HISTORICAL DISTURBANCE AND RECENT MANAGEMENT FACTORS DRIVING *QUERCUS GARRYANA* VEGETATION COMMUNITIES IN THE PUGET SOUND LOWLANDS

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Abstract

HISTORICAL DISTURBANCE AND RECENT MANAGEMENT FACTORS DRIVING *QUERCUS GARRYANA* VEGETATION COMMUNITIES IN THE PUGET SOUND LOWLANDS

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Garry oak (*Quercus garryana*) ecosystems used to cover 111,000 hectares in the Puget Sound, yet currently occupy approximately 3% of this former land area. Today, most Garry oak systems are fragmented and remain outside of protected conservation areas, making them particularly prone to additional land development pressures. However, Garry oaks are a key cultural ecosystem and preferred habitat for multiple endangered and threatened species. Remaining oak ecosystems have gone through a variety of disturbances, making it difficult to determine what types of current management and restoration are effective. This research looks at the history (1853 – 1943) of disturbance and land use for three Garry oak ecosystems, examining how these patterns of human activity have impacted the current ecosystem structure and vegetation. Results show that density of oak trees on these ecosystems is tied to a number of different environmental variables. Past history of both the frequency and intensity of grazing and logging appear to be large driving factors, yet additional research will be required to confirm how much of an affect both of these activities had on the overall ecosystem dynamics of each site. Additional partnerships with a variety of researchers, local Native American tribes and individuals are recommended for future projects at these oak sites, as well as oak ecosystems throughout the Puget Sound region.

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DEDICATION

To Rita – you were the smallest sapling of your family, but you were always a mighty, wise oak to me. Thank you for your unwavering love and support. I love and miss you.

And to Miles – nature was always your church. I hope your spirit is dancing among the tree limbs now.

1. INTRODUCTION

1.1 Introduction to Garry oak

Although *Quercus garryana* (subsequently “oak” and “Garry oak”) ecosystems occupy a small area within their range - which stretches from southern British Columbia to Northern California (Figure 1.1) - a region known as the Willamette Valley-Puget Trough-Georgia Basin Ecoregion (ILAP 2004). Garry oak ecosystems are home to thousands of native plants, animals, and insects of the region, making them a hotbed for regional diversity (GOERT 2007). Oak systems are also a defining cultural landscape for the region - Native Americans harvested a number of foods and medicines from Garry oak, and many oak systems were deliberately burned, weeded, tilled and planted for millennia (Turner 1999).

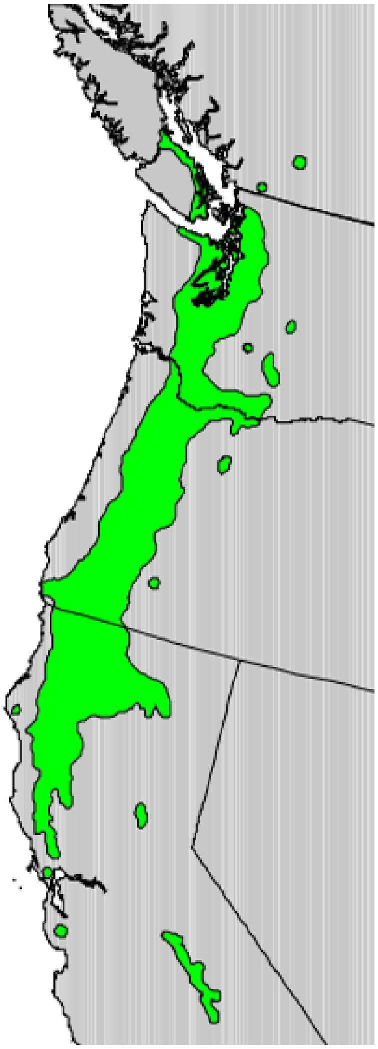

Figure 1.1: Historic extent/native range of Garry oak. Little, 1971.

However, oak ecosystems are in danger of disappearing. Many oak communities are rapidly declining in number and health due to encroachment from species like Douglas-fir (*Pseudotsuga menziesii*) and Scotch broom (*Cytisus scoparius*). Human activities and developments have left many oak systems fragmented (Crawford and Hall 1997), with multiple (and often private) landowners each owning small portions of habitat, making connected, overarching oak management goals difficult to implement. Oak ecosystems are currently designated as a Priority Habitat for management in Washington (Larsen and Morgan 1998). British Columbia lists Garry oak, as well as 100 of its associated plant, insects, and animal species, as "at risk" under the Species at Risk Act (Pellatt *et al.* 2012, GOERT 2007). For example, none of the Garry oak communities in southeastern Oregon/eastern California, are under permanent protection, and most of the fragmented remains of the oak populations are privately owned (Stoms *et al.* 1998). *Quercus garryana* is the only oak species native to Washington State.

Additionally, oak systems have not historically been categorized as an ecosystem independent of prairies, and so aspects of these systems remain somewhat ill-defined. Despite having many unique processes and often very different historic land activities and underlying uses, oak sites are frequently given the same management prescription as neighboring prairie environments. Sometimes, oak ecosystems are left out of the management plan entirely. Due to this historic tendency to clump Garry oak environs with Western Washington prairie communities, facets of the oak's growth and survival rates are not well-known (Gould, Harrington, and Devine 2011). Although there are a number of listed species with documented use and need for oak habitat, these knowledge gaps present the possibility that the number of species that rely on oak systems is much greater than currently estimated (Dunwiddie 2005). Almost all oak systems in the Pacific Northwest have undergone different forms of disturbance, invasive species encroachment, or fire management, so defining a reference ecosystem or community for each oak site is routinely difficult (MacDougall *et al.* 2004) or must come from a variety of sources (GOERT 2011).

