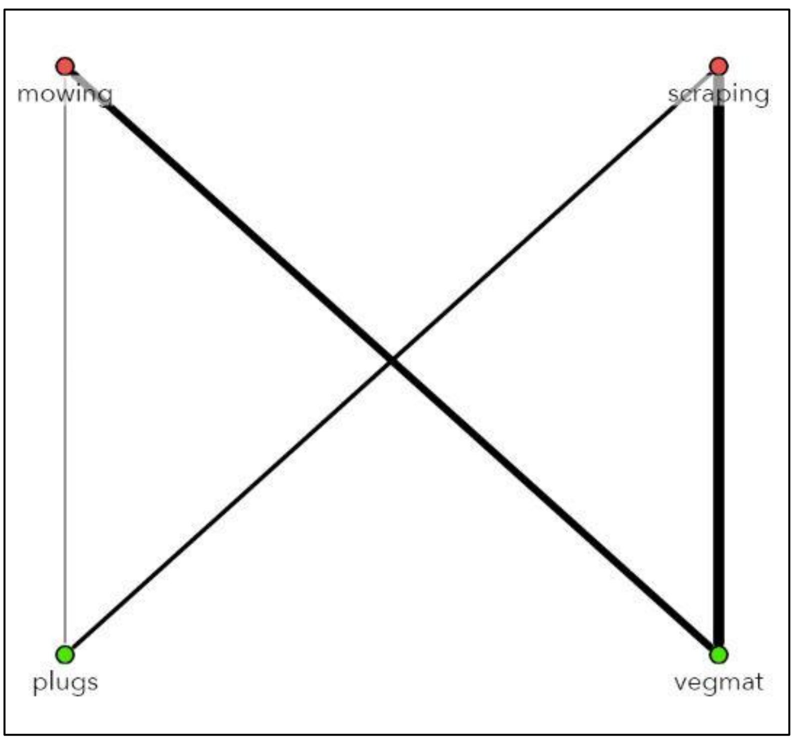


Figure 47: June 2020 relation of treatment and planting type on native plant aerial cover.

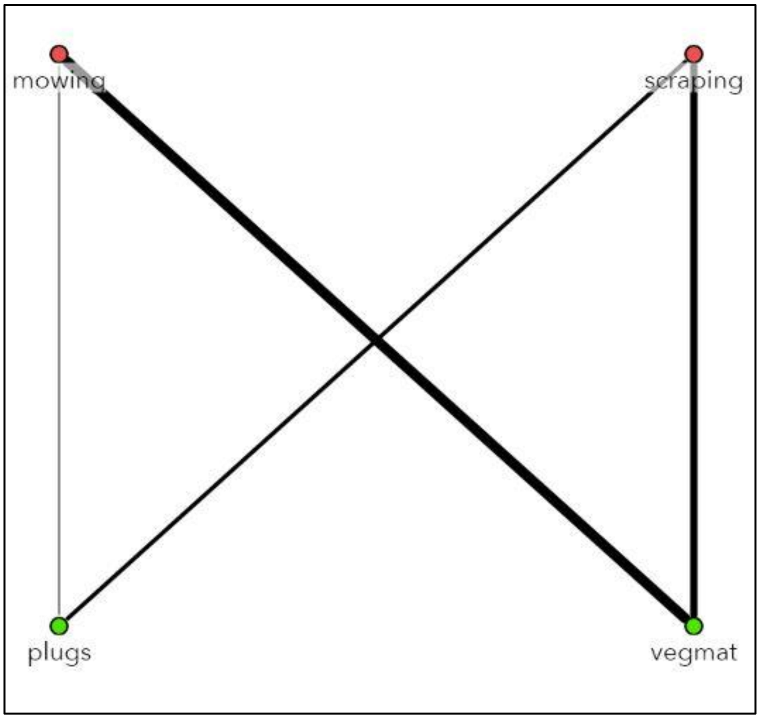


Figure 48: October 2020 relation of treatment and planting type on native plant aerial cover.

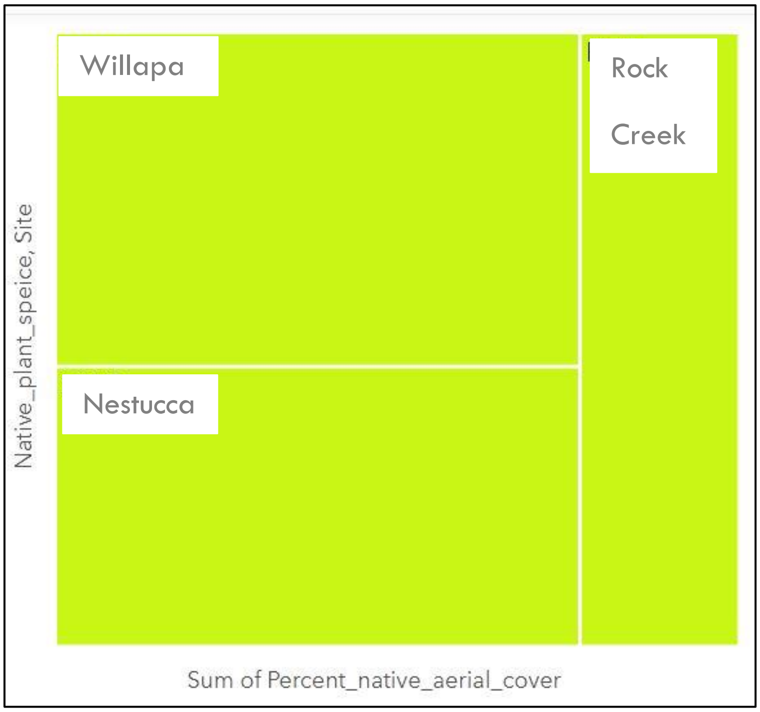


Figure 49: June 2020 total *Viola adunca* aerial cover by site.

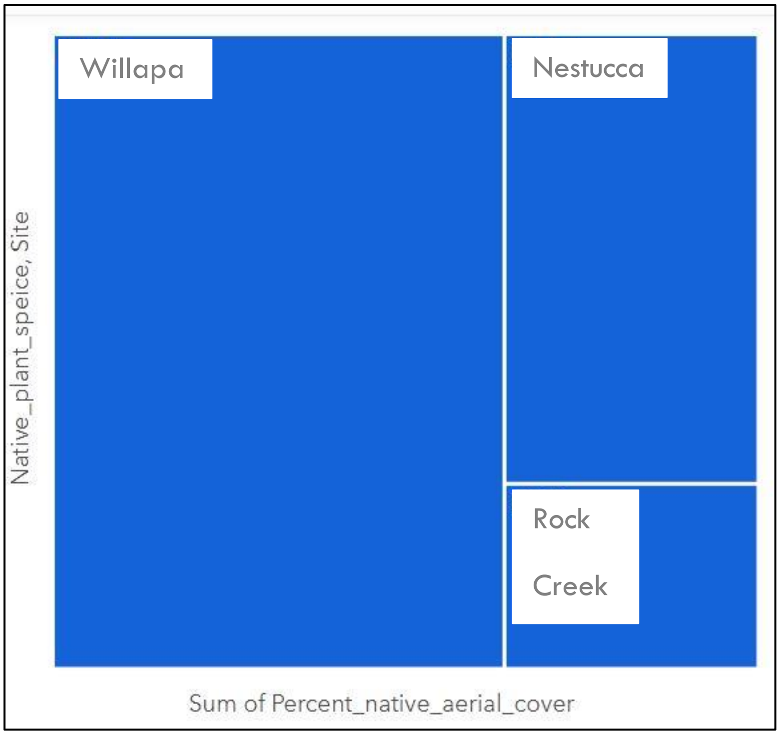


Figure 50: October 2020 total *Viola adunca* aerial cover by site.

