ELWHA RIVER REVEGETATION 2013:
A PLANT PERFORMANCE STUDY

by

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ABSTRACT

Research on vegetation response post dam removal is an emerging science. Dam removal is becoming increasingly common as dams begin to become structurally unsound and reach their life capacity. This study is part of a larger plant monitoring project examining revegetation efforts following the removal of two large dams on the Elwha River in Olympic National Park. It is intended to provide project managers with data on species-specific performance in a unique environment. The data will be used to improve future restoration techniques in the newly exposed substrates.

Revegetation of native woody vegetation is a key component to ecosystem restoration in the Elwha River watershed. This project will investigate plant performance of five woody species planted in the former Lake Mills reservoir. In 2013, seedlings from five woody-species were tagged and monitored over three sites between June-September 2013. Although overall plant survivorship was found to be high, survivorship was lowest in substrates made up of sand, gravel and cobble and was higher on substrates made up of silt and clay. Survivorship was affected by site and sediment moisture content. In general it was found that low gravel content at the sites related to high survivorship. Site prescription also had an effect on survivorship. Only *Salix scouleriana* was below 90% and the four other species all had survivorship rates over 90% across the three sites in the first year. *Pinus monticola* had the highest average survivorship at 98%. High overall survivorship of the plants tagged in the study show potential for the use of all five woody species in future restoration plantings in the Elwha River Watershed.

KEYWORDS

plant survivorship, plant performance, dam removal, Elwha River revegetation, restoration

INTRODUCTION

The dam removal project on the Elwha River watershed is the largest of its kind to date and represents a unique opportunity to watch restoration in a novel ecosystem. The restoration project is being watched closely and has the potential for relatively quick restoration due to the fact that 83% of the watershed is located within the boundaries of Olympic National Park and is federally designated wilderness (USDI 1996).

With a background and undergraduate degree in environmental studies and art from UC Santa Cruz, the dam removals on the Elwha River intrigued me for the watershed's potential for restoration and the story that the river and history of the watershed hold. In my undergraduate studies I focused on the Klamath Basin, a river that is blocked in several locations by seven dams. It is also a river that many dam removal proponents would like to see without dams. For my undergraduate degree I completed a photographic essay on the Klamath Basin. The undergraduate project told the story of the social and political conflict surrounding the watershed through 19 black and white photographs, extensive text and a hand painted map of the watershed. It was an exploration of a watershed heavily impacted by dams. In a way, this project was also an exploration of a watershed impacted by dams. However, instead of focusing on the social and political aspects, this project looked at restoration post dam removal with a micro lens, examining questions of plant survivorship, soil texture and site conditions.

Over the years I have worked for several organizations involved in habitat restoration on rivers, in watersheds and along bay shorelines. Focused on community-based restoration these organizations strove to bring back ecosystem services, decrease non-native vegetation, increase native vegetation and engage the local community. Many times during these restoration projects volunteers would ask what the survivorship rate of the plants were that they were so laboriously planting, transplanting or stewarding. This was always a confounding question for me because while we monitored the habitat restoration projects, we never took data on plant survivorship on an individual, plant-by-plant basis. None of the organizations that I worked for had this information or took data that could answer that question.

When I began talking to Joshua Chenoweth about doing a plant survivorship project on the Elwha I was immediately attracted twofold. I was attracted to the Elwha because of the experimental nature of the project, the novelty of both the resulting ecosystem and also of the dam removal itself and because it would provide me the opportunity to answer the plant survivorship question within an existing, large-scale, habitat restoration project.

It is exciting to be involved on a project that strives to restore an ecosystem heavily impacted by over a 100 years of the presence of dams. It is exciting to witness the change and exciting to be able to provide information that will help park managers plan for the future. My project has provided me with so many lessons learned and I look forward to being able to learn so much more about the restoration

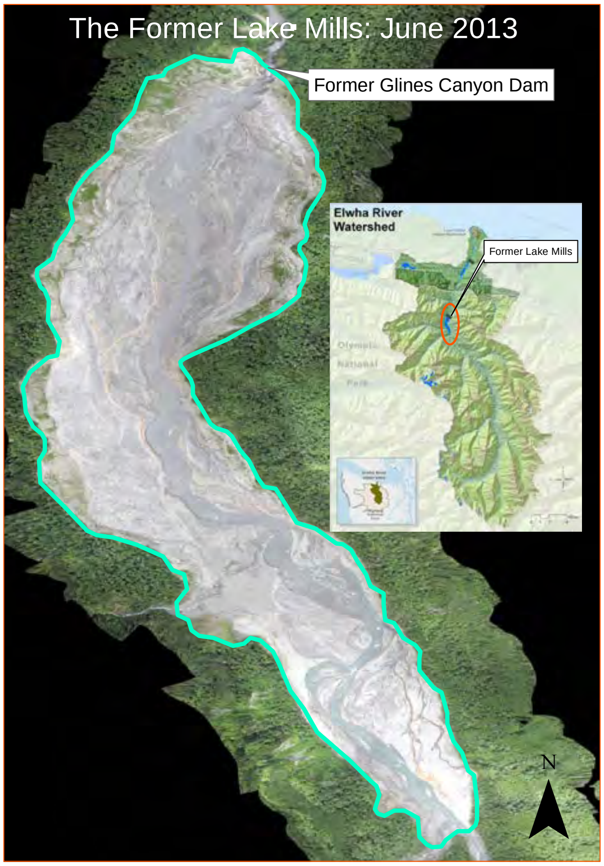

Figure 1. Map of the Elwha River Watershed and the former Lake Mills.

of this novel ecosystem from all the others that are researching, conducting field experiments and working within the Elwha River watershed.

BACKGROUND

There were two dams on the Elwha River (Figure 1). The first dam constructed was 4.9 miles upriver of the mouth of the Elwha River. Named the Elwha Dam, it created the former Lake Aldwell reservoir. The second dam, Glines Canyon Dam was located at river mile 13.4, and created the former Lake Mills reservoir (Chenoweth et. al. 2011). The headwaters of the Elwha River are located high in the Olympic Mountains and start at around 4500’ elevation. From the headwaters the river flows for approximately 45 miles to the mouth where it drains into the Strait of Juan de Fuca (Adamire and Fish 1991, Chenoweth et. al. 2011). One of the larger watersheds on the Olympic Peninsula, the Elwha River watershed is 321 square miles with 83% of the watershed lying within Olympic National Park boundaries (USDI 1996, Mapes 2013).

The Elwha Dam was constructed and completed in 1913 without fish passage and its creation has been controversial from the beginning (Adamire and Fish 1991). Its completion effectively blocked all natal spawning grounds for salmon above river mile 4.9 for the last 100 years. With the removal of the Elwha Dam, the process of opening up 45 miles of mainstem salmonid habitat and nearly a hundred miles of habitat in associated streams and tributaries was initiated (Chenoweth et. al. 2011). Glines Canyon Dam, completed in 1927 was also constructed without fish passage (Adamire and Fish 1991). The dam removal process on the Elwha River, initiated in September 2011 on the Elwha Dam, has moved quickly. The Elwha Dam was fully removed by March 2012. The removal of the larger dam, Glines Canyon Dam is slated to be complete by the fall of 2014 (NPS 2014). The final removal of the remaining 30 feet of dam will mark the end of over 100 years of fish passage blockage on the Elwha River (NPS 2014).

Revegetation of native natural vegetation is a key component to ecosystem restoration in the Elwha River watershed (Chenoweth et. al. 2011). Managed reforestation of the former reservoirs will take seven years and crews will install a variety of native plant species in different forms from seed to bare root. Goals of the ecosystem restoration and revegetation within the watershed are focused on minimizing the colonization of invasive species, stabilizing ecosystem processes and restoring native forests (Chenoweth et.al. 2011).

SITE LOCATION

Located on the Olympic Peninsula in Washington State, Glines Canyon Dam is located approximately 14 miles from Port Angeles and approximately 80 miles from Seattle (Google 2014). The Olympic Peninsula, located in the Pacific Northwest is characterized by a maritime climate influenced by the proximity of the Pacific Ocean (Barbour and Billings 2000). Average annual rainfall based on data from the Elwha Ranger Station between the years of 1990-2014, is 53.84 inches. Annual precipitation is lowest on average in the month of July (Figure 2), with average overall precipitation lowest in the summer months between June-September (WRCC 2014).

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2013	3.68	4.63	5.14	4.31	3.66	1.29	**0.00**	1.42	7.12	2.59	4.13	0.00	**37.97**
Mean (1990-2014)	9.29	5.83	6.50	3.20	2.06	1.36	0.76	1.21	1.49	5.16	9.05	9.00	**53.84**
Standard Deviation	4.42	4.29	4.05	2.00	1.36	0.74	0.64	1.38	1.70	3.46	4.49	4.17	18.43

Table 1. Precipitation averages from 1990-2014.

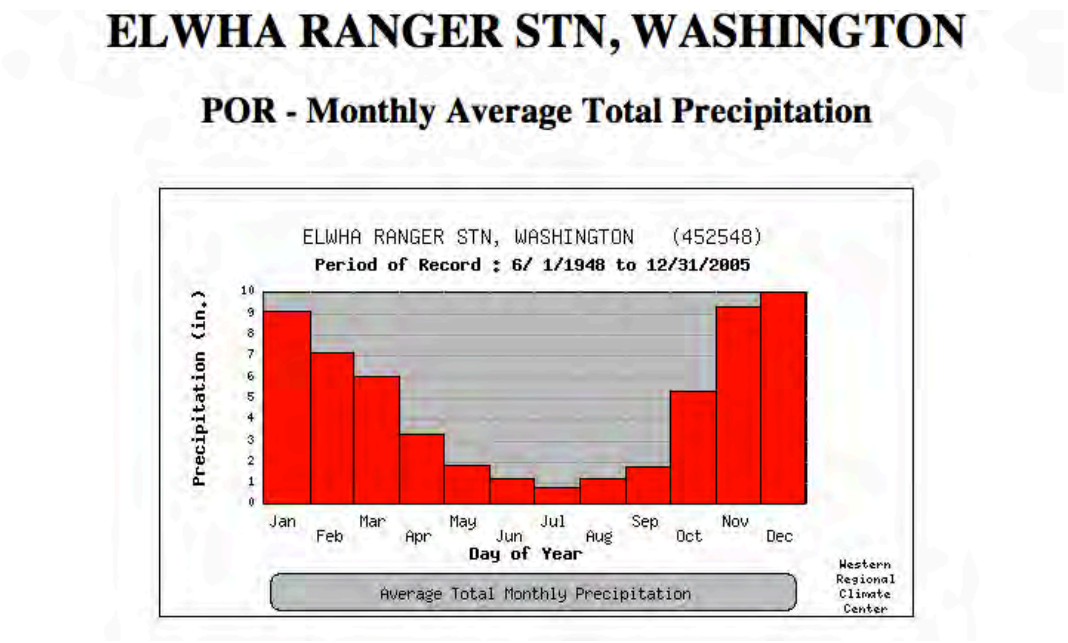

Figure 2. Monthly precipitation averages Elwha Ranger Station.

Fall rain came early and the September 2013 average was over 5 inches greater than the annual mean for the month of September between 1990-2014 (Table 1). Spring rainfall for 2013 was very close to annual averages with slightly elevated monthly precipitations for April and May 2013. June rainfall remained very close to annual averages and July had no recorded precipitation for the month. While rainfall is usually below 1 inch on average for the month of July, July 2013 precipitation was still low when compared with the annual mean. Average annual rainfall for 2013 came in below the 24-year average at 37.97 inches (Table 1). Overall, 2013 had low overall rainfall when compared to previous annual averages in the last 24 years (Figure 2).

The low to middle elevation areas of the Olympic Peninsula, like those surrounding Lake Mills are characterized in the *Tsuga heterophylla* or Western Hemlock zone. In general the *T. heterophylla* zone occurs in very wet to moderately dry habitats around the Olympic Peninsula. These forests exhibit *Pseudotsuga menziesii* dominated stands and common shrubs including *Gaultheria shallon, Acer circinatum, Vaccinium parvifolium, Mahonia nervosa* (Henderson et al. 1989, Franklin and Dyrness 1988).

HISTORY

The history of the site is long and complex but several historical dates warrant mentioning and forever changed the trajectory and historical outcomes of the Elwha River watershed. In 1899, Thomas

Aldwell began buying land along the Elwha River with the idea of building a dam. In 1910, the construction of the Elwha Dam was initiated with the interest and support of a wealthy Canadian, real estate man George A. Glines. In 1912, the lower portion of the Elwha Dam “blew out,” flooding areas below and taking out bridges and houses, although no deaths were caused by the dam failure. That year, officials began communicating with Thomas Aldwell, asking for dam construction to include fish passage. By 1913, the Elwha Dam was complete and fully operable with no constructed fish passage of any kind. In 1915 an agreement was made to offer a hatchery below the dam as mitigation for fish passage blockage. By 1922, due to many problems associated with its operation, the hatchery was closed. In 1926 construction on Glines Canyon Dam began and by 1927 the dam was fully operational. In 1938, one year after the park’s establishment, Lake Mills became part of Olympic National Park, although the dam itself remained privately owned (Adamire and Fish 1991). In 1992, seventy-nine years after the Elwha Dam was completed, the Elwha River Ecosystem and Fisheries Restoration Act was signed into law, initiating the dam removal process (Mapes 2013). In it Congress agreed to support restoration of the Elwha river watershed and associated native anadromous fish (USDI 1996).

Native People

“It’s such a blessing to see this start happening and know it’s going to become real. All kinds of people, all kinds of agencies worked on it; it’s going to happen. I’m just so grateful it’s going to come in our lifetime; it’s an answer to our ancestor’s prayers. They were always thankful because the river provided enough for them.” ~Rachael Hagaman (Mapes 2013).

While my research is not focused on the Native American people of the Elwha River watershed I find it hard to talk about the region or even restoration of the watershed without the mention of the Native People that lived here for thousands of years prior to “discovery.”

The first people of the Olympic Peninsula, the Native Americans that called the Elwha River home were the Elwha Klallam. The Elwha Klallam is now federally recognized as the Lower Elwha Klallam Tribe. Historically, their cultural practices were similar to many other Salish coastal people of the Olympic Peninsula. Salmon were their main resource but they utilized the forests, sea and land for hunting and gathering and many other tribal resources for daily life (Crane 2011). With the building of the dam, the onslaught of immigration from white settlers and unfamiliar disease, the Elwha Klallam found many obstacles to their existence. They were forced to conform to a culture not their own within a restricted land base. The Lower Elwha Tribe is integral to the restoration of the Elwha River, and the tribe plays a crucial and critical role in the restoration of the salmon runs.