In order to effectively manage the remaining oak ecosystems of Western Washington, it is important to understand how different human activities have affected, and currently affect, oak system species diversity. My research attempts to both better define and examine human activities on South Puget Sound-area oak systems in recent history (past 170 years, or the approximate time of the Washington state Native American treaties), and investigate what primary forces have changed vegetative density and diversity.

Structure has increasingly been used as a method of defining and measuring biodiversity in an effort to develop more sustainable ecosystems (McElhinny 2002). However, while indications of species present and absent are helpful in determining some aspects of an ecosystem, this ignores many ecological processes. Franklin *et al.* (1981) suggest describing ecosystems by their composition, structure, and function to better understand the spatial arrangements, the ecological processes at hand, and the variety of components present. This project follows that methodological model by recording several features of the forest structure and composition, then analyzing the associated data to better understand what the critical underlying functions of Garry oak woodlands and savannas are.

1.2 History of Human Activity on Garry oak Systems in Puget Sound

Oak ecosystems were much more widespread in the early Holocene - fossil pollen deposits in lake sediments show oak populations between 8,000 and 6,000 years BP (Heusser 1983) occupied an estimated 111,000 hectares in the Puget Sound Lowlands (Chappell 2005). In 2005, this same area had approximately 8,000 hectares of oak ecosystems - a figure that includes those oak communities under private ownership. Of these hectares, approximately 2,000 are predominantly Garry oak, and less than 3,600 are co-dominated by Garry oak and Douglas-fir (Chappell 2005).

Changes in regional climate conditions are a major reason for oak decline. Garry oak prefers drier, hotter conditions that were common in the early Holocene, and as conditions became milder and cooler, oaks were less predisposed to their native environment. Models produced by Pellat and Gedalof (2014) that removed prescribed burning in oak ecosystems estimated that Garry oak would have become extinct in the Pacific Northwest due to lack of suitable habitat and climate conditions around 3,800 years ago.

Garry oak ecosystems we see today are partially a result of regular, intentional burns set by Native Americans (Taylor and Boss 1975; Pellatt *et al.* 2001; Brown and Hebda 2002). Native Americans of the region used fire to support a wide range of purposes and processes in several ecosystems. Although mature oaks have thin bark relative to species like Douglas-fir, Garry oak is able to withstand some cambial kill in low severity fires (Agee 1993), with seedlings at least 3 meters tall able to resist top-kill in these low-severity fire environments (Tveten and Fonda 1999). Stand density of oak sites is often determined by the severity and frequency of a burn. Regan (2001) and Agee (2004) documented fire effects over a six-year period, noting that approximately three fires per decade produce oak savanna ecosystems, while less than two fires per decade produce the mixed oak/Douglas-fir woodlands or mixed mature oak/sapling thickets. Many oak environments today, as a result of fire exclusion and/or suppression, have much thicker understory. This understory is a mix of traditional native species as well as invasive species like Scotch broom, which can cause fires to burn at a much higher severity due to the increased fuel loads. Mature oak mortality, although rare, does occur after severe burns (Thysell and Carey 2001). However, these higher severity fires provide good regeneration sites for oak seedlings (Agee 1993) with biomass highest in microsites with higher concentrations of ash (Regan 2001).

Despite issues of fire suppression, Garry oak ecosystems remain important cultural landscapes. Many significant Native American foods derived from plants grow in cultivated Garry oak ecosystems, such as camas root, Western bracken fern and oak acorns (Norton 1985, Pojar and MacKinnon 1994; see Appendix B for plant scientific names). Each of these species have a noted advantage in burned environments, and often grow more robustly and reproduce more vigorously after a prescribed burn (Storm and Shebitz 2006, Regan and Agee 2004). Shallow burns in the oak understory leave plants such as camas (which are dormant in the summer) unharmed, yet help eliminate weeds and unwanted woody species such as Douglas-fir, whose saplings regularly encroach on oak systems (Turner and Peacock 2005).

In addition to burning for agricultural purposes, Native Americans also lit fires to facilitate capturing protein sources – clearings made it easier to see ungulates during hunting (Turner 1999), yet some communities also used fire to herd deer and other game species to smaller areas (Lewis 1973). Some Native American people would also go into areas immediately after a burn to collect grasshoppers, which they often dried and ground up to use in cooking (Boyd 1986). Studies of fire intervals for oak ecosystems found the average time between burns to be 11 to 34 years between 1700 and 1900 (Kertis 1986), although this result may be somewhat skewed due to limited data.

The importance of fire and intentional burning practices is reflected in the language of many Puget Sound area Native American people. Upper Chehalis people, whose current reservation is 86 miles south of Seattle, have more than 20 words that refer to a part or aspect of a fire-maintained environment, including “sʔaxálaqʷm” (prairie fire), “sləx” (place burned over for berries) and “q’wʔt’áytmš” (land on fire; Storm and Shebitz 2006).

Active management of Garry oak over several millennia allowed these systems to remain common in the Pacific Northwest even after climatic conditions became less suitable for sustaining these communities. Oak trees, along with their associated understory, were “an important managed crop” that supported a number of food, medicinal and other resources that could be traded or stored for personal use (Norton 1985). Today, oaks are a signature feature on a landscape that can inform current land managers, ethnobiologists and archaeologists about past human activities (Storm 2002).

However, several circumstances limited Native Americans’ management and activities in oak systems between the late-1700s and mid-1800s. Many nonnative settlers who came to the region wanted to homestead on lands that were flat and open, which were often oak systems and neighboring prairies (Rogers 2015). The town of Oak Harbor, for instance, was originally settled on an oak savanna (Neil 1989). Homesteads, European forms of agriculture, and grazing by animals like cows, chickens and other livestock prompted new types of disturbances that oak ecosystems had never experienced in millennia prior. Land surveys from the General Land Office and the Washington State Timber Cruise between 1850 and 1910 further encouraged this idea of using oak and prairie sites for European-derived forms of agriculture (Washington State Archives 1908). Higher numbers and variety of human activities in oak ecosystems made it increasingly difficult for Native Americans to practice traditional oak ecosystem management.