Figure 51: October *Viola adunca* with vegetative mat on scraped areas. Willapa, Nestucca and Rock Creek.

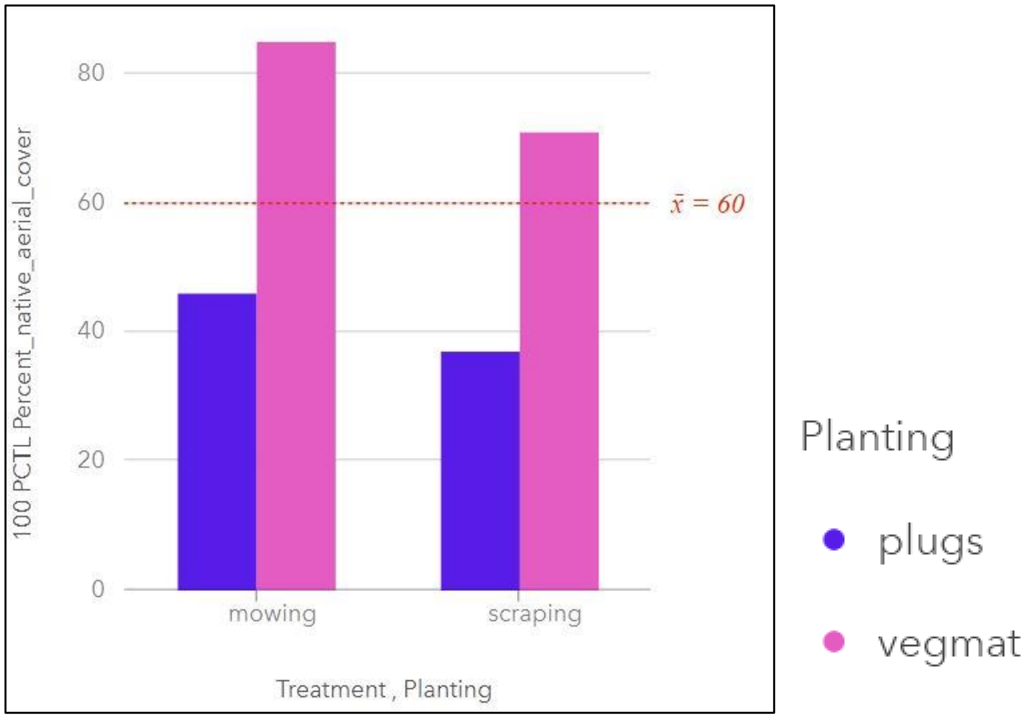


Figure 52: October 2020 percent native aerial cover based on treatment and planting type.

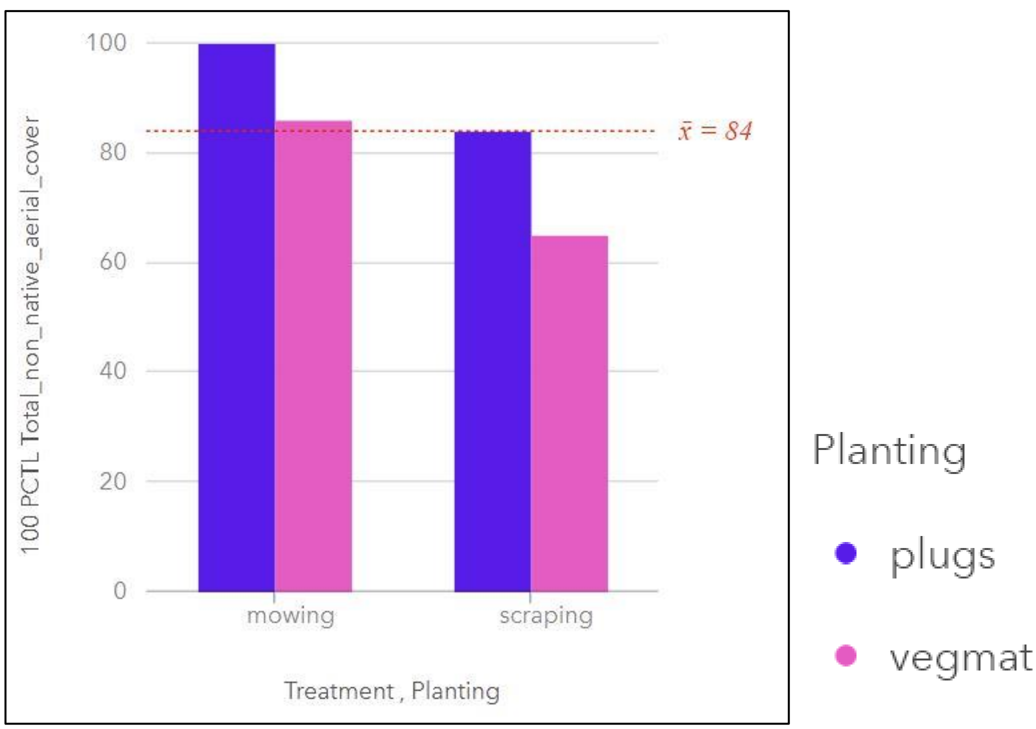


Figure 53: October 2020 percent non-native aerial cover based on treatment and planting type.