Anadromous Fish

There are eight types of anadromous fish that were once found in the Elwha River: coho, summer-run, fall-run and spring-run chinook, summer and winter-run steelhead, pink, chum, sockeye, sea-run cutthroat trout and char (USDI 1996). At least 22 species of animals utilize the salmon in some way as a food resource and they are an important cultural resource for the region as well (USDI 1996).

“The biggest salmon in Puget Sound, [Chinook] were so vital, so integral, and so important to this place that in Chinook jargon, their name tyee is synonymous with chiefly status. But Elwha River restoration is so much more than a fish story. Taking the dams out is about rebuilding the whole house of *tyee”* (Mapes 2013).

Restoration

Revegetation is the establishment of plant vegetation on a disturbed site, while the goal of restoration is a self-sustaining plant community (Cargill and Chapin III 1987). Restoration within the Elwha River watershed is focused on ecosystem processes rather than restoration to historical conditions. The Society for Ecological Restoration (SER) primer states, “An ecosystem has recovered-and is restored-when it contains sufficient biotic and abiotic resources to continue its development without further assistance or subsidy” (2004).

Primary successional habitats are environments with few biological legacies and are environments at their earliest stage of biological succession. Primary succession provides the most appropriate model for restoring severely disturbed ecosystems of both natural and anthropogenic origins (Walker and del Moral 2009). The conditions of the exposed substrate found in the former reservoirs are expected to be more closely associated with areas disturbed by volcanic eruptions or glacial retreats versus conditions found after fire disturbance or wind-throw. Due to drastic differences in the former reservoir areas of Lake Aldwell and Lake Mills, restoration will be geared towards promoting primary succession and ecosystem processes that promote soil generation, erosion control, salmon habitat, and the establishment of pioneer species.

“The goals for revegetating the reservoirs are to minimize invasive exotic species establishment, stabilize ecosystem processes and establish native forests” (Chenoweth et. al 2011). Coniferous species that are able to colonize and be part of early succession, whether through restoration or natural regeneration are usually thought to be slow growing (Van Pelt et al. 2006). Late-successional species that might be planted or be present in early stages of restoration might not assume dominance until early successional species die (Cargill and Chapin III 1987). Establishment of deciduous species will speed recovery. Leaf litter from early successional deciduous species will provide organic material (OM) to the developing landscape accelerating forest development. OM from plants is considered essential to the development of damaged ecosystems (Whisenant 2003). OM is essential to soil development and aids in soil water retention and water availability to plants (Brady and Weil 2010). In addition, restoration of the vegetative communities in the former Lake Mills reservoir will help stabilize sediments and speed up vegetative succession (Mussman 2006).

Total restoration activities in the Lake Mills and Lake Aldwell areas will take seven years and crews will install a variety of native plant species in different forms from seed to bare root. Planting within the former reservoir areas started in 2011 and will continue through 2017 (Chenoweth et.al. 2011). Over the project period over 400,000 seedlings, trees and live stakes will be planted. In addition 2,000 pounds of seed will be applied to the Lake Mills restoration project area (Chenoweth et. al. 2011). By March 2014, 175,000 seedlings scheduled for installation within the former reservoirs were planted (Joshua Chenoweth Personal Communication 2014).

The one biological legacy that is present in the former Lake Mills reservoir is the abundance of large woody debris (LWD). Biological legacies such as LWD influence rates of succession, as well as the trajectory that succession takes (Chenoweth 2007). Sites with biological legacies have been found to recover more quickly than sites with minimal biological legacies present (Halpern and Harmon 1983). Additions of LWD to the restoration sites are expected to have a positive influence on restoration efforts in the watershed (Chenoweth et. al. 2011). Seedling survival is determined by site conditions that effect site moisture (del Moral and Wood 1993). Wood detritus and LWD are thought to provide safe sites for seedlings, giving protection such as shade, protection from wind and additional soil moisture content. Logs also aid in plant succession by stabilizing surfaces and providing organic matter and nutrients (Halpern and Harmon 1983).

SITE CONDITIONS

The most common soil order in the Olympic Peninsula is inceptisols (Henderson et. al 1989). However, the historic soils have been buried by sediments deposited in the reservoirs over the past 100 years, creating a novel condition for plant establishment.

Prior to inundation, the former Lake Mills reservoir was a low-gradient valley that was constricted by bedrock at the location of Glines Canyon Dam (Figure 3). Here the river was forced into a steep gorge where it traveled for several miles until it reached another low-gradient valley that became the former Lake Aldwell reservoir.

The former Lake Mills reservoir inundated approximately 438 acres (Chenoweth et.al. 2011). Sediments that normally moved through the watershed were trapped behind the former Glines Canyon Dam. Original estimates from 1994 vastly underestimated the amount of stored sediments behind Glines Canyon Dam, which have now been estimated to be 20.4 million cubic yards deposited in the former Lake Mills reservoir alone (Bountry et al. 2010). There are three main types of landforms that are now found in the former reservoir: valley wall, delta terraces, and floodplain (Chenoweth et al. 2011). The delta terraces are particularly novel landforms that are only associated with lake formation and subsequent draining. The delta that formed in Lake Mills was nearly one mile long and 80 feet thick prior to the start of dam removal. Dam removal was specifically designed to erode the delta slowly as the reservoir receded.

As the river and delta gradually receded into the disappearing reservoir, sand and gravel 10-20 feet thick was deposited on top of 10-40 foot lacustrine deposits of fine sediment. The result is that the entire valley bottom is now covered with 20-60 feet of sediments with the top layer composed of 10-20 feet of coarse sediments. The fine sediment deposits of silt and clay sized particles are approximately 1-5 feet thick on the valley wall, which lies above the reservoir floor (Personal Communication Joshua Chenoweth 2013).

Figure 3. Photo of the valley floor prior to inundation of Lake Mills. Photo courtesy of the Clallam County Historical Society.

Soil is made up of different fractions of cobble, gravel, silt and clay. These fractions or percentages define the structure or texture of a substrate (Barbour et. al 1980). Coarse sediments are sediments made up of sand, gravel and cobble, while the fine sediments are primarily made of silt and clay (Mussman 2006). In general silt and clay help store nutrients and hold moisture, while larger particles provide the soil structure (Barbour et. al. 1980). Soils with high clay content have higher water-holding capacity and higher soil organic matter (SOM). They are known to drain more slowly and have less porosity. In contrast soil with high sand and gravel content have low water-holding capacity, lower organic matter, good aeration and rapid drainage rates (Brady and Weil 2010, Henderson et al. 1989).

In the former Lake Mills reservoir, nearly 100 acres of delta terraces will be outside of the future floodplain, leaving perched terraces as legacies to the era of the dam and its subsequent removal. These surfaces will be high above the water table and may be slow to develop vegetation due to lack of soil moisture as the areas dry out over time (Chenoweth et. al. 2011). In addition, plant material was expected to perform differently in the fine and coarse sediments. Fine sediments were expected to detract from plant performance and impede the establishment of native woody species (Chenoweth et. al. 2011).

Tributaries

There are five large tributaries that feed into the Elwha River in the area within the former Lake Mills reservoir. They are Hurricane, Sege and Wolf Creek on the east side and Boulder Creek and Stukey Creek on the west side of the former reservoir (Chenoweth et. al 2011). There are several seasonal tributaries that are worth mentioning for their proximity to my study sites. One tributary flows perpendicular to plot MP13-11f, draining adjacent to the plot but not directly into it. Two small tributaries flow between plots in MP13-12. One flows between MP13-12e and MP13-12c and the other flows between plots MP13-12c and MP13-12d, draining out through the site towards the river.

Study Site

The location of my study is the exposed sediments in the former Lake Mills reservoir. The study sites were chosen in early 2013 by the restoration botanist for the Olympic National Park (ONP), Joshua Chenoweth. The study area is part of a larger area that was selected for planting and seeding over the late winter and early spring of 2013. The study location has three sites: Mills Planting 2013 Site 10 (MP13-10), Mills Planting 2013 Site 11 (MP13-11) and Mills Planting 2013 Site 12 (MP13-12). Sites MP13-10 and MP13-11 are located on the western side of the former reservoir, in the valley bottom in thick deposits of coarse-textured sediments (Figure 4). Approximately one mile northeast of sites MP13-10 and MP13-11, site MP13-12 is located on the eastern side of the former reservoir along the former valley wall in the fine sediments.

The sites were selected based on time since draw-down, substrate texture and species performance. MP13-10 and MP13-11 were located in the valley bottom on deep deposits of coarse-textured delta sediments and the third site, MP13-12 was located on the valley wall in the fine sediments. Each site is approximately six acres and divided into six 0.25 acre plots which were planted.

Site MP13-10 was treated with 220 pieces of LWD scattered on the site to create safe sites for the seedlings. MP13-11 has very little naturally occurring LWD, while MP13-12 has large amounts of naturally occurring LWD that was deposited during the process of reservoir draw-down.

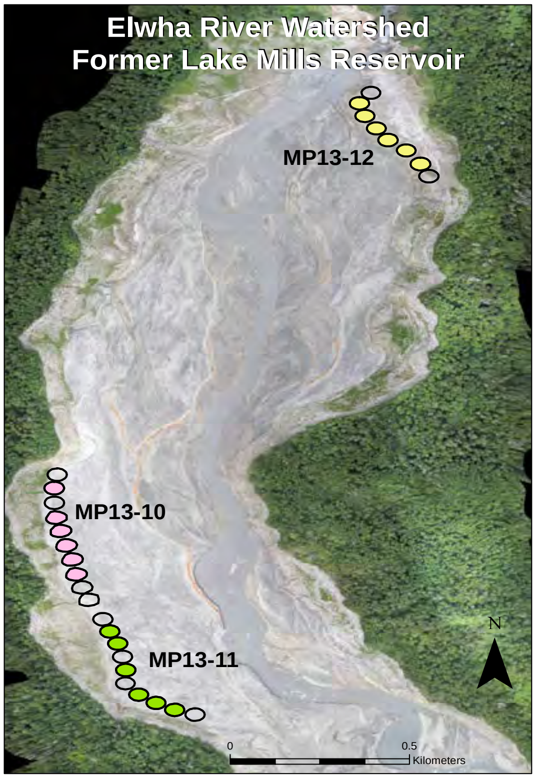

Figure 4. Map of sites and plots.

Study Plots and Planted Species

Six plots were randomly chosen for treatment of high or low density planting, resulting in eighteen study plots which were planted in February and March of 2013 by Washington Conservation Corps members and National Park Service employees and volunteers. High density plantings were planted three and a half feet on-centers and low density plantings were planted on nine foot on-centers (o.c.). While sites were planted at low and high densities, density is not thought to have an effect on plant survivorship in the initial year of restoration (Joshua Chenoweth Personal Communication 2013). Plots a-c (i.e. MP13-10a) are high density for all sites and plots d-f are low density for all sites (Figure 4). Low density plots are planted on nine foot o.c., while high density plots are planted on three and a half foot o.c. The sites were also seeded.

The project planted approximately forty different species throughout the reservoir not counting the species found in the seeding mix. Out of forty, five woody species were chosen for the study. The five species were: Western white pine (*Pinus monticola*), Douglas-fir (*Pseudotsuga menziesii*), Grand fir (*Abies grandis*), Big-leaf maple (*Acer macrophyllum*), and Scouler's willow (*Salix scouleriana*) (Figure 5). Sitka willow (*Salix sitchensis*) was possibly tagged due to cross-hybridization or mis-identification of the willow species during seed collection or tagging since there were many naturally occurring young willows present.

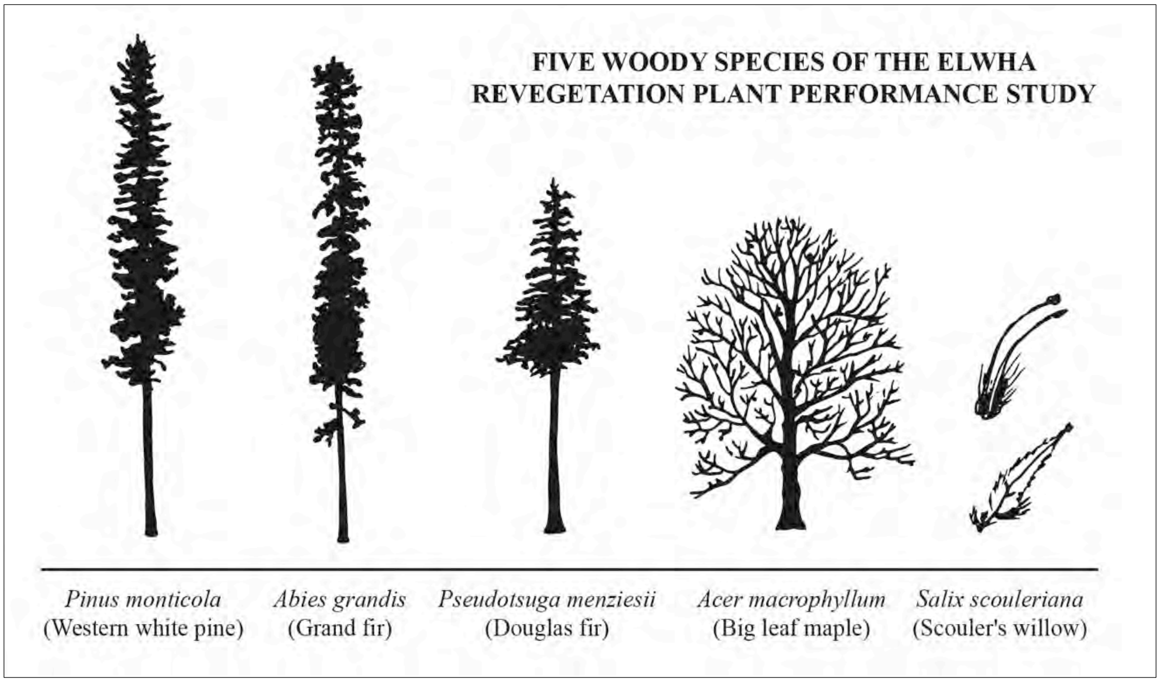

Figure 5. Five woody species of the Elwha River watershed. Adapted from Pojar and Mackinnon 1994.

Pinus monticola

P. monticola is a medium-sized coniferous tree commonly found in moist to dry habitats at low to subalpine elevations (Pojar and MacKinnon 1994). It is a mid-successional species that does best in shade on dry sites and full sun on moister sites (Griffith 1992). *P. monticola* has been severely affected by white pine blister rust (*Cronartium ribicola*), which was originally introduced from France (Pojar and Mackinnon 2004). The *P. monticola* used in the 2013 plantings were a cultivar from the USFS that was bred for the eastern Olympic Peninsula and is resistant to *C. ribicola* (Personal Communication Joshua Chenoweth 2013).