In addition to many settlers homesteading on oak ecosystems, new nonnative residents were frightened or confused by Native American use of fire (White 1975) for land management purposes: “At times they saw the Indians as incurably nomadic, wandering across the land in search of food. But this was hard to reconcile with the strong Salish attachment to their permanent villages and their reverence for the graves of their ancestors.”

Treaties established in the 1850s forced many Native Americans to live on reservations, which were often far away from many of their traditional hunting, living, and harvesting sites. The Treaty of Medicine Creek, signed on December 26, 1854, gave Native Americans residing in southwest Washington “the privilege of hunting, gathering roots and berries, and pasturing their horses on open and unclaimed lands” (Stevens 1854). As mentioned above, due to the fact that oak ecosystems were sought after for new settlers to homestead on, the amount of “open and unclaimed” oak woodlands and savannas quickly dwindled in the years following the treaty. This lack of access - along with a series of five epidemics between 1793 and 1853 that killed an estimated 50 to 75% of the Native American population in the Pacific Northwest (Agee 1993) - forced many people to stop these traditional oak activities. With limited access to the sites and much smaller numbers of people who could actively implement various harvesting, planting, and burning techniques, many of these human processes that had occurred for thousands of years all but ceased. How much this loss of human activity changed oak ecosystems is not fully understood.

Today, the most intact oak stands in Western Washington are found on Joint Base Lewis-McChord (JBLM), the army/air force base built atop lands that were previously part of the reservation lands reserved in the Treaty of Medicine Creek for the Nisqually people (Stevens 1854). Two-thirds of the original Nisqually Reservation lands were condemned in 1918 to build the military fort, including the vast majority of the important village sites for the Nisqually (Carpenter *et al.* 2008). An annual Honor Walk is held on JBLM every year, and gives Nisqually tribe members the opportunity to visit more than

30 different cultural and spiritual sites. These sites are largely relegated to the northern half of JBLM; however, traditional harvesting, fishing and hunting areas span a much wider distance, with many important cultural sites located as far as Mount Rainier (Hooper 2015) and beyond. It is highly likely that most oak sites on JBLM were intentionally burned for thousands of years by the Native American people (Storm 2002).

Despite knowledge (Taylor and Boss 1975, Pellatt *et al.* 2001, Brown and Hebda 2002) that current Garry oak systems exist largely due to processes revolving around “cultural keystone species” - a term coined by ethnobiologists A. Garibaldi and N. Turner (2004) - no in-depth work has explicitly examined oak restoration and management through a cultural lens for these ecosystems in the Puget Sound region. However, for most of this project, I did not have direct consultation by Native American individuals. Because of this, I have limited the amount of cultural assessment in this project, yet have included some resources (see Appendix A) that examine additional cultural considerations for oak ecosystem management in the future.

<u>The primary questions for this study are</u>:

1. How do current/recent management practices influence oak ecosystem structure and vegetative diversity?
2. How does site history influence oak ecosystem structure and vegetative diversity?

Data collected through land manager interviews, timber sale records, prescribed burning plans, geospatial data, and land management reports were used to answer question 1. Data collected from historic land and timber surveys, land records, census data, and other historic maps were used to answer question 2. Environmental data (vegetation, tree, soil, and canopy) were used to answer both question 1 and 2.

2. METHODS

2.1. Study Location: Rainier Training Area

This research began on an oak ecosystem on the Nisqually Reservation. However, due to political decisions in the winter of 2016, I moved my research study sites to JBLM (Figure 2.1). For more information on lessons learned and reflections on this previous research, please see Appendix A. JBLM is located in the Puget Sound Lowlands region of western Washington State. The Puget Sound region is bordered by the Olympic Mountains to the west, and the Cascade Range to the east.