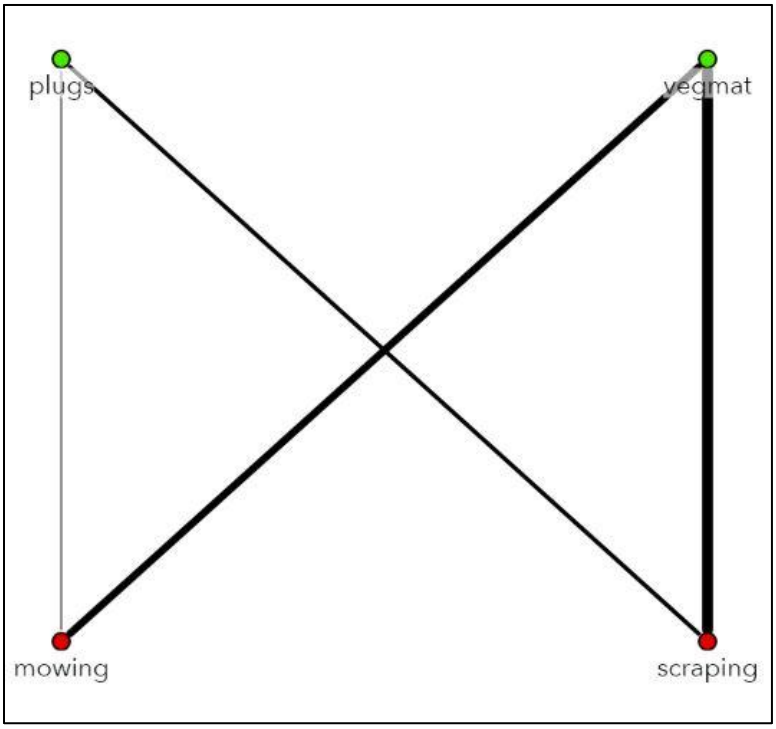


Figure 54: June 2020 relation of treatment and planting type on target native plant aerial cover.

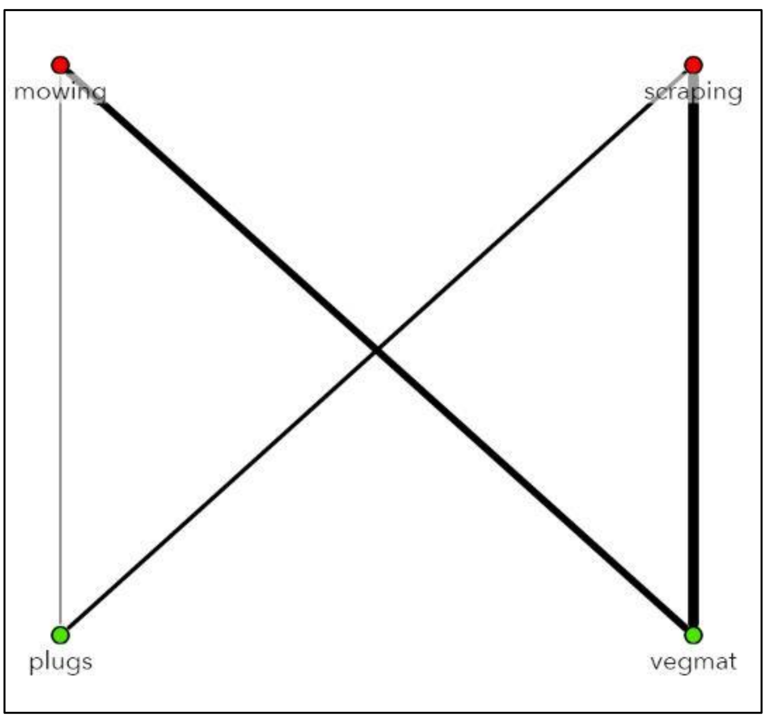


Figure 55: October 2020 relation of treatment and planting type on target native plant aerial cover.

Willapa National Wildlife Refuge

Figure 56: December 2019 vegetative mats with scraping at Willapa.

Figure 57: June 2020 vegetative mats with scraping at Willapa.

Figure 58: October 2020 vegetative mats with scraping at Willapa.

Figure 59: December 2019 vegetative mats with mowing at Willapa.

Figure 60: June 2020 vegetative mats with mowing at Willapa.

Figure 61: October 2020 vegetative mats with mowing at Willapa.

Nestucca Bay National Wildlife Refuge

Figure 62: January 2020 vegetative mats with scraping at Nestucca.

Figure 63: June 2020 vegetative mats with scraping at Nestucca.

Figure 64: October 2020 vegetative mats with scraping at Nestucca.

Figure 65: January 2020 vegetative mats with mowing at Nestucca.

Figure 66: June 2020 vegetative mats with mowing at Nestucca.

Figure 67: October 2020 vegetative mats with mowing at Nestucca.

Rock Creek Siuslaw National Forest

Figure 68: January 2020 vegetative mats with scraping at Rock Creek.

Figure 69: June 2020 vegetative mats with scraping at Rock Creek.

Figure 70: October 2020 vegetative mats with scraping at Rock Creek.

Figure 71: January 2020 vegetative mats with mowing at Rock Creek.

Figure 72: June 2020 vegetative mats with mowing at Rock Creek.

Figure 73: June 2020 vegetative mats with mowing at Rock Creek.

DISCUSSION & CONCLUSION

The future potential for this research to explore and grow is immense. There are many other plants that host endangered insects in peril, this restoration technology holds opportunities to explore and improve the functions of these relationships (Bierzychudek & Warner, 2015; Dunn, 2005; Hill et al., 2018; Shuey et al., 2016; Stiling & Moon, 2005). Following a Two-way MANOVA test of the results for October's monitoring with planting type as the factor, indicated a statistically significant difference in native to non-native aerial plant cover between planting types (plugs and the vegetative mats) for October $F(3, 416) = 203.39$, $p \leq (0.001)$. This statistically significant difference can be seen in the stack bar charts of the two planting types for October (see Figure 75). Additionally, the study was able to analyze the interaction effect between treatment types (scraping and mowing) on native and non-native aerial plant cover for October plots. An additional Two-way MANOVA test with treatment as the factor indicated a statistically significant difference in native aerial plant cover between the restoration treatment types (mowing and scraping) for October $F(3, 416) = 15.58$, $p \leq (0.001)$. The vegetative mats grew *Viola adunca,* other native plant species and maintained interstitial space more effectively than the plugs planted in scraped or mowed areas (see Figures 44, 52, 74 & 75). Moreover, scraped area treatments planted with plugs and mats grew *Viola aduna* and the other native target species more effectively than the mowed area treatments (see Figures 54 & 55). While plugs in the scraped areas grew native species like *Viola adunca* and other target species in amounts comparable to the mats, the amount of open and available bare ground (baregr) for future plant recruitment in the scraped plug planted areas was less in comparison to the space still available for plant recruitment in the vegetative mats (vegmat) (see Figure 75).