Pseudotsuga menziesii

P. menziesii is a large tree that is adapted to a wide range of habitats. In moist-to-dry sites *P. menziesii* is a natural successor after major disturbances like fire (Pojar and Mackinnon 1994). The *P. menziesii* used in the restoration project were two-year old plants. The park wanted this species studied due to its relative abundance in surrounding forests (Joshua Chenoweth Personal Communication 2014). *P. menziesii* is an early colonizer but it does not become a dominant vegetative cover for many years. It does best in soils with good aeration, a neutral pH and plentiful, available nutrients (Uchytil 1991).

Abies grandis

A. grandis is a tall, coniferous tree that is usually slightly taller than *P. menziesii* but can be commonly found alongside it. It prefers low to mid-elevation habitat and is usually found in the overstory of mid to late successional forests (Howard and Aleksoff 2000). It has a broad habitat range and can be found in river bottoms to dry, sloped habitats (Pojar and MacKinnon 1994). *A. grandis* is a good candidate for restoration projects because it naturally occurs after disturbances like fire. Despite it being an early colonizer, it is slow to grow and does not become a dominant overstory for many years but its presence is an indicator of a productive forest. It also can grow in a variety of substrates with lower organic matter (Howard and Aleksoff 2000).

Acer macrophyllum

A. macrophyllum is a large, deciduous tree that is commonly found alongside *P. menziesii* in disturbed areas. *A. macrophyllum* is not found at high elevations and usually grows at low to mid-elevations in moist sites (Pojar and MacKinnon 1994). *A. macrophyllum* grows well in riparian areas and occurs in all stages of succession (Fryer 2011). It can grow in gravelly soils and alluvium deposits but is moisture limited. It is said to be good for restoration due to the litter that it contributes to the forest floor, which aids in soil pedogenesis (Fryer 2011).

Salix scouleriana

Salix spp. is thought to be a good initial colonizer of a site, altering site conditions to favor coniferous species (Van Pelt et al. 2006). *S. scouleriana*, considered by many to be a small tree, is also commonly categorized as a tall shrub. It is found in riparian areas, wetland edges, hillside thickets, open forests and clearings. It prefers moist but not wet areas at low to mid-elevation (Pojar and MacKinnon 1994). It is known to be good for use in revegetation after disturbances and is said to provide protection to some species of coniferous seedlings by providing micro-habitats within the landscape in the form of shade and added soil nutrients from leaf litter (Anderson 2001).

Seeding

Each site was broadcast seeded with a native seed mix of herbaceous plants. The seed mix included *Elymus glaucus* (Blue wild rye), *Deschampsia elongata* (Slender hairgrass), *Agrostis exarata* (Spike bentgrass), *Eriophyllum lanatum* (Oregon sunshine), *Achillea millefolium* (Common yarrow), *Carex deweyana* (Dewey sedge), *Carex pachystachya* (Thick-headed sedge), and *Artemisia suksdorfii*

(Sukdorf wormwood). Seed was spread by hand and seeding occurred in March 2013. A total of thirteen pounds, fifteen ounces of seeds were spread across the sites (Personal Communication Joshua Chenoweth 2014).

STUDY DESIGN

This thesis project involves year two of the revegetation project in the Elwha River watershed. Site conditions such as soil moisture and substrate texture will be analyzed. Monitoring tagged individuals will help determine the effect of site and site prescription on rates of survivorship in the xeric conditions of exposed lakebed sediment. It is assumed that soil moisture conditions at the site level will influence growth and plant survival.

Research Questions

1. Is plant survivorship affected by site?
2. Is the distribution of soil particles or substrate material similar across the sites?
3. Do sites with LWD have higher plant survivorship?

HYPOTHESIS

1. The soil conditions of the exposed substrates are projected to be very challenging for plant survivorship. In particular the fine sediments will be more challenging than the coarse substrates.

2. Soil moisture will decrease over the summer months correlating with an increase in plant mortality.

METHODS

Selection of woody plants and prescriptions

The five species for the study were chosen by park staff to add to the six species studied in 2012 by Marisa Whisman of Evergreen College. The six species that she examined for her thesis were: ocean spray (*Holodiscus discolor*), Nootka rose (*Rosa nutkana*), thimbleberry (*Rubus parviflorus*), western redcedar (*Thuja plicata*), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), and Douglas-fir (*Pseudotsuga menziesii*) (Whisman 2013). *P. menziesii* was studied again because the *P. menziesii* tagged in 2012 were one year plugs grown in a greenhouse from Silvaseed Company in Roy, WA, while the 2013 *P. menziesii* were two year old bare-root stock provided by Fourth Corner Nursery in Bellingham, WA. All five woody species used for the study are common in the Elwha and were grown from seed collected from the Olympic Peninsula. The plants were chosen because they are prominent species in the surrounding forests and park managers wanted to gather information on their ability to persist in the xeric conditions of the newly exposed substrate in the former Lake Mills reservoir (Personal Communication Joshua Chenoweth 2014).

Research Design//Plant Tagging

Plants were tagged in May and June of 2013. The original study design called for tagging a total of 684 plants in the three sites. Within each plot four *S. scouleriana,* five *A. macrophyllum,* nine *P. menziesii*, ten *P. monticola* and ten *A. grandis* were tagged. Each plant was tagged using a round metal plant tag with a unique identifying number. Tags were affixed to a metal stake with metal wire and placed near the base of each plant. Care was taken to ensure that the tags were not inserted into the plant's root system and were placed approximately a foot or more away from the stem base of each seedling. Due to herbivory, environmental factors and inability to relocate some plants after the tagging process, only 675 plants of the specified species were monitored over the summer field season (Table 2).

Woody Plants Selected for Elwha Plant Performance Study

		Total tagged by site			**Total planted by site**		
Species	**Total tagged**	MP13-10	MP13-11	MP13-12	MP13-10	MP13-11	MP13-12
Big Leaf Maple *(Acer macrophyllum)*	84	29	30	25	105	105	107
Douglas Fir (*Pseudotsuga menziesii*)	162	54	54	54	198	198	198
Grand Fir *(Abies grandis)*	183	62	60	61	330	330	330
Scouler's Willow *(Salix scouleriana)*	66	23	24	19	111	111	111
Western White Pine *(Pinus monticola)*	180	60	60	60	924	924	921
Grand Total	675	228	228	219	1,668	1,668	1,667

Table 2. Woody plants tagged and planted for all sites.

For *A. macrophyllum, P. menziesii* and *S. scouleriana,* all available plants were tagged in the low-density plots. If sufficient *S. scouleriana* or *A. macrophyllum* were not found in the low-density plots in May, some tagging was necessary during the June survey.

For *P. monticola*, and *A. grandis,* there were more than ten of each species planted at each plot so ten plants of each species had to be randomly selected for tagging in both the high and low density plots. Plants were selected using a random number generator for azimuth and distance. Numbers between 0-360 were randomly generated using my iPhone app for azimuth. Numbers between 0-18 were generated for distance. Eighteen was equal to 18 meters (m), the radius of each plot. I pre-generated a list of random compass bearings and distance prior to going out into the field. If additional numbers were needed out in the field, I generated them using my iPhone.

Figure 6. Field technician using a compass to determine plant selection and re-location.

For each plant I chose the first randomly generated azimuth reading and first randomly generated distance. Using the pre-generated list of random compass bearings, I would select the first number. Standing at the center point of each plot I would walk in the direction of the randomly selected cardinal direction and walk the randomly selected distance (i.e. 240 degrees and a distance of 15 m) (Figure 6). When I reached the randomly selected point, I would select the closest one to three plants of the designated species for tagging. The plants that were within a planting distance (nine feet or three and a half feet) were selected for tagging. If there were three plants within that distance they were tagged. If there was only one, it was tagged. No more than three plants were selected for tagging at a time. If they were farther away than this they were not selected for tagging. If applicable I selected more than one plant at a time so that plants would be located in small clusters and easier to find during return visits.

Vegetation Monitoring

Survivorship and Plant condition

Survivorship was recorded during each field visit for all individual plants. Plant survivorship was recorded using a 0/1 scoring system with “0” for a dead plant and “1” for a live plant. Plant mortality was determined by lack of foliage, red or brown appearance and scratching of the cambium layer. If any green was visible underneath the scratch, the plant was determined to be “live” (Whisman 2013).

Counts were taken monthly and converted to percent mortality or proportion survivorship for each species, plot and site.

Plant condition was recorded using a modified five point Likert scale (Whisman 2013). Scales are used frequently to create qualitative data on plant health and vigor. In addition they are frequently used in the social sciences and also adapted for the natural sciences. Upon each visit, individual plants were recorded for plant condition. The plant condition and plant vigor scale used was as follows: 0 = dead; no sign of life; when the cambium is scratched, no green layer present; 1 = poor, plant color poor, withering leaves, mostly brown/yellow/reddish leaves; 2 = stressed; signs of leaf discoloration (some yellow or brown leaves); 3 = good; plant may show slight signs of stress or herbivory but also has green leaves; 4 = thrive; healthy, new, green leaves, signs of vigorous growth.

Measurements of growth

Height was measured using cloth tapes in one millimeter (mm) increments and taken from the root crown to the apical bud on all species (Figure 7). Stem diameter was taken using a caliper and taken at ten centimeters (cm) from the substrate surface (GENERAL ® digital caliper). When plant height was less than or equal to 10 cm, plant width was taken at 5 cm, or at 2 cm if the plant was shorter than 5 cm.

Large-woody debris

LWD measurements were taken in September 2013. Using soft tapes or pvc pipes with 1 meter and a .5 meter (m) pre-marked, plants were measured for their proximity to LWD. Any plants farther than 1 m from LWD were not recorded. For each plant it was noted if it was within a .5 m or 1 meter of LWD (Figure 7). LWD was categorized as anything more than 10 centimeters in diameter (Harmon and Sexton 1996).

Figure 7. *P. monticola* within .5 m of LWD.

Soil Methods

Gravimetric Water Content

Figure 8. Grab Sampling for GWC.

Grab samples for soil moisture content were taken monthly with each field visit. To establish soil collection sites, I randomly selected three sites within each plot. These locations were marked with pin flags for subsequent visits. Randomized site selection followed the same protocol that was used for plant tagging. Soil samples were taken at a depth of 20 cm using a trowel and taken from the sidewall of the each pit (Figure 8). The sites were selected using the same methodology employed for plant tagging (Whiseman 2013). Samples were taken at a different location each month but within 1 m of the pin flag each time. Samples were taken at three pit locations per plot (Van Pelt et al. 2006). Soil grab samples were deposited into individual Ziploc® freezer bags and stored out of the sun during each field visit. The bags were then put into a cooler, transported to Seattle, and refrigerated until they could be processed in the lab.

Grab samples were processed in the UW Restoration Ecology lab. Samples were weighed on a scale (Scout Pro SP601 Ohaus Corporation), and dried for at least 48 hours at 105 degrees Celsius in the lab oven (VWR 132OE) and weighed again (Brady and Weil 2010, Personal Communication Darlene Zabowski 2013). GWC was averaged by plot and by site.

Figure 9. Mechanical sieve used for

Soil Particle Analysis

Coarse soil particles are anything greater than 2 mm, which include both gravel and cobble. Gravel particles are anything larger than 2 mm but smaller than 7.5 cm in diameter. Sand is categorized as particles smaller than 2 mm but larger than 0.05 mm. Silt particles are anything smaller than 0.05 mm but larger than 0.002 mm. Clay particles are smaller than 0.002 mm (Brady and Weil 2010). Based on the available sieves and consultation with Professor Zabowski (2013) I used the following sieve sizes to separate soil particles: cobble (>7.5 cm), gravel (> 2 mm-7.5 cm), sand (>.043 mm- 2 mm), silt and clay (<.043 mm). Silt and clay were grouped into one soil particle size for the purpose of this study and classified as "fine sediments" (Personal Communication Darlene Zabowski 2013). All sieves were placed in a W.S. Tyler Company RO-TAP® testing sieve mechanical shaker located in the lab. Grab samples were separated by soil particle size and weighed (Adam® PGL 2002) (Figure 9). I shook each sample for five minutes, stopped the shaker and used a rubber stopper to break up the clods. The sample was then put in the shaker for an additional five minutes. The shaker was stopped a second time and I used the rubber stopper to break up any remaining clods. The sample was then put in the shaker for an additional three to five minutes. Some samples from site MP13-12 included large amounts of organic matter primarily in the form of woody-debris fines and litter, which was not separated out of the particle classes but was instead included in the calculation of cobble, gravel, sand or silt/clay.

For soil particle analysis, I used the weights of all separated particle sizes added together as the total weight for each sample. All weights were in grams (g) rounded to the nearest tenth.

DATA ANALYSIS

Of the 685 plants that were initially tagged for the study, due to relocation difficulties over the summer, only 675 plants of the original 685 tagged plants were used for data analysis. Data were analyzed using RStudio (RStudio R version 2.15.3 (2013-03-01) and Microsoft Excel (Microsoft Excel for Mac 2011 Version 14.3.9). To test if there was a significant difference between sites and survivorship, the proportions between sites MP13-10 and site MP13-12, as well between site MP13-11and MP13-12 were tested with a two sample test for equality of proportions. GWC and plant survivorship were analyzed using linear regression. LWD data was analyzed using a Fisher's Exact test. Due to the low rate of mortality, it was deemed that the Pearson's chi-squared test would not be as accurate for analysis. Both tests were run along with linear regression for comparison but Fisher's Exact test results were reported.

RESULTS

Plant survivorship

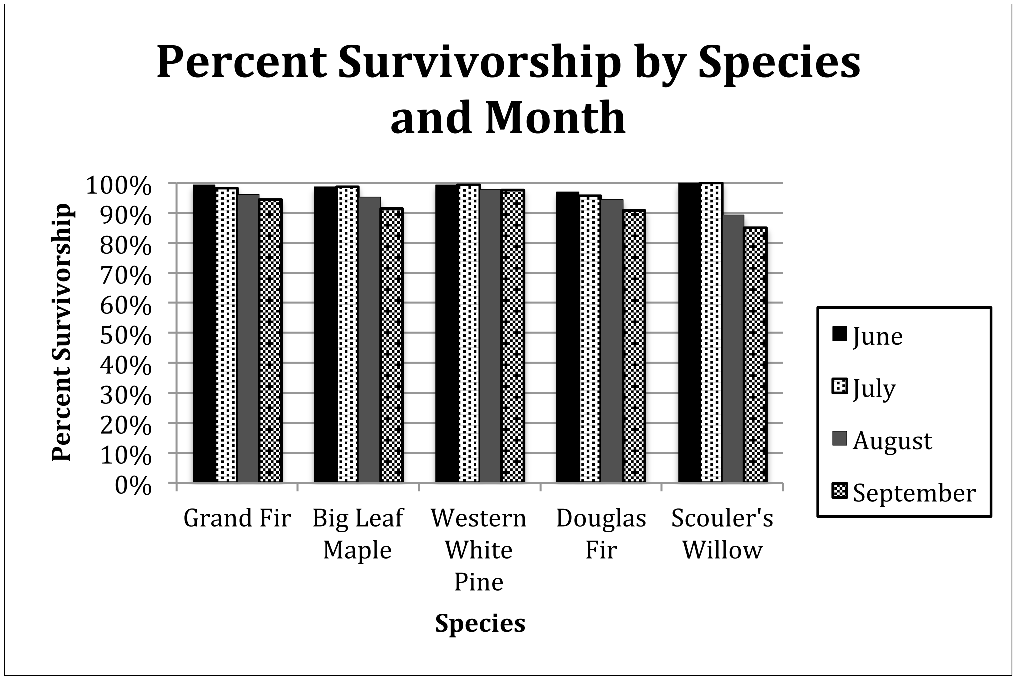

Figure 10. Survivorship of all five species over the 2013 summer monitoring period.