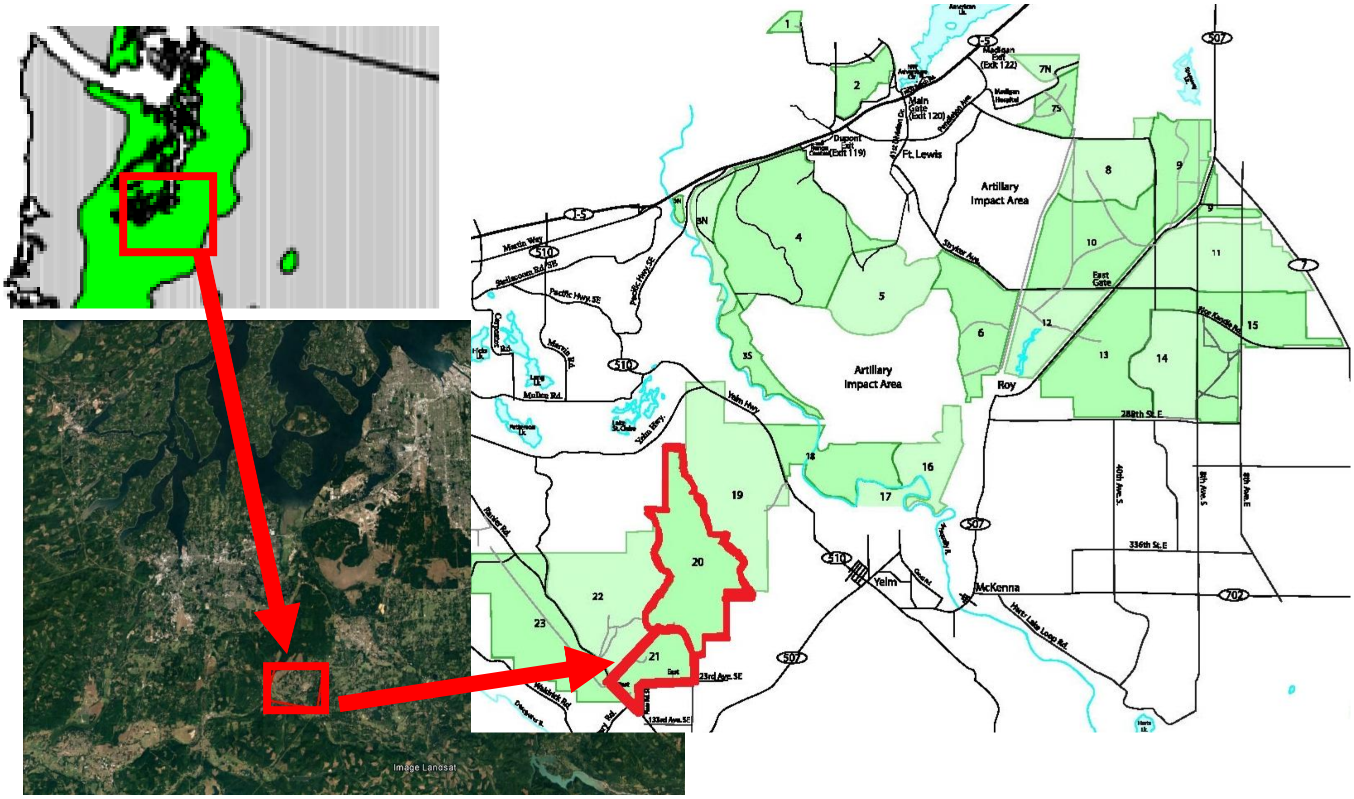

Figure 2.1: Maps showing study location. The upper-left figure outlines the Puget Sound region in Washington State, the lower-left outlines the location of Rainier Training Area, and the right-hand figure outlines RTA 20 and 21 – the locations of the three study sites. Little, 1971; National Geospatial Program, U.S. Geological Survey, 2015; JBLM Range Operations, 2001.

The Lowlands, as their name implies, are primarily composed of landscapes at elevations of 100-500 meters (Booth 1994) that were largely shaped by Pleistocene-era glaciation, in which the Cordilleran ice sheets - up to 1,035 meters thick - carved and compacted the landscape. The last major glaciation covered the area between southern British Columbia and Olympia about 16,400 years ago, and then rapidly retreated 15,000 years before present (Porter and Swanson 1998). The first signs of human inhabitants in the region appear at approximately the same time as the last glacial recession (Gugliotta 2013).

Climate in the region is characterized by mild temperatures year-round, with wet, mild winters and dry summers. Western Washington experiences about 75% of its precipitation between October and March (Franklin and Dyrness 1988). JBLM (Figure 2.1) is situated between the cities of Tacoma and Olympia, which receive approximately 101.6 and 127 centimeters of rain per year, respectively. Temperatures for the region range from 1.7 to 7.2 degrees Celsius in January and 10 to 26.7 degrees Celsius in August (NOAA-NCEI 2011).

Soils in the southern Puget Sound are classified in the Spanaway Series, which was formed by the remains of glacial outwash and volcanic ash, and are typically described as being “excessively drained” (Pringle 1990). Soils in this series are highly acidic, have high organic matter, and have fewer nutrients than most soil types (Giles 1970, Dorner 1999). Spanaway soils were categorized as “anthropogenic” soil by Ugolini and Schlicte (1973) due to the high charcoal content of soils in the area, which they attributed to Native American intentional burns.

Vegetation for oak ecosystems in the Puget Sound are dominated by long-stolon sedge, common snowberry, common camas, Alaska oniongrass (*Melica subulata*) and Western swordfern, with frequent invasive/exotic species being Scotch broom, Douglas-fir, common velvetgrass, colonial bentgrass, tall oat-grass (*Arrhenatherum elatius*), and ox-eye daisy (*Leucanthemum vulgare*) (ILAP 2004; see Appendix B for unlisted plant scientific names)

Both climate and soil conditions in the region strongly influence the vegetative (and therefore faunal) communities that can establish and thrive in this region. Plants here must be able to both survive dry summer conditions and grow during wet, cooler periods of the year (Dorner 1999), as well as succeed in nutrient-deficient environments. Conversely, the presence or absence of certain species in an oak ecosystem can alter the soil environment - a loss or addition of a species can change the soil decomposer communities, which can alter the flow of water and nutrients throughout the soil (Spehn *et al*. 2000). Loss of sentient inhabitants can also prompt soil changes - Mazama pocket gophers, for example, provide localized soil aeration and disturbance (The Nature Conservancy of Washington 2000), which can affect soil moisture and plant diversity.

Listed species associated with oak communities remain a high priority for site management. For example, if a listed species such as white-topped aster (*Sericocarpus rigidus*) were found in a mixed oak/conifer ecosystem, land managers may decide to manage and restore that ecosystem to an oak savanna/open woodland, a system in which white-topped aster is more likely to thrive (The Nature Conservancy of Washington 2000).

Current management objectives for oak ecosystems on JBLM are based around maintaining and restoring the native diversity in these ecosystems. The main objective for all oak ecosystems is to retain all remaining oak communities by preventing further encroachment by species like Douglas-fir and Scotch broom. Invasive and exotic species cover is managed through a mix of prescribed burns, mowing, weeding, and herbicide treatments, as well as timber harvests. Oak sites that act as ecotones between different land types (Douglas-fir forest to prairie, for example) are currently a priority due to their need for heavier thinning and more regular active management (Fort Lewis 2005). Secondary management objectives surround restoring currently degraded oak ecosystems. This includes removing invasive cover, seeding and planting native species, and providing oak release for trees that have been suppressed by overtopping conifers (Fort Lewis 2005).