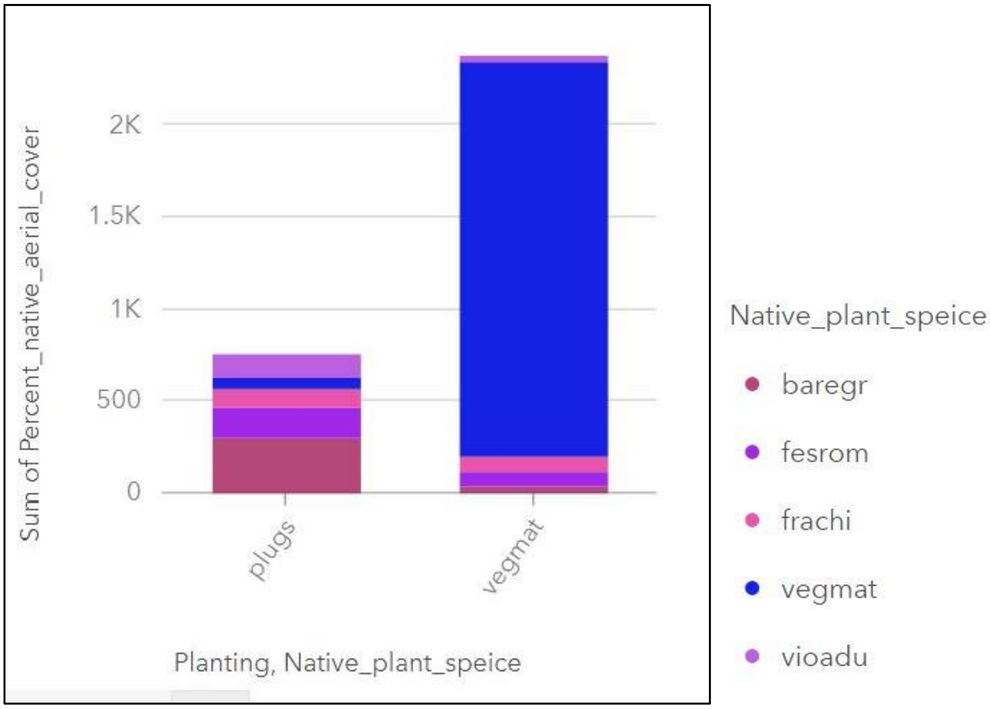


Figure 74: June target native aerial cover by planting type.

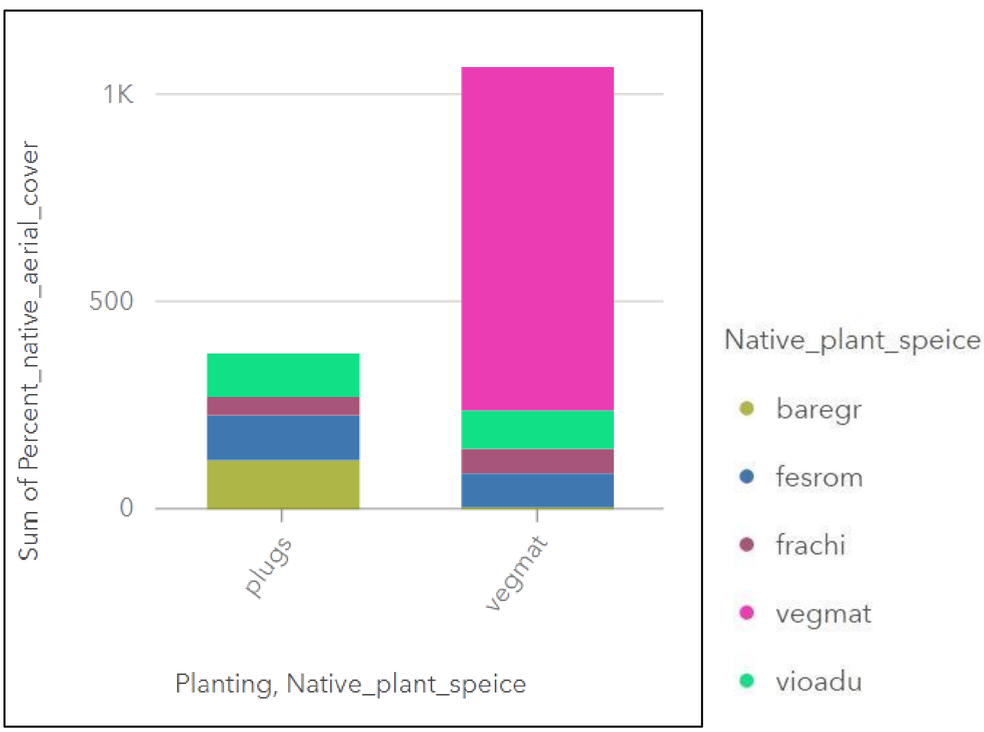


Figure 75: October target native aerial cover by planting type.

The vegetative mats were also associated with less non-native vegetative height across the sites (see Figure 46). This is another key finding as plant height influences *Viola adunca's* ability to grow as well as *Speyeria z. hippolyta's* ability to seek out the plant to lay its eggs (Schaeffer, 1992). Prior research points to habitats that used to support the butterfly as having violet densities ranging from (20 to 100 per m^2) (Kiser, 1993; Schaeffer, 1992). While both the plug and mat plantings in scraped areas were able to yield *Viola* cover, site variability, soil moisture, avian disturbances to the mats, and other variables did not allow for *Viola adunca* coverage to be greater than (16%) at sites like Willapa at any one plot (see Figures 76-78). With next year marking the first year for the release of captively reared *Speyeria z. hippolyta* at Willapa this is encouraging, as the site is one of the more degraded and undergoing active restoration. However, it should also be noted that Willapa was the first site planted on 12/16 and 12/17/2019, which could have played a factor in *Viola* growth and recorded cover as Nestucca and Rock Creek were planted a month later. Future research into the vegetative mats ability over time to achieve these *Viola* densities as well as further research to investigate if adult butterflies are attracted to the mat structure and plant community for ovipositioning and other behavior, should be conducted (Kiser, 1993).

Research into *Speyeria z. hippolyta*'*s* larval survival within the mats themselves would prove to be invaluable information in the quest to save a highly localized insect, while moving towards a global consciousness of insect conservation (Bierzychudek & Warner, 2015; Bierzychudek et al., 2009; Crone et al., 2007; Samways, 2020; Thorpe & Stanley, 2011). Other interesting field observations of the vegetative mats included qualitative data recording on the phenological suppression of the vegetative mats to the surrounding plant community, which showed some association between the plant phenology to the planting and treatment types. In addition to suppressing non-native aerial plant cover and height, the mats also appeared to slow the flowering and fruiting of both native and non-native species. Plugs of *Viola adunca* planted appeared to flower in June whereas *Viola adunca* growing within the mats were flowering and fruiting during monitoring events in October (see Figure 35). Plant associations to each other in the mat and scraped treatment areas warrant additional research and a management experimentation at sites such as Rock Creek and Nestucca, where scraped areas with a seed bank of *Viola adunca* yielded germination and establishment of the plant (see Figure 35). The role of soil disturbance in *Viola adunca's* germination along with other species could provide an alternative to fire or herbicide (Almasi & Kollmann, 2007; Dunwiddie & Martin, 2016; Jutila & Grace, 2002). Mats could be planet on hillsides or hilltops to provide a *Viola* colony in which seed banks could be built, promoted and stimulated around the mat by scraping the surrounding soil biannually. Scraping also played an instrumental role in the mats ability to establish soil contact and the planted plugs ability to yield greater *Viola* growth by reducing the overall existing plant biomass (see Figures 76 – 78). Other link charts created for June and October datasets show the top down hierarchical relationships of the planting types on native aerial plant cover by species (see Figures 79 & 80). Here the association of the planting type to the sum of native plant species aerial cover, is reflected in the thickness of the lines that point to the plant code, with thicker lines reflecting greater associations with the planting type (see Appendix for native plant codes). Data exploration of these link charts and others along with an ArcGIS Story Map of the MES Research project can be found online at (https://arcg.is/998KK2).