Plant survivorship declined over the summer months as expected, with survivorship dipping in August and continuing into September (Figure 10). Site MP13-10 had a 92% overall survivorship across species and plots, MP13-11 had 88% survivorship and MP13-12 had 96% survivorship (Table 3).

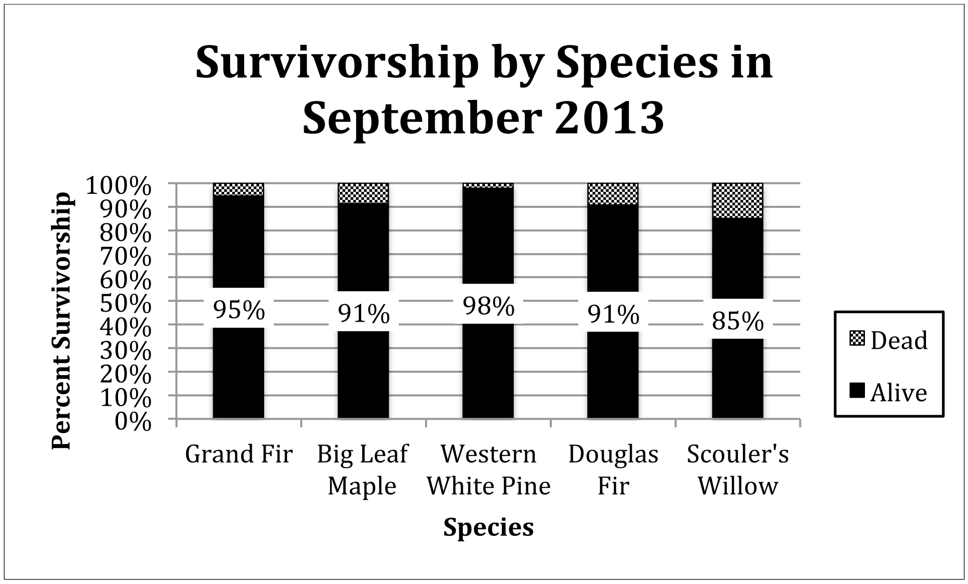

Figure 11. Surivivorship by species for September 2013.

Woody Plants Selected for Elwha Plant Performance Study											
		Total Dead in September			**Total Live in September**				**Total Percent % Live for September**		
Species	**Total tagged**	MP13-10	MP13-11	MP13-12	MP13-10	MP13-11	MP13-12	Total Live	MP13-10	MP13-11	MP13-12
Big Leaf Maple *(Acer macrophyllum)*	84	2	3	5	27	27	20	74	93.10	93.10	86.96
Douglas Fir (*Pseudotsuga menziesii*)	162	6	6	3	48	48	51	147	88.89	88.89	94.44
Grand Fir *(Abies grandis)*	183	3	8	0	59	52	61	172	96.72	86.67	100.00
Scouler's Willow *(Salix scouleriana)*	66	5	6	4	18	18	15	51	81.82	78.26	100.00
Western White Pine *(Pinus monticola)*	180	3	5	0	57	55	60	172	98.28	94.83	100.00
Grand Total	675	19	28	12	209	200	207	616	91.76	88.35	96.28

Table 3. Plant survivorship numbers and survivorship percentages for September 2013.

Plant survivorship was highest for *P. monticola* (98%) and lowest for *S. scouleriana* (85%) across all three sites (Figure 11). Overall, survivorship was considered high across species and sites. ONP did not set a parameter for restoration site success but anecdotally, any survivorship over 80% was considered good (Personal Communication Joshua Chenoweth 2014). Overall survivorship for species at the site level showed that four out of five species had over 90% survivorship rate with the exception of the *S. scouleriana* (Figure 11). Four out of five species had highest survivorship at site MP13-12, the site with the highest silt/clay content and therefore greatest water availability. The exception was *A. macropyllum*, which experienced high herbivory at site MP13-12.

To test if there was a significant difference between sites and survivorship, the proportions between sites were tested with a two-sample test for equality of proportions. Using a significance level of .05, site had a significant effect on survivorship when site MP13-10 and site MP13-12 were compared (p = .004). There was a highly significant effect on survivorship when site MP13-11 and site MP13-12 were compared (p < .01). There was not a significant difference between sites and their effect on survivorship when site MP13-10 and site MP13-11 were compared (p = .0548).

Plant Vigor

Plant condition showed declining vigor and increased stress between June 2013 and September 2013. As early as June plants were starting to show signs of stress through leaf discoloration. No species reported median values for plant vigor above "3." In June the median plant vigor rating for all species across the three sites was "3" (Table 4). By September all species were showing signs of stress (Table 4). Across all sites, *A. macrophyllum* was reporting a median of "1." Additionally, *S. scouleriana* had a median vigor rating of "2" at sites MP13-10 and MP13-11 but a median vigor rating of "3" at site MP13-12 (Table 4).

Vigor data June and September 2013						
	Vigor for June			Vigor for September		
Species	MP13-10	MP13-11	MP13-12	MP13-10	MP13-11	MP13-12
Big Leaf Maple *(Acer macrophyllum)*	3.00	3.00	3.00	1.00	1.00	1.00
Douglas Fir (*Pseudotsuga menziesii*)	3.00	3.00	2.00	3.00	3.00	2.50
Grand Fir *(Abies grandis)*	3.00	3.00	3.00	3.00	2.00	3.00
Scouler's Willow *(Salix scouleriana)*	3.00	3.00	3.00	2.00	2.00	3.00
Western White Pine *(Pinus monticola)*	3.00	3.00	3.00	3.00	3.00	3.00
Median of Plot	3.00	3.00	3.00	3.00	2.00	3.00

Table 4. Median vigor values for June and September 2013.

Plant Growth

Plant growth measurements were pooled by plot and summary statistics were run for each species (Appendix 1). Most species showed signs of growth over the summer months. Increased height between the summer months of June and September was most evident at site MP13-12.

Soil Moisture Content

Gravimetric water content (GWC) declined over the summer months (Figure 12 and 13). There was a distinct difference in GWC between sites MP13-10, MP13-11 and site MP13-12, with GWC being highest in the fine sediment sites of MP13-12 and lowest in the coarse substrate sites of MP13-10 and MP13-11. Site MP13-12 had an average GWC of 42% while site MP13-10 had an average GWC of

3.26% and site MP13-11 had an average GWC of 2.46%. Site MP13-11 had the smallest standard deviation between plots and across all months. Site MP13-12 had the largest standard deviation. Site MP13-11 had a minimum GWC of 1.19% and a maximum of 5.96%. In contrast site MP13-12 had a minimum GWC of 26.53% and a maximum of 52.83% (Table 5). Using linear regression to examine the relationship between GWC at the site level and survivorship, statistical results showed a significant difference between sites MP13-10 and MP13-11 and site MP13-12 (p =.004) when GWC is examined over time (Figure 12).

Summary Statistics for GWC data

	MP13-10	MP13-11	MP13-12
Mean	3.26	2.46	42.00
Median	2.77	2.33	41.81
Minimum	1.45	1.19	26.53
Maximum	13.10	5.96	52.83
1st Quartile	2.32	1.93	38.06
3rd Quartile	3.67	2.71	45.86
Standard Deviation	1.75	0.83	5.79

Table 5. Summary Statistics for GWC data.

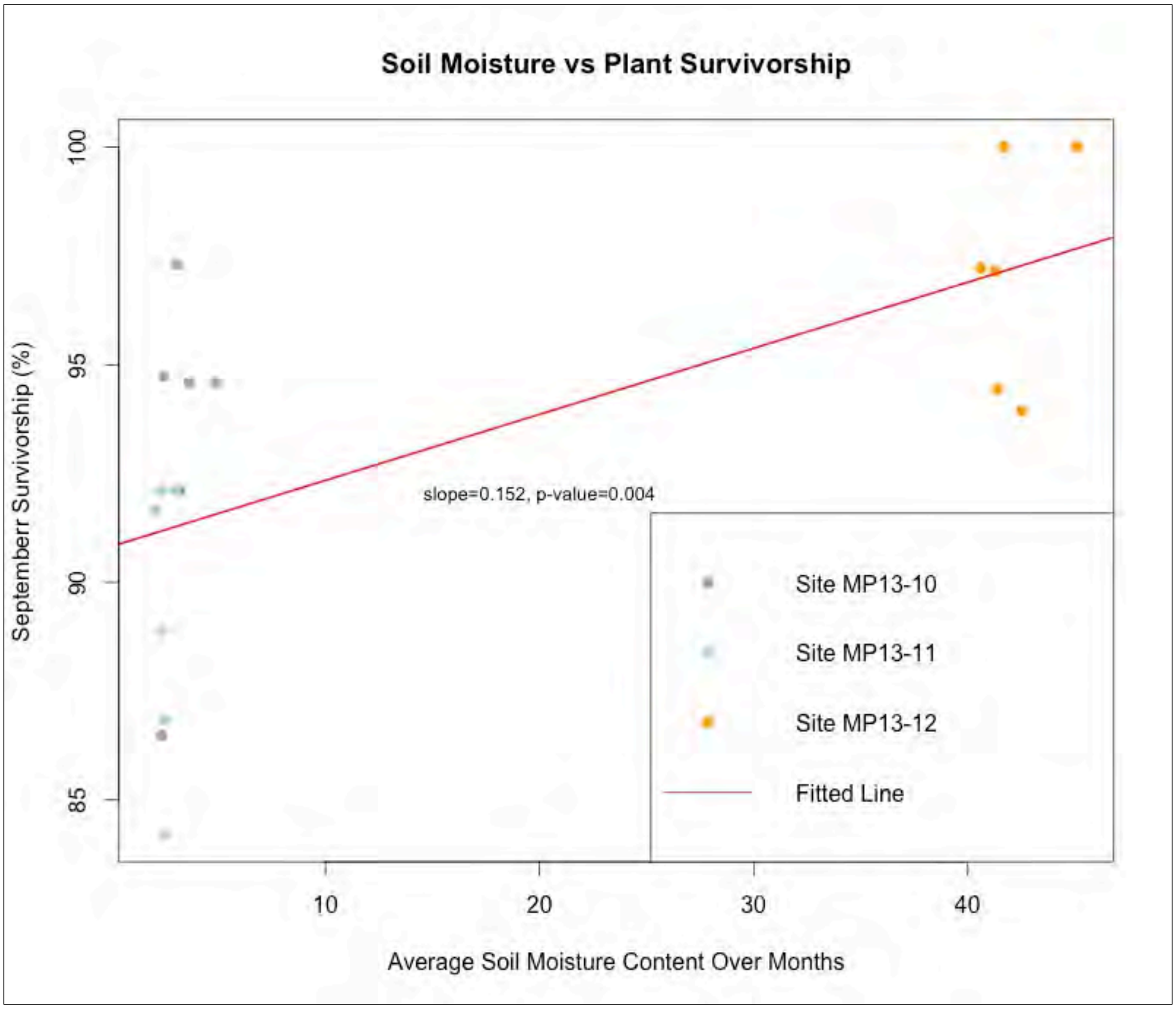

Figure 12. Soil Moisture vs. Plant Survivorship.

Plotting GWC for sites MP13-10 and MP13-11 using a whisker box plot, sites MP13-10 and MP13-11 are more closely related (Figure 13). Site MP13-10 has more variability across the site than MP13-11. When plotted next to site MP13-12, the site differences between MP13-12 and sites MP13-10 and MP13-11 are readily evident in the box plot distributions (Figure 14).

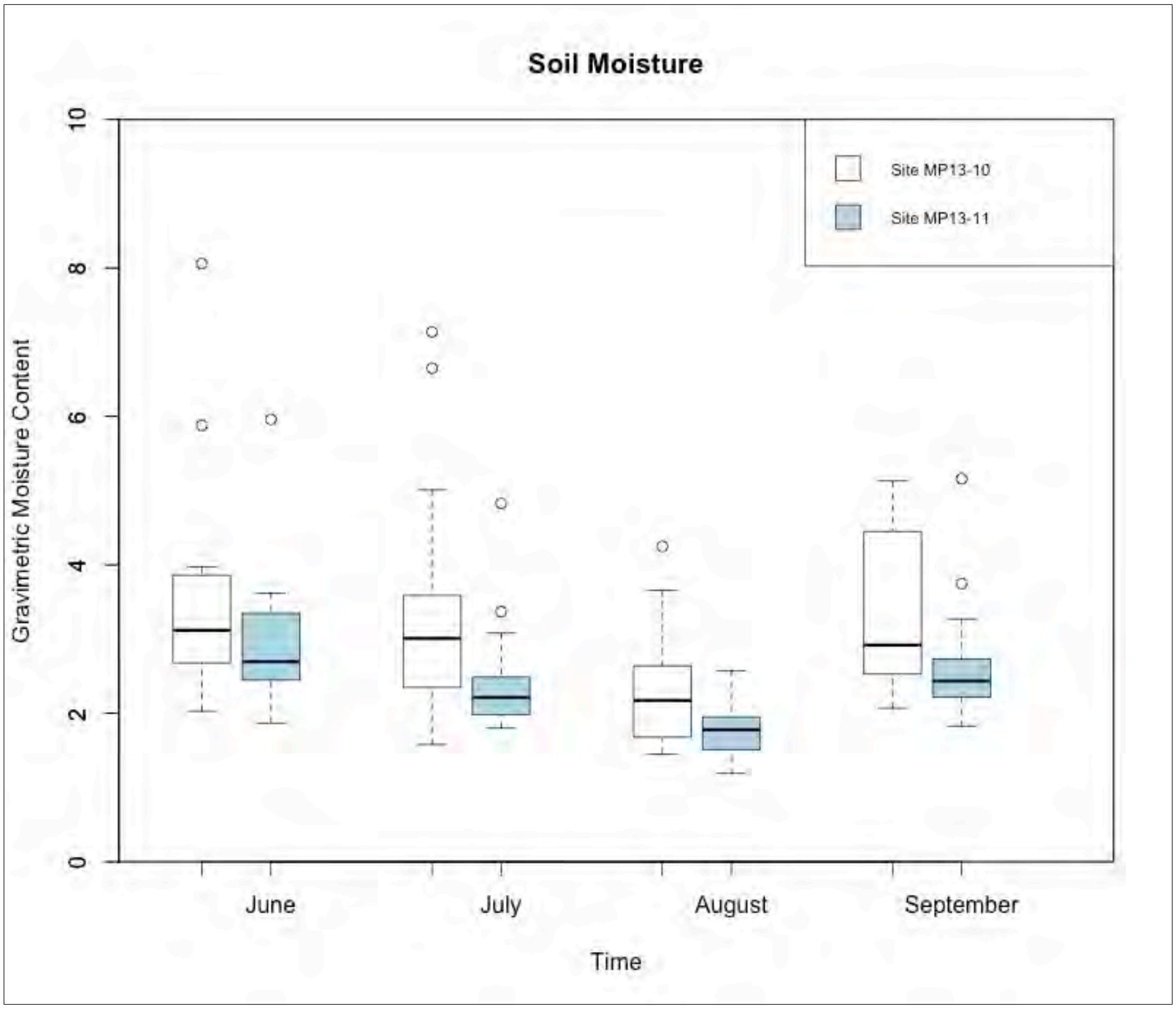

Figure 13. Comparison of GWC for sites MP13-10 and MP13-11.