2.2 Study Sites

Due to site connectivity and likelihood of previous burn history, I choose to conduct this research at the Rainier Training Area. Rainier Training Area (RTA), is a 6,944-hectare space that has been owned by Joint Base Lewis-McChord since 1943, when the base first purchased it from the Weyerhaeuser Company, smaller private timber owners, and several homesteaders, farmers, and ranchers (Fort Lewis 2005, Washington State Archives 1908). JBLM has been actively managing the space since 1987. Rainier Training Area is located southeast of the JBLM's central base (see Figure 2.1), and approximately five kilometers northwest of the town of Rainier, WA.

All three study sites for this research are located in RTA 20 and 21, off of Rainier Road SE and Military Road SE (between 46°54'32.673" N, -122°43'57.107" W and 46°56'5.953"N, -122°39'21.815"W, Figure 2.1). Access to both areas is limited to military personnel, with additional access occasionally granted for research purposes and some recreation activities, including horseback riding, dog training, photography, and some hiking (JBLM Range Operations 2001). Military personnel currently use RTA 20 and 21 for staging purposes, as a landing/drop zone for personnel in the airborne school, and for drill practices, among other uses (pers. obs.). Logging is permitted in this area, and multiple timber sales have occurred on RTA 20 and 21 in the past 20 years. RTA 20 and 21 are characterized by prairie and oak ecosystems, with sections of both training areas currently under intensive management prescriptions. Both areas are primarily managed by JBLM's Fish and Wildlife (JBLM FW) and Forestry departments, with secondary management coming from local land stewardship agencies like the Center for Natural Lands Management (CNLM). Prescriptions are largely limited to supporting habitat requirements for US Fish and Wildlife Service's listed species that are both known and thought to use these ecosystems, as well as the budget and labor force available implement the prescriptions (Zuchowski *et al.* 2016).

I selected my three oak study sites in RTA 20 and 21 based on differences in their presumed levels of recent (within the past 20 years) human activities, presence of listed species, as well as oak ecosystem type (Table 2.1). Since RTA 20 and 21 are on the southern half of JBLM, there are not any spots here that are documented as important cultural/spiritual sites that I could find from my sources. Additionally, RTA was added to the base in 1943, and was not part of the original Nisqually Reservation land condemned in 1918 to develop JBLM. Additional preliminary considerations for each site were based on information collected during informal interviews with JBLM FW management staff in spring 2016, introductory field visits, and a brief examination of historic survey and aerial photo records (Figure 2.2). Restoration activities for oak ecosystems on RTA 20 and 21 include prescribed burning, logging activity (including oak release and thinning), native herb and grass planting, and mowing.

Table 2.1: Primary differences between three study sites. I used the criteria below to assess differences at the beginning of the project. Historic land type vs. current implied different changes in disturbance pathways, while bordering ecotypes effect the types of species that may encroach into each site. Burning and logging are often intensive disturbances. Site shape can change the edge effects, and therefore the community structures, of a site.

	Swift Tower	**Weir Slope**	**Upper Weir**
Historic Categorization	Forest	Prairie	Prairie
Current Type	Mixed oak woodland	Mixed oak woodland	oak woodland/savanna
Bordering Ecotypes	Prairie and Douglas-fir forest	Prairie	Prairie and Douglas-fir forest
Slope	Flat, little to no slope	Steep slope	Flat, little to no slope
Recent (20 yrs) Burning Activity	None	Frequent	Frequent
Recent (20 yrs) Logging Activity	Little	Moderate	Little
Site shape	Round	Narrow, oblong	Round

Between 1943 and 1987, all three oak sites were exclusively used for military training purposes. All sites have visible signs of human disturbance, including old fox holes. Upper Weir's far-east end has very visible trenches dug (illegally) during the 1990s. No official records of these disturbances between 1943 and 1987 were taken/currently available. Areas in RTA 20 and 21 came to the attention of JBLM FW and Forestry staff after white-topped aster (*Sericocarpus rigidus*), a plant native to the prairie and oak ecosystems, was found here – *S. rigidus* was formerly listed in Washington state as threatened (USFWS 1975). Threats of invading Douglas-fir and Scotch broom prompted staff to create management, monitoring, and restoration plans for areas of concern in RTA 20 and 21. Digging became illegal in RTA 20 and 21 after 1987 (Zuchowski *et al*. 2016).

While prairie vegetation was the focus of early management, oak understory vegetation became a management priority for JBLM FW and Forestry in the early 2000s. The Western gray squirrel (*Sciurs griseus*) was listed as Washington's endangered species in 1993(WAFWS 1993), and JBLM staff began a program to translocate the remaining population of squirrels to the base for added protection between 2007 and 2012 (Wiles 2016). Western gray squirrel nests and resides in oak/Douglas-fir ecosystems

(Figure 2.6). During the translocation process, JBLM FW noticed that gray squirrel predators could hide in the tall native (such as snowberry) and nonnative (such as Scotch broom) brush on many sites, and so staff began focusing efforts around developing shrub and vegetative diversity at oak/fir sites to provide more visibility to the squirrels.

Figure 2.2: Study site locations. Swift Tower is highlighted blue, Upper Weir is yellow, and Weir Slope is highlighted red. Black areas are prescribed burns conducted shortly before these aerial photos were taken. ESRI, 2015.

Upper Weir (UpWe) is 4.32 hectares in area (Figure 2.3). Although JBLM's prescribed burn program on RTA 20 and 21 dates back to 1987, early burning was relegated to prairies. UpWe has consistently been burned since February 1993, with prescribed burns occurring in 1994, August 2002, 2009, 2014, and late summer 2016. All burns were conducted by JBLM Fish and Wildlife (FW) and CNLM staff (Zuchowski *et al.* 2016).