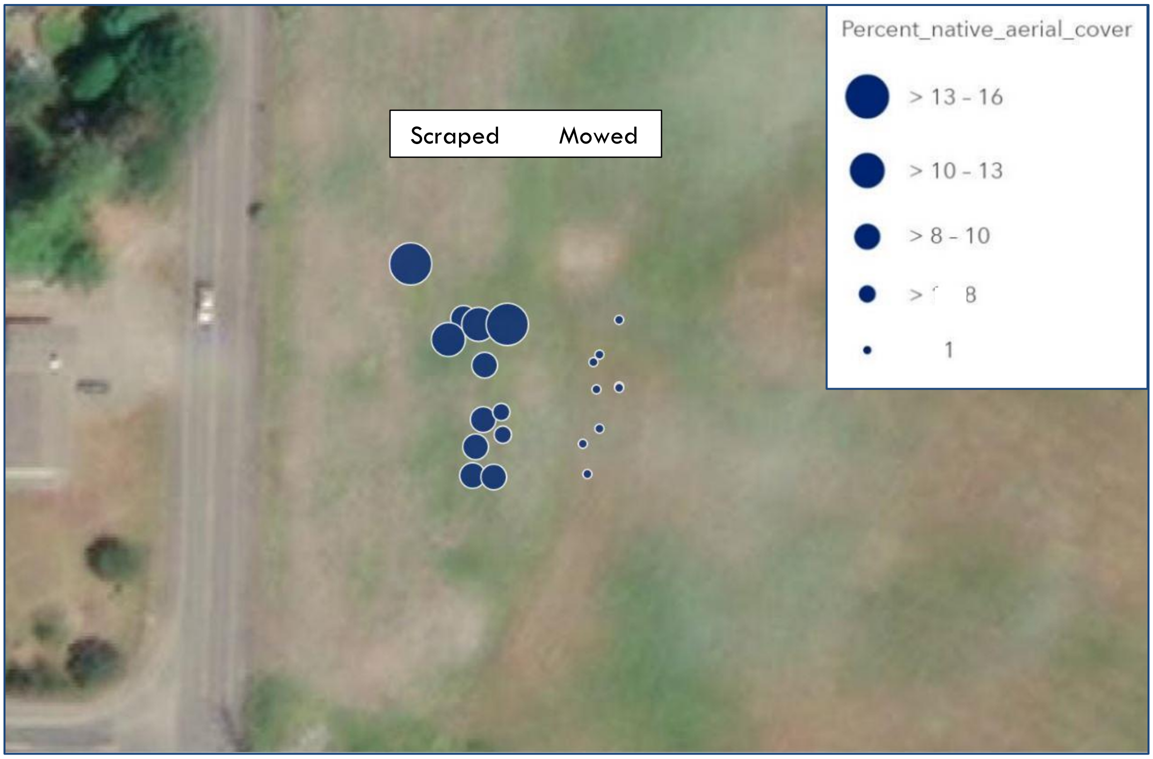


Figure 76: Willapa October 2020 planted *Viola adunca* aerial cover.

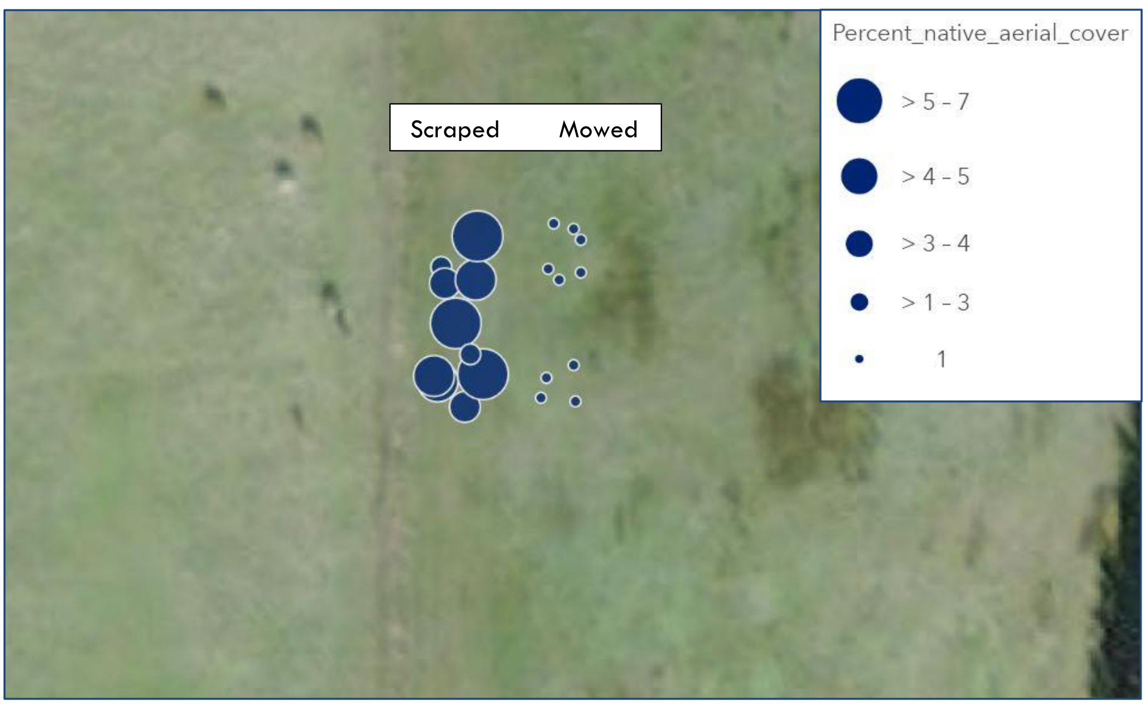


Figure 77: Nestucca October 2020 planted *Viola adunca* aerial cover.

Figure 78: Rock Creek October 2020 planted *Viola adunca* aerial cover.