Using linear regression to test the differences between sites when GWC is examined over time, statistical analysis found significance between site MP13-10 when tested against site MP13-12 (p <.001) and statistical significance between site MP13-11 when tested against site MP13-12 (p <.001) for the months of August and September using a significance level of .05 and June as the reference month. The low p-values indicate a strong association between GWC, time and site. GWC did not have a statistical significance on survivorship for the month of July when site MP13-10 was tested against site MP13-12 and site MP13-11 was tested against site MP13-12. The box plots display the fluctuation in overall site moisture over time and while delayed, site survivorship is also reflective of this oscillation pattern.

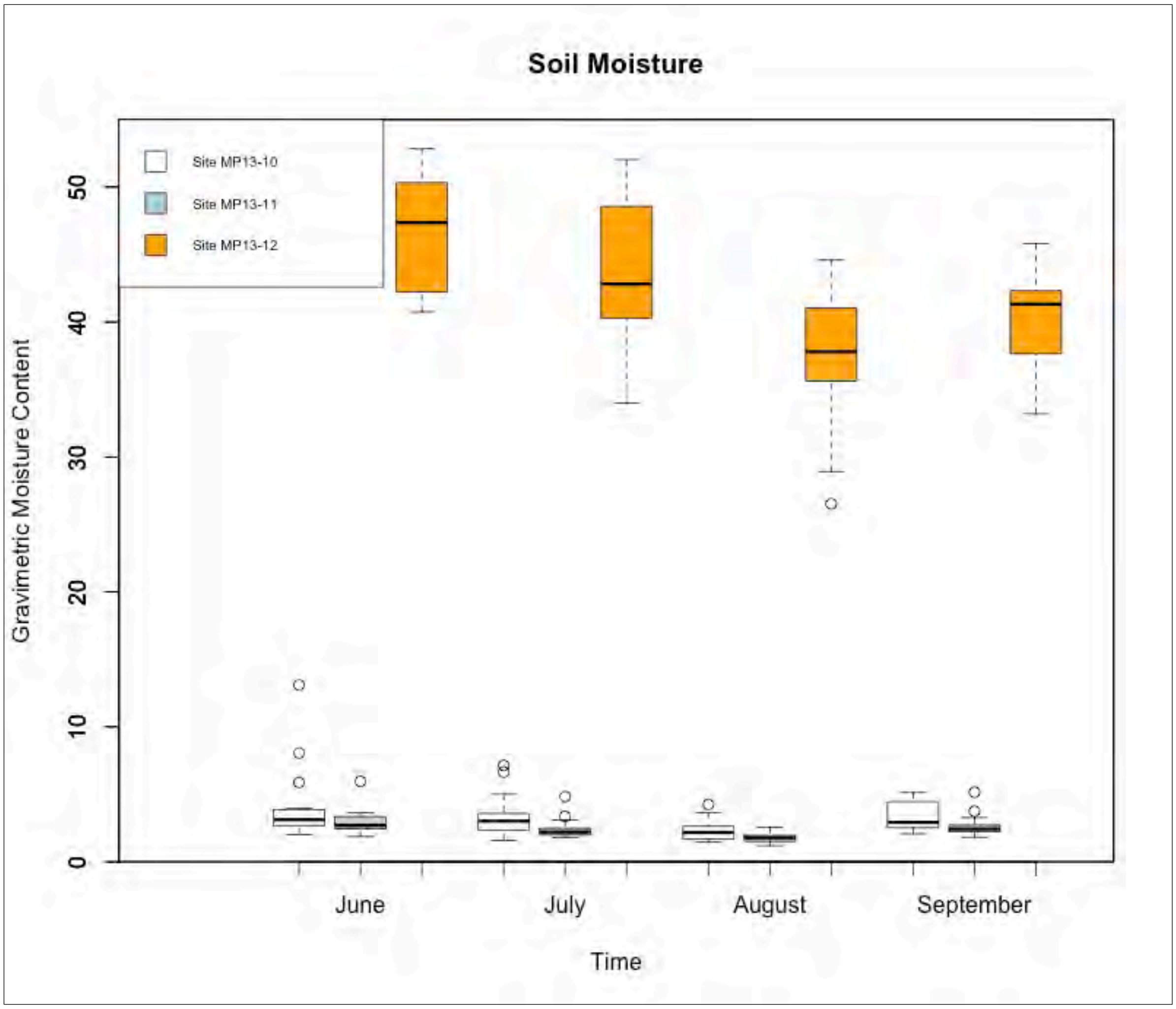

Figure 14. Comparison of GWC for all three sites.

Soil Particle Analysis

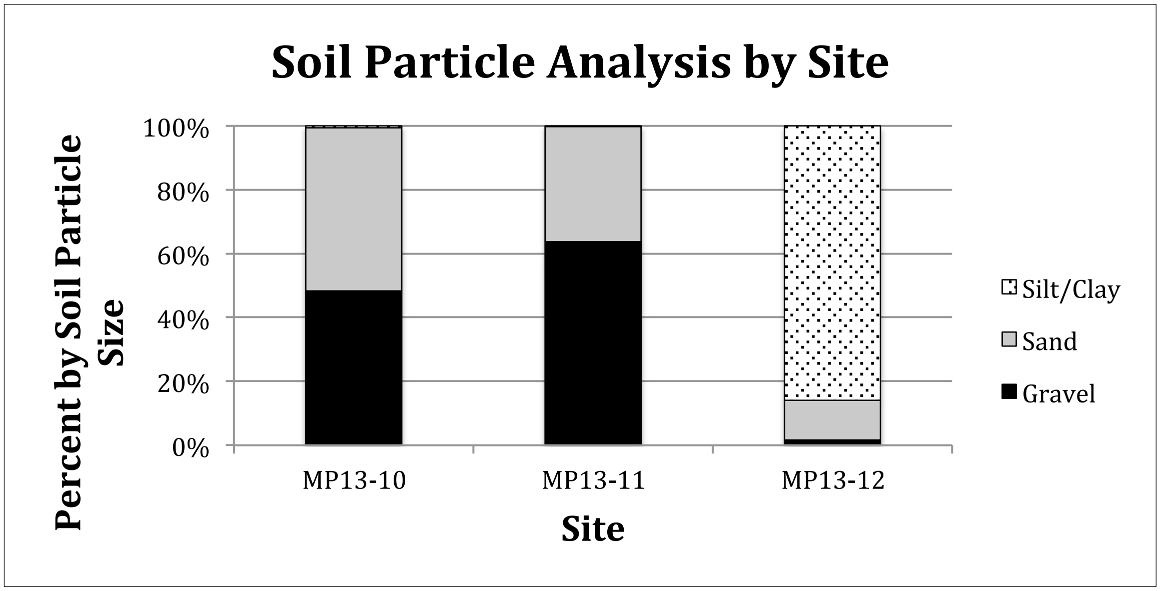

Figure 15. Soil particle size by site.

Soil particle analysis showed that the substrate at sites MP13-10 and MP13-11 had high sand and gravel contents. The substrate at site MP13-12 was distinctly different with a high silt/clay content found across the site (Figure 15). Three plots within site MP13-12 had a >85% silt/clay content. Site MP13-11 had five plots with a >50% gravel content, while site MP13-10 had three plots with a >50% gravel content (Figure 16). When averaged by site MP13-12 had an overall 85% silt/clay content, while site MP13-10 had <1% silt/clay content and site MP13-11 had <.05% silt/clay content at the site level. In contrast site MP13-10 had 48% gravel content at the site level and MP13-11 had 64% gravel content. In comparison site MP13-12 had <2% gravel content (Figure 15). Site MP13-10 had the highest sand content and site MP13-10 had the most equitable distribution of sand and gravel particles with 48% gravel and 51% sand at the site level (Figure 15).

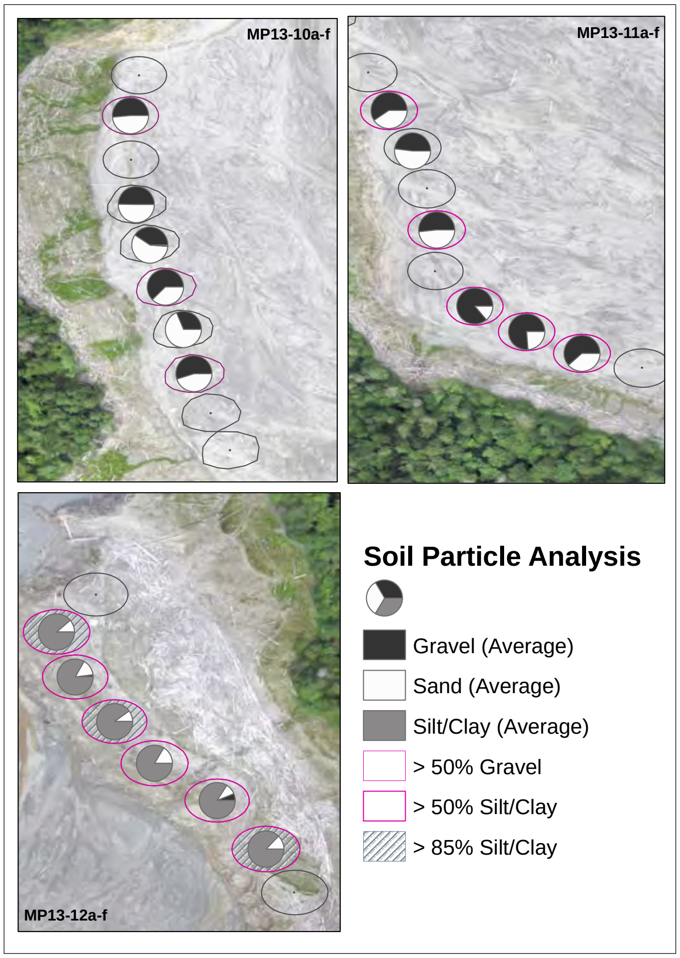

Figure 16. Map of soil particle distribution across sites and plots.

Normalized data

Data were normalized by plot for survivorship, GWC and % gravel content. Data were normalized to a scale of 0 to 1 and data was normalized for easy comparison of values. When normalized data were graphed against each other several patterns emerged. When GWC was graphed against gravel (Figure 17) it was very evident that low gravel content in the site substrates at the plot level corresponds to high moisture content. In other words the plots with the highest silt/clay content had the highest GWC by plot. Low gravel content corresponded to high moisture at the plot and site level.

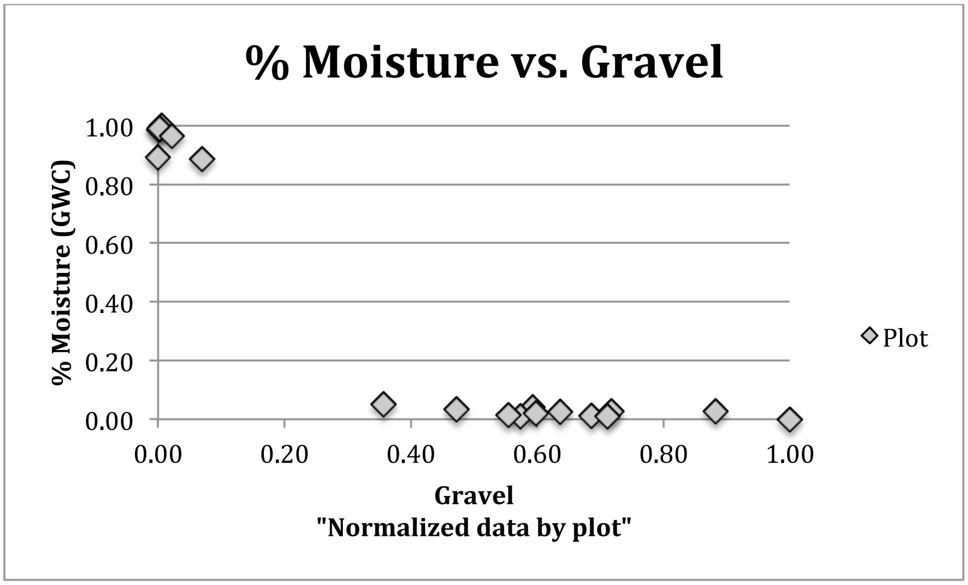

Figure 17. Percent moisture vs. gravel across plots.

When percent survivorship was graphed against GWC, plots with the highest GWC had the highest survivorship (Figure 18). Generally speaking, the plots with the highest GWC were also the plots with the lowest % gravel and highest silt/clay content.