Burning is conducted as part of the management prescription to help minimize invasive species presence and cover, help propagate native understory species - many of which are fire-adapted - and to add inputs of charcoal (carbon) into the soil. The site was burned in late July 2016, after I collected understory vegetation and tree density data. Weir Prairie borders the site to the east and south, Weir Slope borders it to the West, and dense Douglas-fir borders it to the north. Upper Weir is categorized as a Garry oak/long-stolen sedge-camas community (ILAP 2004).

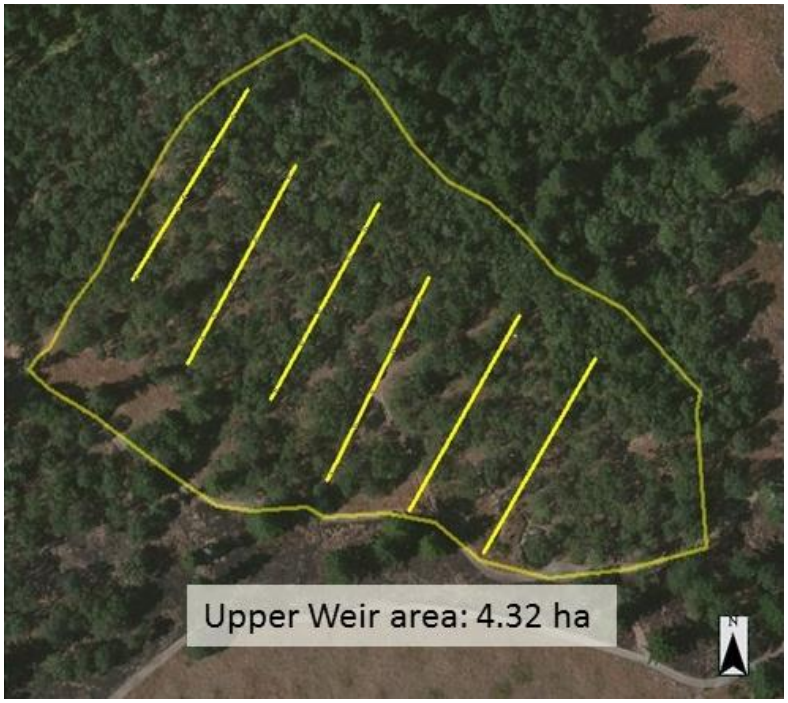

Figure 2.3: Close-up of Upper Weir. The yellow polygon delineates Upper Weir's extent, while the six interior lines delineate experimental transect locations. ESRI, 2015.

Weir Slope (WeSl) is the largest of the three sites at 6.17 hectares (Figure 2.4). WeSl is long and narrow, and a primary objective of ongoing restoration work that began in 2006 is to make Weir Slope a more effective oak ecotone between Upper and Lower Weir prairies. WeSl, similar to UpWe, has undergone intentional burning on a regular basis. Weir Slope's first prescribed burn occurred in 1993. Weir Slope was burned again in 2001, 2010 and 2014 (Zuchowski *et al.* 2016). Approximately 221.26 cubic meters of Douglas-fir were removed from Weir Slope in 2006, and live Scotch broom were mowed in winter 2010 and spring 2014 by collaborating CNLM staff (Johnson 2016).

Figure 2.4: Close-up of Weir Slope. The red polygon delineates Weir Slope's boundaries, while the six interior lines delineate experimental transect locations. ESRI, 2015.

Some Douglas-fir were left on-site after 2006 with the expectation that they would to help protect the oak from weather damage. Most of the oaks are suppressed by Douglas-fir, yet were also shielded from severe weather by the Douglas-fir. The current management prescribes cutting down Douglas-fir trees over several seasons to allow the oak to acclimate and strengthen on-site. Research from Devine and Harrington (2004, 2006) showed that both partial and full oak release treatments had no statistical difference, and both treatments (compared to the control) increased overall acorn production and tree regeneration. There are currently a number of Douglas-fir on Weir Slope slated to be girdled for 2017. Weir Slope is categorized as a Garry oak/Roemer's fescue community type (ILAP 2004).

Swift Tower

Swift Tower (SwTo) is 4.04 hectares (Figure 2.5). Unlike UpWe and WeSl, No prescribed burns have occurred on Swift Tower in recent (1943 - 2016) history (Zuchowski *et al.* 2016); however, all three sites have oaks with visible burn scars, indicating past burn activity. Swift Tower was slated to have a prescribed burn in summer 2016, but this was postponed due to weather and scheduling conflicts.

Figure 2.5: Close-up of Swift Tower. The blue polygon delineates Swift Tower's boundaries, while the seven interior light blue lines delineate experimental transect locations. ESRI, 2015.

JBLM FW mowed all live broom on Swift Tower in February 2016. JBLM started a live broom mow at Swift Tower in 2014, but the project ended halfway through due to the threat of site damage (ground rutting) due to the malfunctioning equipment used by the contractor (Johnson 2016). Part of the SamX Timber Sale occurred on Swift Tower in 2008.

Prior to this research, no understory surveys had been conducted in recent (20+ years) history at this site. During initial site visits and visual surveys in March 2016, SwTo's understory was the most diverse of the three sites, and it also contained the highest concentration of native oak woodland species. SwTo is characterized as a Garry oak/Douglas-fir/common snowberry/sword fern community (ILAP 2004).