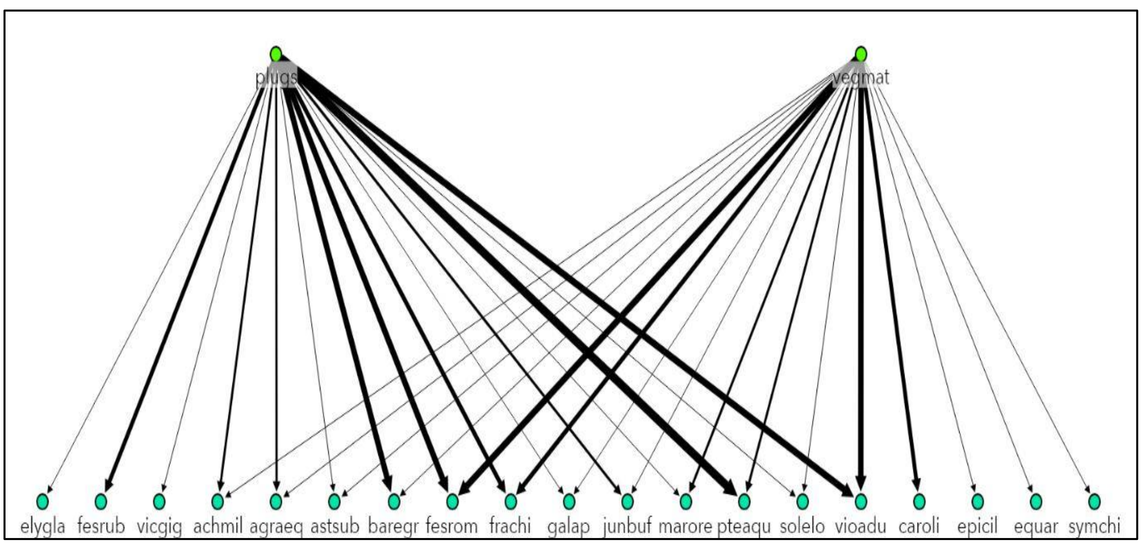


Figure 79: Link chart of June native plant species aerial cover and association with planting type.

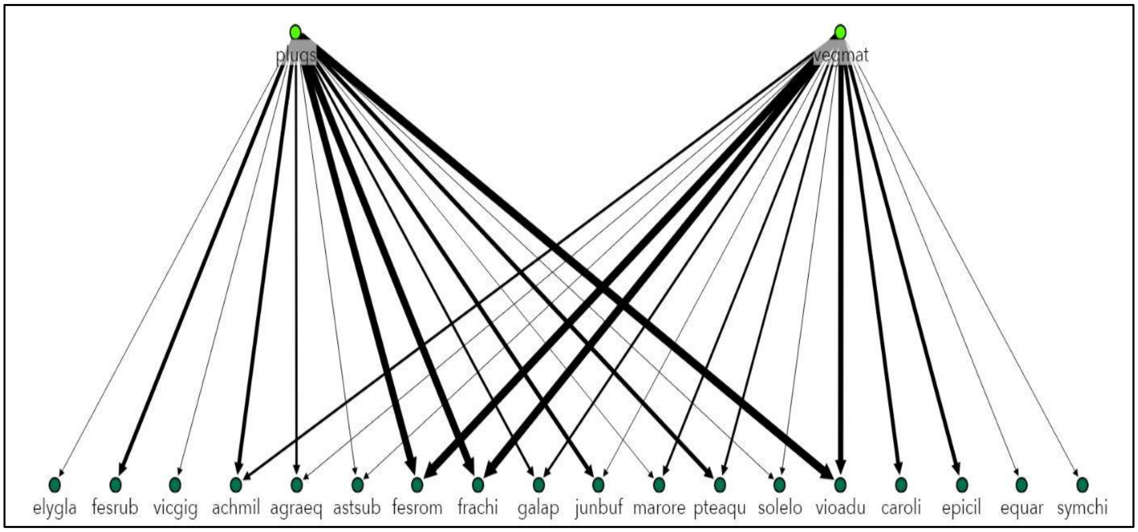


Figure 80: Link chart of October native plant species aerial cover and association with planting type.

The association of the native plant community to planting and treatment types could help to reveal a greater understanding of the correct combinations of prairie restoration prescriptions. Developing a clearer understanding of these best management practices over time will inform a place based approach towards future restoration and habitat enhancement in the coastal prairie ecosystem (Petix et al., 2018). These associations can help to create a high resolution understanding of how localized adaptive management practices effect plant structure, and how the structure of the plant community itself might influence the survival and quality of host plants and other restoration target species (Awmack & Leather, 2002; Bauerfeind & Fischer, 2013; Menéndez et al., 2007; Sivakoff et al., 2016). An ordination test on June and October datasets would be of value to developing a sense of the role ocean proximity and salt spray might play in maintaining coastal prairie plant community height and structure across all sites. Soil and surface level salinity experimentation should be conducted on the vegetative mats to observe the response of non-native and native plants such as *Viola adunca* to examine the herbicidal effects of salt water (Kiser, 1993; Schaeffer, 1992).

Figure 81: Viola adunca ecosystem. The role of structure and plant associations for insects.

Based on visual observations of some of the most successful mats harboring the project's three target species, it could be hypothesized that the three may help to co-facilitate *Viola adunca's* biology and protect the life cycle of the caterpillar of *Speyeria z. hippolyta* as it moves through its six instar phases and the violet propagates (see Figure 81 - 83). Eggs laid on *Viola adunca* hatch, the larva consumes its egg casing and begins its new diet of *Viola adunca* leaves. As the caterpillar moves closer to diapause it moves into the *Festuca romeri* for a protected place to go through diapause. *Festuca romeri* may help provide *Viola adunca* with the soil structure and moisture it needs for germination and establishment of new seed with micro shade from the bunch grass. Following diapause, the larva wakes up and walks out to eat on *Viola adunca* leaves and is protected visually from predators by *Fragaria chiloensis* as it develops and seeks new violets. The evergreen leaves of *Fragaria chiloensis* could also help to shade and shed water towards *Viola aduca*, promoting further seed and leaf production by the plant. These leaves may also help to preclude light from non-natives while also keeping vegetative growth lower and lateral benefiting *Viola adunca.* Moreover, *Fragaria chiloensis* could attract pollinators of the violet and another insect in need of conservation action—solitary bees (Freitas & Sazima, 2003; Tonietto & Larkin, 2018). Finally, the caterpillar climbs up *Festuca romeri* to pupate and metamorphizes into the form of the Oregon silverspot butterfly (*Speyeria zerene hippolyta*). Insects reveal to us the value of life's relationship to itself. A way to see one's self as part of a whole ecological value; protecting, restoring and inspiring our ecosystem.

Figure 82: *Viola adunca* mat ecosystem. The role of structure and plant associations for insects.