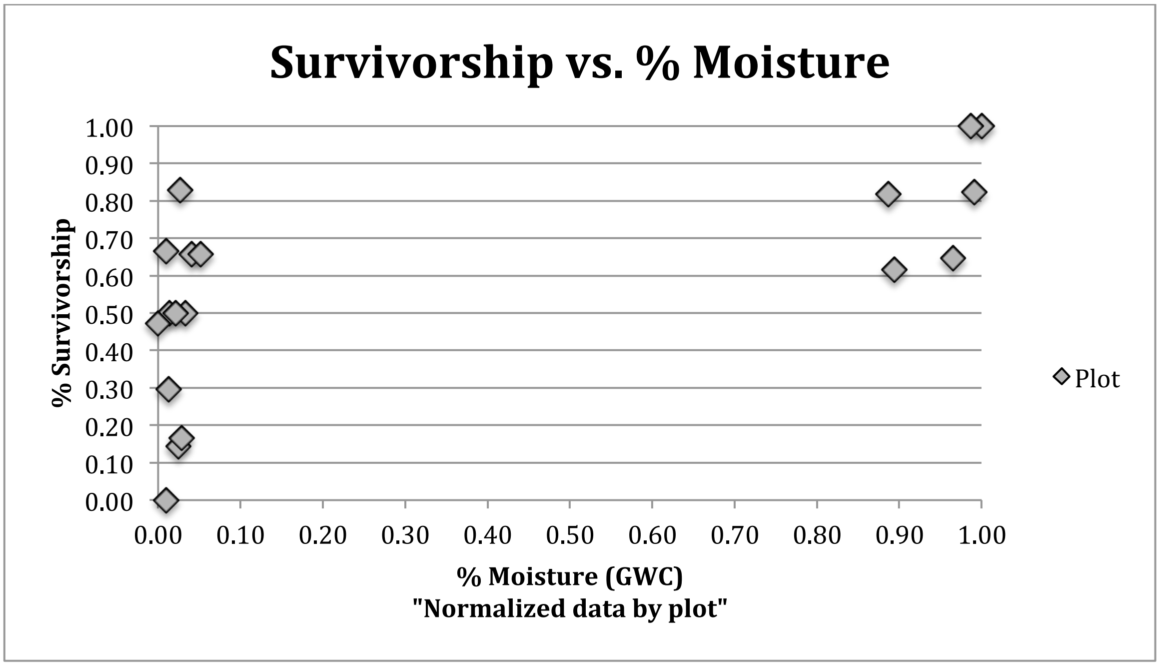

Figure 18. Survivorship and percent moisture across plots.

When percent survivorship was graphed against % gravel content, (Figure 19) plots with a very low gravel content, which were the six plots of site MP13-12, had high survivorship. The rest of the data was stochastic and no trends were noted as gravel content by plot increased.

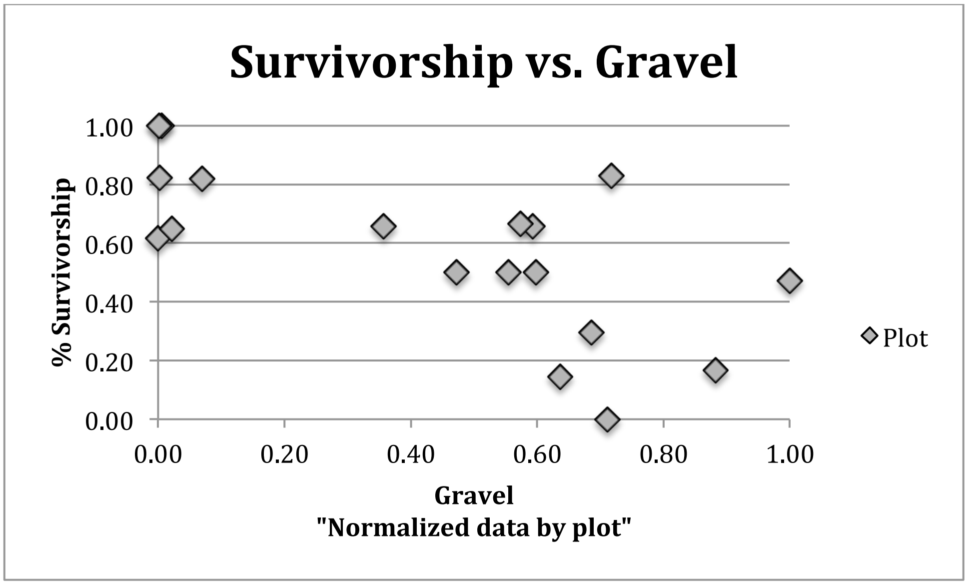

Figure 19. Percent survivorship vs. percent gravel contents by plot.

Site MP13-12 had the lowest percent gravel content by site and plot, the highest GWC overall and the highest survivorship numbers by site and plot. Using the graphs of the normalized data, the trends that were revealed are that low gravel content led to higher survivorship, while high moisture content was found in plots with low percent gravel content.

Large-woody debris

Results from LWD surveys of the plants and plots in September 2013 show that the presence of LWD across all sites did have an effect on survivorship. When data were analyzed with a Fisher's Exact Test, results show a high significance on survivorship with the presence of LWD within either .5 m or 1 m (p = .001) with a p-value of .05 as significant. When plants were in the presence of LWD, plant survivorship was 97.6%. In contrast, plants not close to LWD had a 91.1% survivorship.

When distance from LWD was analyzed separately the plants that were within .5 m of LWD showed a significant relationship between survivorship and proximity to LWD (p = .01). When survivorship and proximity to LWD was analyzed looking at just plants within 1 m, the relationship was marginally significant (p = .05).

When survivorship and proximity to LWD was evaluated by individual site, with a p-value of .05 as significant, site MP13-12 had a p-value of 1. The high p-value indicated that the null hypothesis could not be rejected and that we could not say that the presence of LWD affected survivorship at site MP13-

12. For site MP13-11 results of the statistical model indicated there was not enough evidence to support or deny the effect of LWD on survivorship (p = .48). For site MP13-10 results indicate a strong association between survivorship and presence of LWD at site MP13-10 (p = .01). While the relationship is significant, the relationship is not as strong as when all sites are examined collectively.

DISCUSSION

Pinus monticola

P. monticola is known to be good for restoration as it has high adaptability to bare root plantings (Burns and Honkala 1990). It is also somewhat drought resistant when compared to other coniferous species (Pojar and Mackinnon 1994). *P. monticola* had the highest rates of survivorship (Figure 11) across the three sites. While the plants were originally container stock, the majority of soil and material were removed from the plants prior to planting for easy transport across the reservoir. The result was that the plants were put into the ground with little nursery soil. While some plants did show stress and needle discoloration, particularly at sites MP13-10 and MP13-11, the majority of stressed plants were found in pockets, which observationally, related to altered site conditions in that particular location. In addition to soil moisture loss, it is also thought that wind might have been a contributing factor to needle discoloration. High winds are found to dessicate needles and cause needle discoloration from moisture loss (Burns and Honkala 1990). Despite some plants showing stress, the high survivorship of *P. monticola* shows that it can do well in both the fine and coarse substrate of all three sites.

Pseudotsuga menzeisii

Survivorship rates of *P. menzeisii* were higher than the results of Whisman (2013) who reported survivorship for the species across her sites at 40% in the coarse sediment sites, 64% survivorship in the fine sediment sites and 90% survivorship in the fine/sandy sediments sites. In contrast I saw 91% survivorship across all three sites and 89% survivorship at the coarse substrate sites of MP13-10 and MP13-11. Twenty-thirteen plantings used a two-year bare root stock of *P. menzeisii*. The more mature planting stock could have led to higher survivorship. In contrast, the *P. menzeisii* planted in 2012 were one-year plugs grown in a greenhouse. Whisman (2013) attributed the higher mortality rates of *P. menzeisii* to environmental factors, low organic matter and the undeveloped state of site soils. In *P. menzeisii* studies, limited nitrogen (N) in forest soils is shown to be a limiting factor in nature (Burns and Honkala 1990). While soil nutrients were not examined in my study, it was thought that soil nutrients in sites MP13-10 and MP13-11 were lower than in site MP13-12.

When the rate of survivorship was examined more closely, the highest decrease in survivorship occurred between the months of August and September at sites MP13-10 and MP13-11. At site MP13-11, a 4% decrease in survivorship took place between the months of June and July and again in the months between August and September. As noted before the overall rate of survivorship for *P. menzeisii* was 91% across the three sites but 89% at site MP13-10 and MP13-11 (Table 3).

P. menzeisii was the only species whose plant condition went up over the summer months. This only occurred at site MP13-12, but the median value for *P. menzeisii* actually increased between June and September (Figure 20 and 21). According to Uchytil (1991) first year *P. menzeisii* seedlings do best in partial shade. While the seedlings used in the restoration are two-year seedlings, it is likely that the shade of site MP13-12 aided in higher survivorship and plant condition of *P. menzeisii* at this site.

Abies grandis

A. grandis is well adapted to the forests of the Olympic Peninsula, where the tree species reaches greater heights than in any other ecosystems where it is found. However, the soils that are usually present in the Olympic Peninsula are not reflective of the sediments in the former reservoir. While *A. grandis* does develop a long taproot that enables it to survive on dry soils, the taproot does not grow rapidly in xeric conditions (Burns and Honkala 1990). The *A. grandis* for this study had an overall survivorship of 95% across the sites. Like many of the other species it had its lowest survivorship at site MP13-11, with 87% overall survivorship (Table 3). Plant vigor median values were also lowest at this site when compared to the other sites (Figure 21). Observationally *A. grandis* displayed visible indications of stress, particularly at site MP13-11, which included needle discoloration and dessication.

Acer macrophyllum

While *A. macrophyllum* had higher survivorship than *S. scouleriana*, the plant was showing clear signs of stress including leaf discoloration, leaf curl and heavy herbivory across the sites (Figure 22). Despite having the same overall survivorship as the *P. menzeisii* and higher survivorship than *S. scouleriana*, *A. macrophyllum* had low median values for plant vigor. Median values for plant vigor in September were “1” across all three sites, suggesting that *A. macrophyllum* was under great stress across the three sites (Figure 21). In comparision *S. scouleriana* had higher mortality but plant condition was particularly good at site MP13-12.

Different factors may have contributed to the poor condition of *A. macrophyllum* at sites MP13-10 and MP13-11 versus MP13-12. We know that there was a significant effect of GWC on survivorship at sites MP13-10 and MP13-11 when compared to site MP13-12. The low GWC at sites MP13-10 and MP13-11 likely contributed to poor growing conditions for *A. macrophyllum* at these two sites. In addition, while it was not formally analyzed, exposure to wind is much higher at sites MP13-10 and MP13-11 than at site MP13-12. Root exposure was common at sites MP13-10 and MP13-11 for *A. macrophyllum* and it is thought that wind exposed root balls likely contributed to lower overall plant condition at these two sites (Figure 22). In contrast, based on observation and field visits, the poor plant condition of *A. macrophyllum* at site MP13-12 was due to heavy herbivory. In the later summer months, many *A. macrophyllum* at site MP13-12 had few leaves and shortened stems from heavy grazing. Browsing by deer heavily influences how tall maple seedlings will grow as they mature, as well as the way in which the stems form, dictating adult plant morphology (Burns and Honkala 1990). Leaves that were present usually looked healthy. With 91% overall survivorship, *A. macrophyllum* had the same percent survivorship as *P. menziseii* across the three sites (Figure 11). However, when plant condition was considered, the overall health of this plant species was not equitable to the plant condition of *P. menziesii* at the three sites.

Salix scouleriana

S. scouleriana had the lowest percent survivorship of the five species with 85% survivorship. While *S. scouleriana* is generally known as a willow that can tolerate drier growing conditions than other willows, the *S. scouleriana* (Anderson 2001), at sites MP13-10 and MP13-11 seemed to be heavily impacted by site conditions. In contrast, the survivorship rates at site MP13-12 was very high, where water availability was higher than the coarse substrate sites of MP13-10 and MP13-11.

S. scouleriana also showed many signs of stress. In June, at that start of the monitoring period, *S. scouleriana* looked green and showed indications of vigorous growth at all sites. At MP13-12 the *S. scouleriana* remained in good condition but plant condition declined drastically at the other sites through the summer months, yielding a median vigor value of “2” at both sites MP13-10 and MP13-11 (Figure 22). *S. scouleriana* suffered from insect herbivory and appeared to suffer at sites MP13-10 and MP13-11 more than the four other woody species examined for this study. With a survivorship of 82% at site MP13-10 and a survivorship of 78% at site MP13-11, in contrast to 100% survivorship at site

MP13-12, the site conditions of MP13-12 clearly catered to the preferred growing conditions of *S. scouleriana*. Field observations revealed the *S. scouleriana* found at site MP13-12 showed signs of vigorous growth with green leaves, less insects and insect damage than at sites MP13-10 and MP13-11.

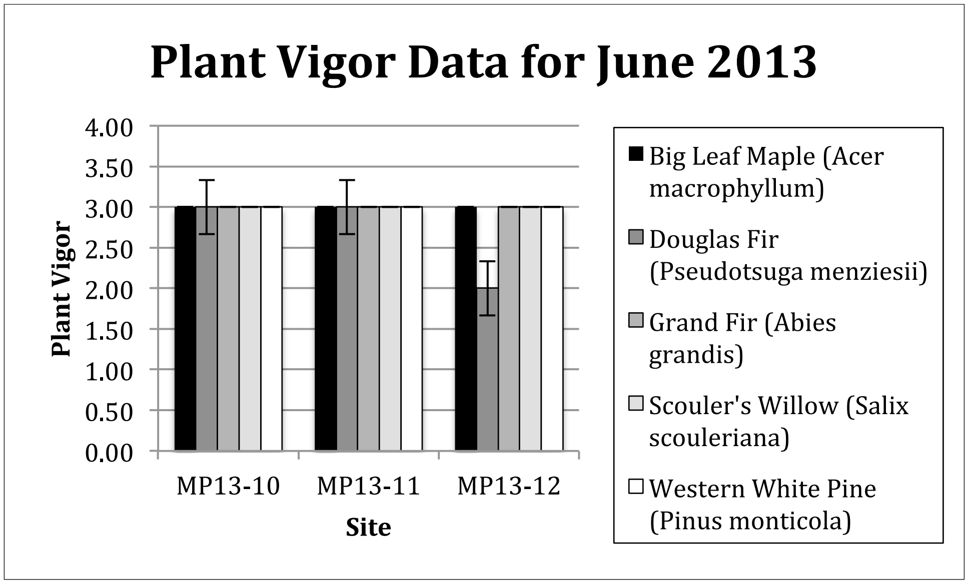

Figure 20. Plant condition for June 2013.

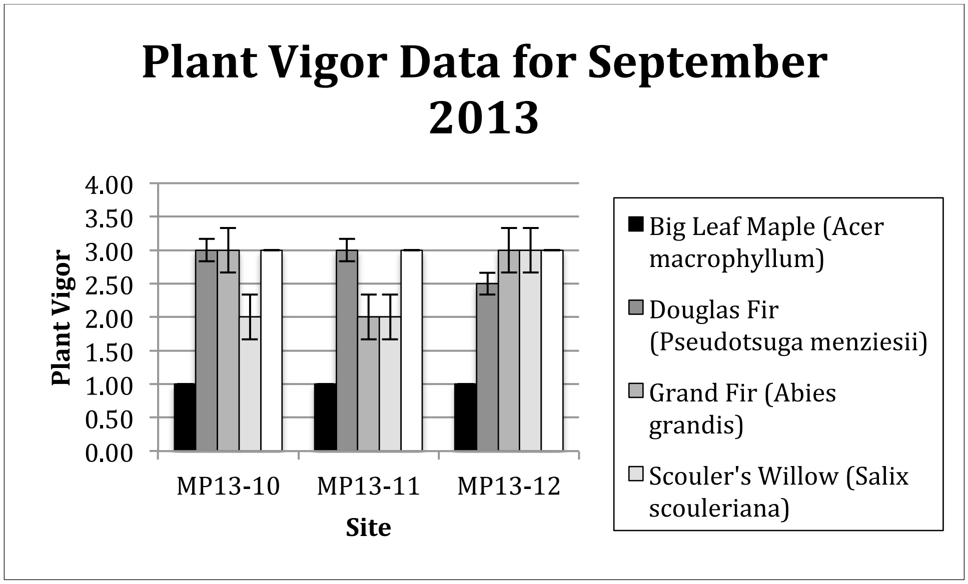

Figure 21. Plant condition for September 2013.