2.3 Endangered and Threatened Species Management

Both WeSl and UpWe border sections of Weir Prairie, a site managed for several endangered and threatened species, including four rare butterflies (Fimbel 2004): Taylor's checkerspot (*Euphydryas editha taylor*i), Zerene fritillary (*Speyeria zerene bremnerii*), Mardon skipper (*Polites mardon*), and Puget blue (*Icaricia icarioides blackmorei*). Weir prairie is considered a high priority habitat for Puget blue butterflies and its "potential to support metapopulation dynamics" of butterflies. Weir Prairie is also noted for its above-average abundance and diversity of native fescue bunchgrasses and forbs (Fimbel 2004), and is home to a relatively large population of a subspecies of the endangered Mazama pocket gopher - the Yelm pocket gopher (*Thomomys mazama yelmensis*; Suckling 2002).

WeSl has a population of acorn woodpeckers (*Melanerpes formicivorus*), which, although more abundant east of the Cascade Mountain Range, are very rare in the Puget Sound region (Seattle Audubon 2003). WeSl's location between two prairies also makes it a good candidate for western gray squirrel (*Sciurus griseus*) habitat, as it has a good mix of oak-Douglas-fir canopy cover. Both Upper Weir and Swift Tower have documented nesting locations for Western gray squirrel (Figure 2.6); Weir Slope currently has no documented nesting sites.

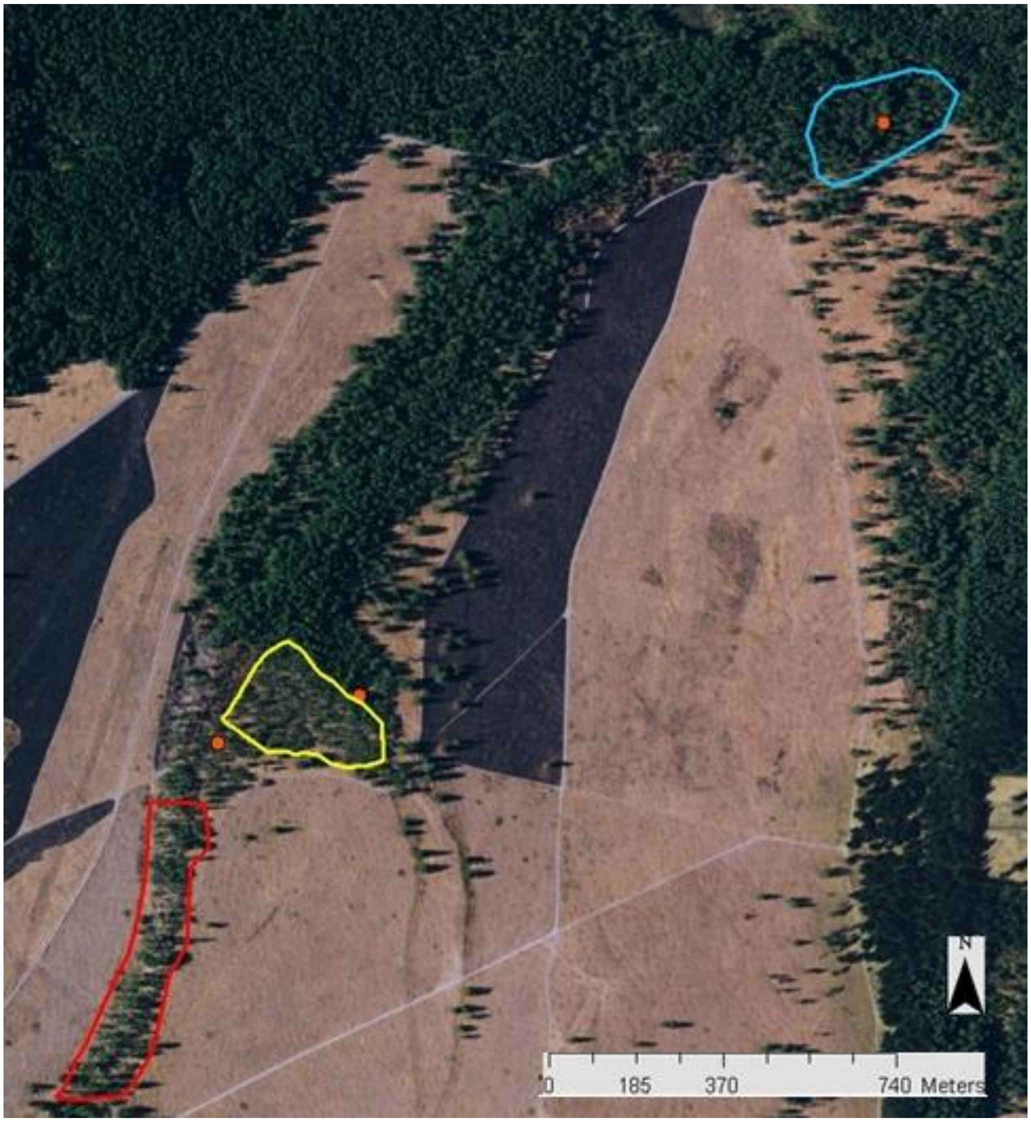

Figure 2.6: Documented Western gray squirrel nesting locations in relation to study sites. Nesting locations are denoted by the orange dots. ESRI, 2015.

2.4 Observational Study Design

Six to seven, 100-meter-by-1-meter, semi-permanent transects were established at each of the three observational study sites (Figure 2.7).