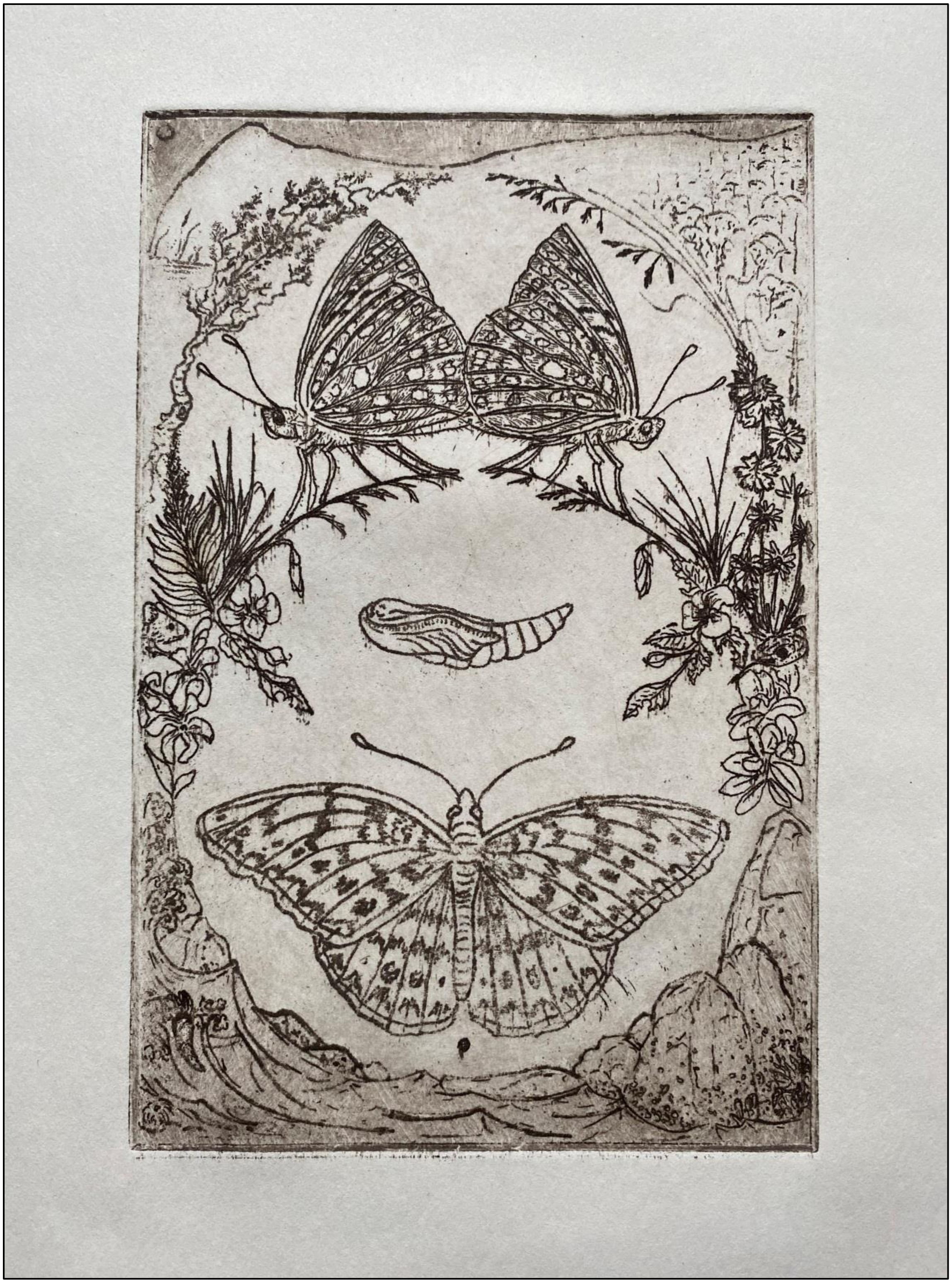


Figure 83: Speyeria zerene hippolyta ecosystem. Hard and soft ground etching, 2014.

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Appendices

Composite Native Plant List of All Sites

Native Plants	**Plant Code**	**Plant Specie**
native	achmil	*Achillea millefolium*
native	acmame	*Acmispon americanus*
native	acmpar	*Acmispon parviflorus*
native	agraeq	*Agrostis aequivalvis*
native	agrexa	*Agrostis exarata*
native	agrhal	*Agrostis hallii*
native	agrpal	*Agrostis pallens*
native	allcer	*Allium cernuum*
native	alnrub	*Alnus rubra*
native	anamar	*Anaphalis margaritacea*
native	anghen	*Angelica hendersonii*
native	angluc	*Angelica lucida*
native	aphocc	*Aphanes occidentalis*
native	aqufor	*Aquilegia formosa*
native	artsuk	*Artemisia suksdorfii*
native	astsub	*Aster subspicatus*
native	blespi	*Blechnum spicant*
native	botmul	*Botrychium multifidum*
native	brocar	*Bromus carinatus*
native	calcan	*Calamagrostis canadensis*

native	calnut	*Calamagrostis nutkaensis*
native	calcil	*Calandrinia ciliata*
native	camqua	*Camassia quamash var. maxima*
native	caroli	*Cardamine oligosperma*
native	carobn	*Carex obnupta*
native	carpan	*Carex pansa*
native	carros	*Carex rossii*
native	carsco	*Carex scoparia*
native	cartum	*Carex tumulicola*
native	caslit	*Castilleja litoralis*
native	chaang	*Chamerion angustifolium*
native	ciredu	*Cirsium edule*
native	claamo	*Clarkia amoena var. caurina*
native	claper	*Claytonia perfoliata*
native	clasib	*Claytonia sibirica*
native	dancal	*Danthonia californica*
native	daupus	*Daucus pusillus*
native	desces	*Deschampsia cespitosa*
native	elygla	*Elymus glaucus ssp. glaucus*
native	epicil	*Epilobium ciliatum*
native	equar	*Equisetum arvense*
native	erigla	*Erigeron glaucus*
native	erilan	*Eriophyllum lanatum*
native	erygut	*Erythranthe guttata*

native	fesam	*Festuca ammobia*
native	fesrom	*Festuca roemeri*
native	fesrub	*Festuca rubra ssp. juncea*
native	frachi	*Fragaria chiloensis*
native	galap	*Galium aparine*
native	gampur	*Gamochaeta purpurea*
native	glyspp	*Glyceria spp.*
native	habgre	*Habenaria greenei*
native	herlan	*Heracleum lanatum*
native	holdis	*Holodiscus discolor*
native	hosgra	*Hosackia gracilis*
native	iriten	*Iris tenax*
native	junbuf	*Juncus bufonius var. bufonius*
native	juneff	*Juncus effusus*
native	junens	*Juncus ensifolius*
native	junpat	*Juncus patens*
native	luplit	*Lupinus littoralis*
native	lupriv	*Lupinus rivularis*
native	luzcom	*Luzula comosa*
native	maidil	*Maianthemum dilatatum*
native	marore	*Marah oregana*
native	monfon	*Montia fontana*
native	navsqu	*Navarretia squarrosa*
native	philew	*Philadelphus lewisii*

native	phycap	*Physocarpus capitatus*
native	picsit	*Picea sitchensis*
native	plamar	*Plantago maritima*
native	plebra	*Plectritis brachystemon*
native	poamac	*Poa macrantha*
native	poapal	*Poa palustris*
native	polmun	*Polystichum munitum*
native	potpac	*Potentilla pacifica*
native	pruvul	*Prunella vulgaris var. vulgaris*
native	pteaqu	*Pteridium aquilinum*
native	pucnut	*Puccinellia nutkaensis*
native	ranocc	*Ranunculus occidentalis*
native	rosgym	*Rosa gymnocarpa*
native	rubpar	*Rubus parviflorus*
native	rubspe	*Rubus spectabilis*
native	ruburs	*Rubus ursinus*
native	rumocc	*Rumex occidentalis*
native	salsco	*Salix scouleriana*
native	salsit	*Salix sitchensis*
native	samarb	*Sambucus racemosa var. arborescens*
native	sancra	*Sanicula crassicaulis*
native	scigla	*Scirpus glaucus*
native	scrcal	*Scrophularia californica ssp. californica*
native	sidhir	*Sidalcea hirtipes*