Figure 22. *A. macrophyllum* planted in the coarse substrates.

Figure 23. Plants at site MP13-11 in September 2013.

Overall plant condition for all plants and species declined over the summer monitoring period (Figure 20 and 21). Observationally, this was also evident in the field (Figure 22 and 23) as many plants, while not dead, started showing signs of stress. This stress was partially indicated by red, brown or yellow leaf discoloration.

Soil Particle Analysis

In general it was found that low gravel content at the sites related to high survivorship. Plant survivorship was highest at sites MP13-12 and lowest at site MP13-11 (Figure 20).

Site MP13-12 had high silt/clay content across plots. At the site level MP13-12 had over 85% silt/clay content. In contrast MP13-11 had less than 1% silt/clay content, 36% sand content and 64% gravel content. Site MP 13-10 also had less than 1% silt/clay content but had 51% sand content and 48% gravel content at the site level. Soils with higher percentages of sand and gravel have lower water holding capacity and lack the ability to hold onto to nutrients, making them generally less fertile and drought prone (Brady and Weil 2010). Silt/clay particles bind to water particles, making water less available to plants immediately but more available to them over time. Water moves slowly in silt/clay dominant soils. In sites with high gravel/sand content, water is more available to plants but not held tightly near the surface and is lost as water easily drains to lower soil horizons. In coarse substrates the water will drain through the soil substrate more rapidly and be available to plants for a shorter period of time.

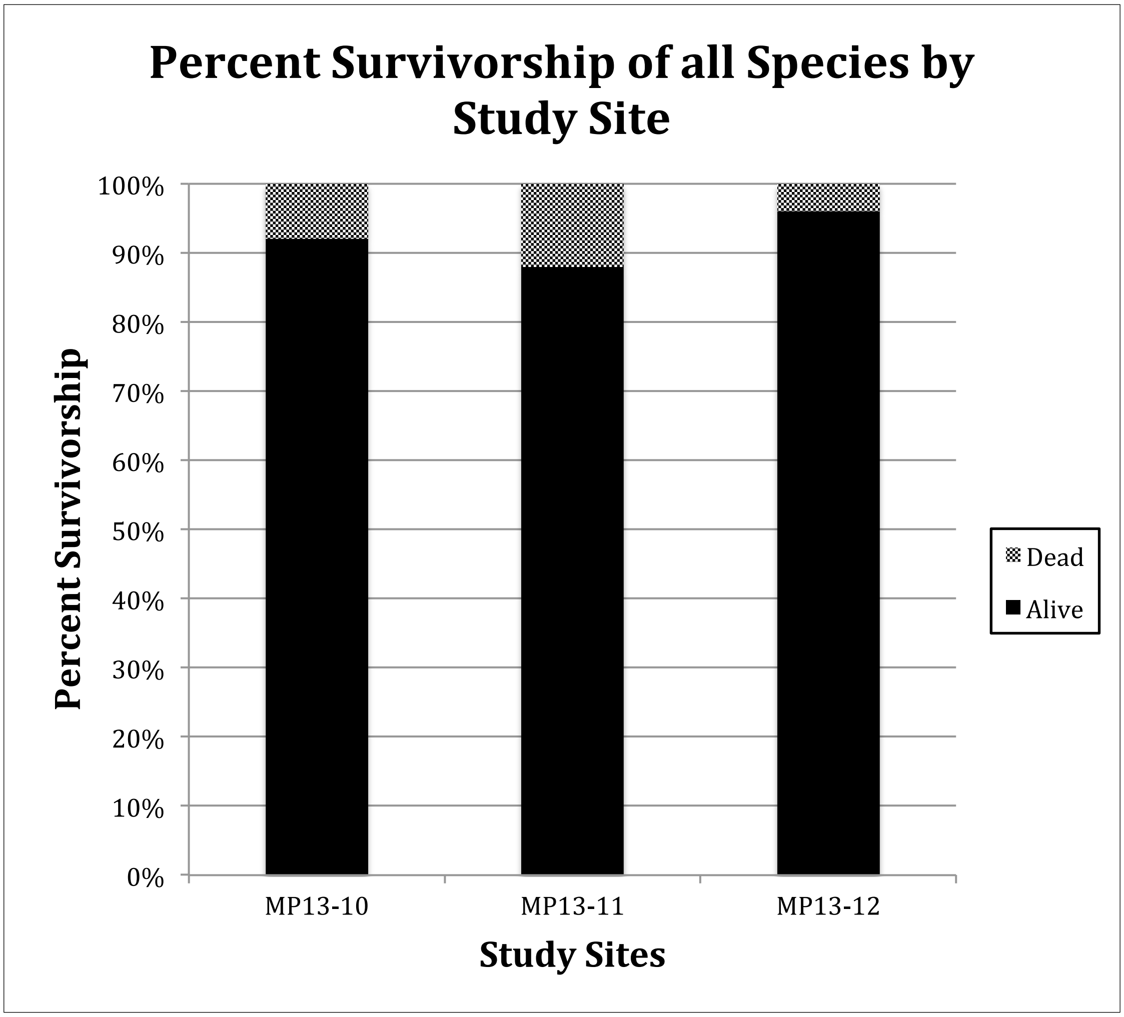

Figure 24. Overall percent survivorship by site.

While ONP projected that the high clay contents of site MP13-12 may pose challenging conditions for woody plants, the rates of survivorship at site MP13-12 were very high and overall plant survivorship was highest at site MP13-12. The plant vigor at these sites also remained high when compared to MP13-10 and MP13-11. The summer of 2013 was dry with zero precipitation in the month of July and above average temperatures. However, the site had been under water less than a year before this study and there was above average precipitation in the Elwha in late August through September. The high silt/clay content and its water retention capacity, coupled with the large amounts of fines and litter spread across the site likely contributed to the highest rates of survivorship at site MP13-12. Although the influence of other variables such as slope, aspect, shade and SOM remain unexamined.

Gravel is not usually looked at closely when examining soil substrate but seemed important to include for my analysis, as there were large amounts of gravel at sites MP13-10 and MP13-11. Whisman (2013) found much higher sand content at the plots/site that were considered to be “coarse” than I did at my plot/sites that were considered to be “coarse” (MP13-10 and MP13-11). The silt/clay content was also much lower in the “coarse” sites than Whisman’s range of 3% to 37% (Whisman 2013). Whisman used the hydrometer method, which could have contributed to greater accuracy in her soil analysis, particularly for the evaluation of the silt/clay content of the site soils. My study continues to support Whisman’s findings that the high silt/clay sites actually have higher rates of survivorship than the sites with higher sand/gravel content. Due to my sampling methods, cobble content might not have been properly characterized for sites MP13-10 and MP13-11. While there were not large amounts of cobble, cobble was present at these sites and the proportion was not captured accurately due to sampling methodology.

Figure 25. Marisa Whisman taking tensiometer measurements in the sediments of the former Lake Mills.

Soil Moisture Content

GWC is a measurement of direct moisture in the soil. Soil samples for GWC were collected in June, July, August and September 2013. It was a wet spring, and across plots and sites, GWC averages were generally highest in June 2013 (Figure 14). GWC remained high in July despite little rainfall but dipped across sites and plots in August, reflecting the zero precipitation of July. GWC rises in September with the rainfall of August and most likely continued to rise through September in response to the late storms that occurred later that month.

GWC data is not the amount of water that is available to plants. Instead, GWC is a direct measurement of the amount of water that is present in the soil during the time period of sample collection. GWC is generally used for calibrating other soil moisture measuring methods (Brady and Weil 2010). The way that the water in the soil interacts with soil texture and organic matter content dictates the amount of water that is available to plants. Soil water potential and soil water content are integral to determining the water that is actually available in the soil for plants (Brady and Weil 2010). Tensiometer readings in the field are one method of collecting soil water potential. Tensiometer measurement data was collected in some of my plots and in adjacent sites by the ONP during my study period. Marisa Whisman also took tensiometer readings in the prior year for her thesis (Figure 25).

Data for 2012 indicated that water availability to plants decreased over the summer months (Whisman 2013). Whisman (2013) found that the decrease in both water availability and GWC had the greatest change over time during her sampling period in the fine sediments. Whisman also found that GWC was repeatedly lower in the coarse sediments (Whisman 2013). My data followed this pattern of the coarse sediments (sites MP13-10 and MP13-11) having the lowest GWC across sites.

Large-woody debris

The park managers were very interested in the relationship between LWD and survivorship. In a study by Acker et. al. (2008), which established a reference site for the Elwha River Watershed prior to dam removal, researchers examined a site that was inundated by flooding after a landslide dam broke. Overall their study found heterogeneity in forest structure and composition due to presence of LWD and substrate composition (Acker et. al. 2008). The presence of artificially placed LWD at site MP13-10, the relative lack of LWD at site MP13-11 and the large amounts of woody-debris in all sizes at site MP13-12 made LWD worth examining for its effects on the survivorship of the five woody-plants that I examined for this study.

Overall it was found that the presence of LWD within 1 m or less of a plant did increase plant survivorship across the three sites. When presence or absence of LWD was evaluated, interesting trends emerged. At site MP13-12, despite the large amounts of woody-debris (litter, fine and coarse), the relationship between survivorship and presence of LWD within 1 m or less was not significant. Despite the high survivorship at site MP13-12 overall, high proportions of survivorship could not be contributed to one variable. In fact, there were probably many factors that contributed to high survivorship including aspect, slope, GWC, soil substrate and proximity to forest edge that need examination beyond the scope of this study. The presence of LWD at MP13-10, while not highly significant, was associated with higher survivorship. At site MP13-11, there was no significant association between presence of LWD and survivorship. At site MP13-11 there was very little LWD, unlike site MP13-10. Overall plant survivorship was lowest at site MP13-11 where gravel content was highest and LWD was not a dominant biological legacy.

Areas for further research

There were several shortcomings to this study, time being one of the main ones. This study would benefit by evolving into a multi-year study. Planting density may also begin to impact future survival of many of the species. Species like *P. menzeisii*, perform better as seedlings on severe sites when some shade is available (Uchytil 1991). In later years, the relationships between planting density, plant condition and survivorship would be interesting to explore and likely provide valuable information to park managers.

In addition, the un-vegetated state of the reservoir sediments exposes plants to the high winds common within the confines of the valley. LWD provides shelter from high wind, improving plant survivorship. Designing a study to determine if the position of LWD relative to prevailing winds influences survivorship may be valuable.

Figure 26. Site conditions and naturally occurring woody-debris at site MP13-12.

My study did not look at substrate organic matter. For my study purposes, organic matter was separated and classified into the fractions of soil substrate for soil texture analysis. Organic matter was most abundant at site MP13-12, and its influence on plant survivorship is likely greatest at site MP13-12, where naturally occurring woody-debris in the form of fines and litter is found in large quantities at the surface. Some plots had so much woody-debris litter that the site looked as if it was mulched (Figure 26). It may be that the large amounts of woody-debris fines and litter in the soil substrate and on the surface at site MP13-12 contributed to plant survivorship. However, ONP management has noted high densities of natural regeneration on all fine sediment sites across the reservoir, including those without any woody debris present. I could not evaluate the influence of all sizes of woody-debris for my study or its effect on plant survivorship. The presence of all sizes of woody-debris and their contributions of nutrients and added soil moisture would definitely be interesting to examine in future research.

SUMMARY AND CONCLUSIONS

In conclusion, survivorship was higher than expected and plant survivorship proportions were higher than results from a similar study performed in the former Lake Mills (Whisman 2013). Survivorship was high across all sites. Survivorship was highest at site MP13-12 and lowest at site MP13-11. Study results showed that site affected survivorship. Which variables contributed to differing levels of survivorship on the site level is still unanswered. Sites MP13-10 and MP13-11 were most closely related in soil particle distribution and site MP13-12 differed greatly from the other two in location, substrate composition and GWC. GWC significantly affected survivorship when site MP13-10 was compared with site MP13-12 and likewise, when site MP13-11 was compared with site MP13-12.

In general, *S. scouleriana* did not perform as well as the other four woody species. *P. menzeisii* had higher rates of survival in 2013 than in 2012 (Whisman 2013). *P. monticola* had the highest percent survivorship of the five woody species examined. LWD did influence plant survivorship overall but the results were less clear on the site level, with the influence of LWD at site MP13-12 not significantly linked to survivorship.

Research on vegetation response post dam removal is an emerging science. Dam removal is becoming increasingly common as dams become structurally unsound or reach their life capacity. Current research on vegetation response to dam removal is sparse but projects like the Elwha Ecosystem Restoration Project are providing new opportunities. Currently, there are relevant studies that examine vegetation response after dam failure or after large disturbances like volcanic eruptions but few exist on vegetation response post dam removal.

This study is part of a larger monitoring project by the ONP. It serves to provide preliminary data for future plantings in the newly exposed substrates. The thesis of Marisa Whisman informed this thesis and shaped the direction of this study. It is hoped that this study will also be a building block and starting point for many more years of research dedicated to vegetation response and plant performance in the former reservoirs on the Elwha River.