native	sisbel	*Sisyrinchium bellum*
native	siscal	*Sisyrinchium californicum*
native	sisida	*Sisyrinchium idahoense var. idahoense*
native	solelo	*Solidago elongata*
native	solgil	*Solidago simplex v. gillmanii*
native	solspa	*Solidago simplex var. spathulata*
native	spirom	*Spiranthes romanzoffiana*
native	stamex	*Stachys mexicana*
native	symchi	*Symphyotrichum chilense*
native	triwor	*Trifolium wormskioldii*
native	vicgig	*Vicia gigantea*
native	vioadu	*Viola adunca*

Composite Non-native Plant List of All Sites

Non - Native Plants	**Plant Code**	**Plant Specie**
non_native	agrrep	*Agropyron repens*
non_native	agrcap	*Agrostis capillaris*
non_native	agrgig	*Agrostis gigantea*
non_native	agrsto	*Agrostis stolonifera*
non_native	airpra	*Aira praecox*
non_native	alopra	*Alopecurus pratensis*
non_native	ammare	*Ammophila arenaria*

non_native	antodo	*Anthoxanthum odoratum*
non_native	arrela	*Arrhenatherum elatius ssp. elatius*
non_native	belper	*Bellis perennis*
non_native	cerfon	*Cerastium fontanum ssp. vulgare*
non_native	cerglo	*Cerastium glomeratum*
non_native	cirvul	*Cirsium vulgare*
non_native	crecap	*Crepis capillaris*
non_native	cynspp	*Cynosurus spp.*
non_native	dacglo	*Dactylis glomerata*
non_native	dandec	*Danthonia decumbens*
non_native	daucar	*Daucus carrota*
non_native	digpur	*Digitalis purpurea*
non_native	erocic	*Erodium cicutarium*
non_native	fesaru	*Festuca arundinacea*
non_native	fesrub	*Festuca rubra*
non_native	gerdis	*Geranium dissectum*
non_native	germol	*Geranium molle*
non_native	gnauli	*Gnaphalium uliginosum*
non_native	hollan	*Holcus lanatus*
non_native	hypper	*Hypericum perforatum*
non_native	hyprad	*Hypochaeris radicata*
non_native	ilaaqu	*Ilex aquifolium*
non_native	lampur	*Lamium purpureum*
non_native	lapcom	*Lapsana communis*

non_native	leuvul	*Leucanthemum vulgare*
non_native	lolper	*Lolium perenne*
non_native	lolspp	*Lolium spp.*
non_native	lotcor	*Lotus corniculatus*
non_native	lotuli	*Lotus uliginosus*
non_native	malneg	*Malva neglecta*
non_native	matdis	*Matricaria discoidea*
non_native	medlup	*Medicago lupulina*
non_native	myodis	*Myosotis discolor*
non_native	parvis	*Parentucellia viscosa*
non_native	permac	*Persicaria maculosa*
non_native	phaaru	*Phalaris arundinacea*
non_native	plalan	*Plantago lanceolata*
non_native	plamaj	*Plantago major*
non_native	poaann	*Poa annua*
non_native	poapra	*Poa pratensis*
non_native	poatri	*Poa trivialis*
non_native	pruvul	*Prunella vulgaris var. vulgaris*
non_native	ranpar	*Ranunculus parviflorus*
non_native	ranrep	*Ranunculus repens*
non_native	rubarm	*Rubus armeniacus*
non_native	rublac	*Rubus laciniatus*
non_native	rumace	*Rumex acetosella*
non_native	rumcri	*Rumex crispus*

non_native	rumspp	*Rumex spp.*
non_native	sagpro	*Sagina procumbens*
non_native	scharu	*Schedonorus arundinaceus*
non_native	senjac	*Senecio jacobaea*
non_native	senmin	*Senecio minimus*
non_native	sensyl	*Senecio sylvaticus*
non_native	senvul	*Senecio vulgaris*
non_native	sisoff	*Sisymbrium officinale*
non_native	solspp	*Solanum spp.*
non_native	sonasp	*Sonchus asper*
non_native	taroff	*Taraxacum officinale*
non_native	tridub	*Trifolium dubium*
non_native	tripra	*Trifolium pratense*
non_native	trirep	*Trifolium repens*
non_native	vulmyu	*Vulpia myuros*

Vegetative Mat *Viola adunca* Hoop House Survival Table

Vegetative Mat ID	Total *Viola* Plant count 12.10.2019 (Directly sown 12.13.18)	Survival rate out of ~ 324 seeds	Total *Viola* Plant count 3.22.2019 (Directly sown 12.13.18)	Survival rate out of ~ 324 seeds	Total *Viola* Plant count 6.14.2019 (Directly sown 12.13.18)	Total Survival rate out of ~ 324 seeds
WA SOP 1	94	29%	69	21 %	48	15 %
WA SOP 2	85	26%	14	4 %	51	16 %
WA SOP 3	144	44 %	28	9 %	47	15%
WA SOP 4	123	38 %	4	1 %	69	21 %
OR CLO 1	201	62 %	31	10 %	68	21 %
OR CLO 2	259	80 %	32	10 %	91	28 %
OR CLO 3	270	83 %	41	13 %	85	26 %
OR CLO 4	256	79 %	13	4 %	60	19 %
OR CLO 5	252	78 %	30	9 %	77	24 %
OR CLO 6	267	82 %	11	3 %	50	15 %
OR CLO 7	280	86 %	35	11 %	101	31 %
OR CLO 8	255	79 %	34	11 %	67	21 %
Average	**207**	**64%**	**29**	**9 %**	**68**	**21 %**

Notes: Each initial vegetative mat grown in a hoop house 3x1 meters in size sown with ~ 324 *Viola adunca* seeds for each sowing. SOP = Salish prairie seed source, CLO = Cascade lowlands seed source.

Cost Benefit Table of Treatment and Planting Types

Site	**Scraping Time**	**Mowing Time**	**Plug Time**	**Mat Time**	**Tools**
Willapa	10 min	5 min	5 hrs 30 min	35 min	Tractor Flail mower
Nestucca	10 min	5 min	5 hrs 30 min	35 min	Tractor Flail mower
Rock Creek	7 hrs 15 min	3 hrs 50 min	5 hrs 30 min	35 min	Weed Whacker Rake Rototiller
Total	7 hrs 35 min	4 hrs	16 hrs 30 min	1 hrs 45 min	Humans
Total Cost @ $35 per hour	$270	$140	$ 578	$62	Total $1050