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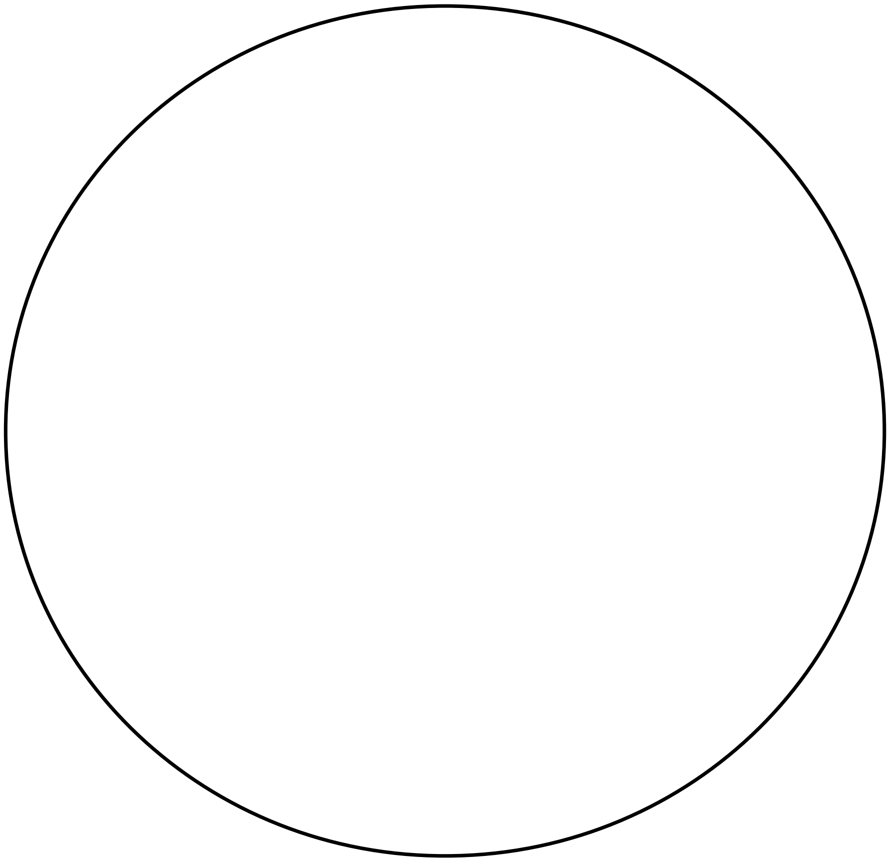
APPENDIX

Summary statistics for plant growth measurements in June and September 2013											
June 2013						**September 2013**					
Site 10						**Site 10**					
	A. grandis	***A. macrophyllum***	***P. monticola***	***P. menzeisii***	***S. scouleriana***		***A. grandis***	***A. macrophyllum***	***P. monticola***	***P. menzeisii***	***S. scouleriana***
Mean height (cm)	23.94	13.33	20.90	47.22	42.94	Mean height (cm)	31.04	13.28	21.10	50.16	43.62
Mean width (cm)	4.07	2.81	5.24	5.81	4.97	Mean width (cm)	4.53	2.91	5.10	5.91	5.98
Median height (cm)	24.52	13.05	20.57	48.75	42.83	Median height (cm)	31.32	13.28	21.12	55.38	42.33
Minimum height (cm)	15.54	9.23	15.10	27.27	35.27	Minimum height (cm)	25.70	7.30	16.00	29.63	26.33
Maximum height (cm)	29.30	19.37	25.00	58.67	51.20	Maximum height (cm)	36.20	19.73	24.93	65.07	61.60
Q1 height (cm)	22.00	10.73	19.62	34.93	36.81	Q1 height (cm)	27.42	11.24	20.23	40.58	34.96
Q3 height (cm)	27.58	14.75	23.52	52.42	48.75	Q3 height (cm)	33.59	18.56	24.01	58.47	46.23
Standard Deviation	4.63	3.37	3.29	11.49	6.42	Standard Deviation	4.00	3.87	2.82	12.75	12.17
Site 11						**Site 11**					
	A. grandis	***A. macrophyllum***	***P. monticola***	***P. menzeisii***	***S. scouleriana***		***A. grandis***	***A. macrophyllum***	***P. monticola***	***P. menzeisii***	***S. scouleriana***
Mean height (cm)	25.53	14.08	21.45	33.24	32.00	Mean height (cm)	28.93	14.37	21.15	38.27	33.51
Mean width (cm)	4.03	2.75	4.83	4.34	3.94	Mean width (cm)	4.30	2.88	4.73	3.89	4.66
Median height (cm)	27.42	13.20	22.13	32.58	32.97	Median height (cm)	29.31	15.33	21.60	38.17	33.78
Minimum height (cm)	20.63	11.47	17.70	24.27	23.43	Minimum height (cm)	25.67	8.40	17.40	28.93	25.70
Maximum height (cm)	27.60	18.23	24.27	41.77	38.03	Maximum height (cm)	31.20	19.13	24.67	48.07	48.50
Q1 height (cm)	23.75	12.04	20.67	27.87	30.93	Q1 height (cm)	27.51	12.14	19.12	30.67	27.53
Q3 height (cm)	27.53	15.83	22.47	39.63	34.00	Q3 height (cm)	30.69	16.53	22.90	45.64	38.99
Standard Deviation	2.84	2.49	2.20	6.69	4.46	Standard Deviation	2.01	3.56	2.54	7.92	8.03
Site 12						**Site 12**					
	A. grandis	***A. macrophyllum***	***P. monticola***	***P. menzeisii***	***S. scouleriana***		***A. grandis***	***A. macrophyllum***	***P. monticola***	***P. menzeisii***	***S. scouleriana***
Mean height (cm)	25.37	9.67	21.49	35.91	21.60	Mean height (cm)	28.28	10.07	23.10	44.00	29.66
Mean width (cm)	4.29	3.15	6.01	5.46	3.86	Mean width (cm)	4.72	3.66	6.66	6.20	5.04
Median height (cm)	26.32	9.68	20.68	35.91	22.05	Median height (cm)	28.25	10.12	22.79	43.80	24.68
Minimum height (cm)	17.80	5.90	18.73	33.27	14.30	Minimum height (cm)	23.17	7.47	19.27	40.67	12.00
Maximum height (cm)	28.93	15.00	26.00	41.03	28.77	Maximum height (cm)	32.57	13.00	27.33	48.75	72.10
Q1 height (cm)	24.95	6.86	18.99	33.97	19.97	Q1 height (cm)	27.05	7.90	19.98	41.37	19.20
Q3 height (cm)	27.83	14.19	24.93	36.30	24.37	Q3 height (cm)	30.18	11.96	26.23	45.78	26.52
Standard Deviation	3.68	3.17	2.75	2.76	4.67	Standard Deviation	2.97	2.19	3.32	2.88	19.65

Appendix 1. Table of growth measurements for all five species for the months of June and September 2013.



Site : **Date:**

PINMON/PSEMEN/SALSCO
ACEMAC/ABIGRA

Notes:

Appendix 2. Map Template

Name:		Date:	Site:	Start time:	End time:	PINMON, PSEMEN, SALSCO, ACEMAC, ABIGRA		___ of ____
Plot #	Tag #	Species	D/L	Plant Condition 0-4	leaf color	Height	Width	Notes: (new growth/herbivory?)
10a	**1516**	**PSEMEN**		0 1 2 3 4	R Y B			
	1517	PSEMEN		0 1 2 3 4	R Y B			
	1518	PSEMEN		0 1 2 3 4	R Y B			
	1519	PSEMEN		0 1 2 3 4	R Y B			
	1520	**PSEMEN**		0 1 2 3 4	R Y B			
	1521	**PSEMEN**		0 1 2 3 4	R Y B			
	1522	PSEMEN		0 1 2 3 4	R Y B			
	1523	PSEMEN		0 1 2 3 4	R Y B			
	1524	PSEMEN		0 1 2 3 4	R Y B			
	1525	SALSCO		0 1 2 3 4	R Y B			
	1526	**SALSCO**		0 1 2 3 4	R Y B			
	1527	**SALSCO**		0 1 2 3 4	R Y B			
	1528	**SALSCO**		0 1 2 3 4	R Y B			
	1501	ACEMAC		0 1 2 3 4	R Y B			
	1502	**ACEMAC**		0 1 2 3 4	R Y B			
	1503	**ACEMAC**		0 1 2 3 4	R Y B			
	1504	**ACEMAC**		0 1 2 3 4	R Y B			
	1505	ACEMAC		0 1 2 3 4	R Y B			

0=dead; no sign of life.;1=poor, plant color poor, withering leaves, mostly brown/yellow/reddish leaves; 2=stressed; signs of leaf discoloration (some yellow or brown leaves); 3=good; plant may show slight signs of stress or herbivory but also has green leaves; 4=thrive; healthy, new, green leaves, signs of vigorous growth).

H/L= high/low density planting

D/L = dead/alive

woody debris size: <1cm diameter=litter; 1-10cm diam.=fine; >10cm diam.=coarse

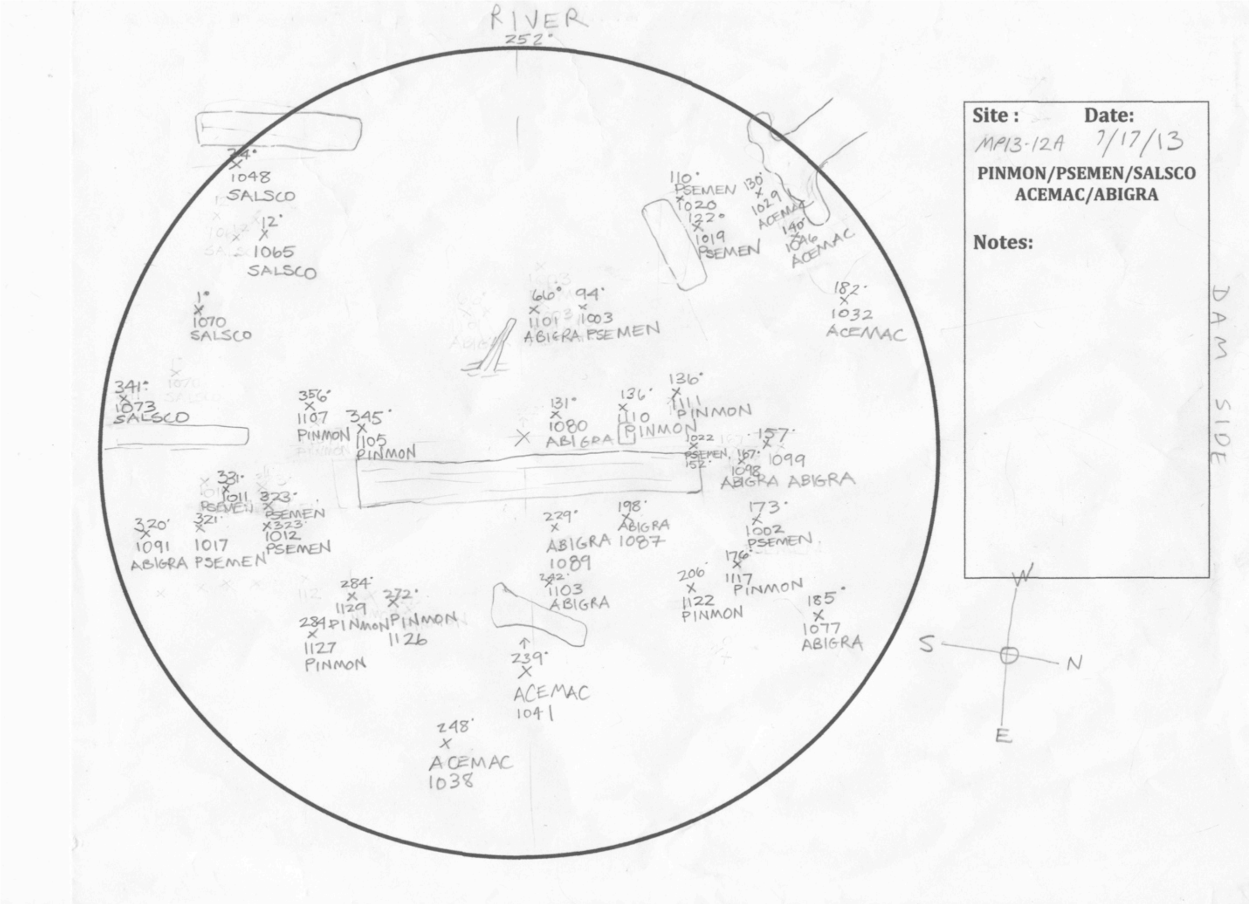
Appendix 3. Data sheet 1.

Name:			Date:	Site:		Start time: End time:			PINMON, PSEMEN, SALSCO, ACEMAC,		___ of ____	
Plot #	Tag #	Species	0/1	Plant Condition 0-4	leaf color	Height	Width	w/in .5m of WD	w/in 1m of WD	woody debris size	aspect of WD	herbivory (M/I)
10a	**1516**	**PSEMEN**		**0 1 2 3 4**	**R Y B**					**C F L**	**N E S W**	**M I**
	1517	PSEMEN		0 1 2 3 4	R Y B					C F L	N E S W	M I
	1518	PSEMEN		0 1 2 3 4	R Y B					C F L	N E S W	M I
	1519	PSEMEN		0 1 2 3 4	R Y B					C F L	N E S W	M I
	1520	**PSEMEN**		**0 1 2 3 4**	**R Y B**					**C F L**	**N E S W**	**M I**
	1521	**PSEMEN**		**0 1 2 3 4**	**R Y B**					**C F L**	**N E S W**	**M I**
	1522	PSEMEN		0 1 2 3 4	R Y B					C F L	N E S W	M I
	1523	PSEMEN		0 1 2 3 4	R Y B					C F L	N E S W	M I
	1524	PSEMEN	0	0 1 2 3 4	R Y B					C F L	N E S W	M I
	1525	SALSCO		0 1 2 3 4	R Y B					C F L	N E S W	M I
	1526	**SALSCO**		**0 1 2 3 4**	**R Y B**					**C F L**	**N E S W**	**M I**
	1527	**SALSCO**		**0 1 2 3 4**	**R Y B**					**C F L**	**N E S W**	**M I**
	1528	**SALSCO**		**0 1 2 3 4**	**R Y B**					**C F L**	**N E S W**	**M I**
	1501	ACEMAC		0 1 2 3 4	R Y B					C F L	N E S W	M I
	1502	**ACEMAC**		**0 1 2 3 4**	**R Y B**					**C F L**	**N E S W**	**M I**
	1503	**ACEMAC**		**0 1 2 3 4**	**R Y B**					**C F L**	**N E S W**	**M I**
	1504	**ACEMAC**	0	**0 1 2 3 4**	**R Y B**					**C F L**	**N E S W**	**M I**
	1505	ACEMAC		0 1 2 3 4	R Y B					C F L	N E S W	M I

0=dead; no sign of life.;1=poor, plant color poor, withering leaves, mostly brown/yellow/reddish leaves; 2=stressed; signs of leaf discoloration (some yellow or brown leaves); 3=good; plant may show slight signs of stress or herbivory but also has green leaves; 4=thrive; healthy, new, green leaves, signs of vigorous growth). mammal=M; insect=I

woody debris size: coarse = ≥10cm diam and 1.5m length; fine = <10cm diam.; litter = ≤1cm diam.

Appendix 4. Data sheet 2.


Site : MP13-12A **Date:** 7/17/13

PINMON/PSEMEN/SALSCO
ACEMAC/ABIGRA

Notes:

Appendix 5. Hand-drawn map of tagged plants for MP13-12a.