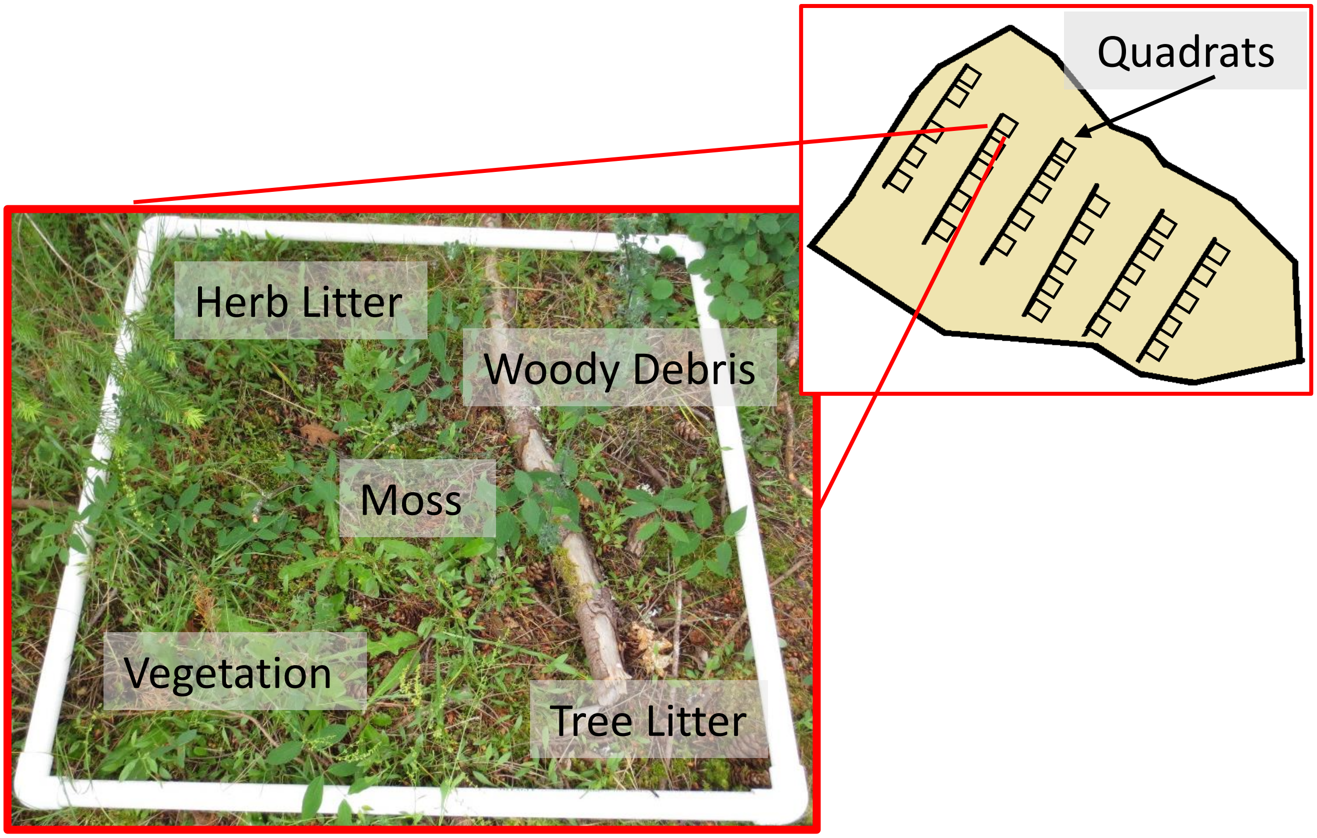

Figure 2.7: Diagram of transect and quadrat observational study design, with image of sample quadrat during study. Photo by Blazina, 2016.

The number of transects at each site was decided upon based on a species-area curve – when plotting transects, I kept track of the number of species over the amount of area I had encountered, When the number of new species stopped increasing with additional area, or reached an asymptote, I stopped adding transects. This method resulted in six transects on UpWe and WeSl, and seven on SwTo. Transects were divided into five 20-meter sections (0 - 20 m, 20 - 40 m, etc.) with one, one-meter-square quadrat established in each 20-meter section. Quadrat location was randomly assigned within each 20-meter section. One-meter square quadrats have been shown to be a better understory sampling method to evaluate overall ecosystem richness and diversity than other methods including line-intercept and Daubenmire plots (Korb *et al.* 2003). Distances between transects on each site were based on the site's width and length to ensure the entire site was covered. Transect start points were based off of the previous transect, and both the distance and direction (north or south) each transect from the previous transect were randomly decided (Table 2.2).

Table 2.2: Explanation of spacing and start locations for all study transects.

Transect	**Start point**	**Distance from previous transect (East-West)**	**Distance from previous transect (North-South)**
UpWe_01	randomly chosen start point	28m E	59.33m N
UpWe_02	UpWe_01 transect start	40m E	27m S
UpWe_03	UpWe_02 transect start	40m E	6m N
UpWe_04	UpWe_03 transect start	40m E	18.67m S
UpWe_05	UpWe_04 transect start	40m E	6.67m N
UpWe_06	UpWe_05 transect start	40m E	0.67m N
SwTo_01	randomly chosen start point	24m E	15m S
SwTo_02	SwTo_01 transect start	25m E	8.6 N
SwTo_03	SwTo_02 transect start	25m E	61.3m S
SwTo_04	SwTo_03 transect start	25m E	61.3m N
SwTo_05	SwTo_04 transect start	25m E	40m N
SwTo_06	SwTo_05 transect start point	25m E	1.5m N
SwTo_07	SwTo_06 transect start	25m E	30m N
WeSl_01	randomly chosen start point	30m E	2m S
WeSl_02	WeSl_01 transect mid point	30m E	9.3m N
WeSl_03	WeSl_02 transect mid point	30m E	15.3m N
WeSl_04	WeSl_03 transect mid point	30m E	16m N
WeSl_05	WeSl_04 transect end point	16m N	18m N
WeSl_06	WeSl_05 transect mid point	30m E	7.3m N

All transect start, mid and endpoints were designated by 45.72-cm-tall orange pin flags: Clusters of three flags designated the start and end points of each transect, while the midpoint was demarcated by a cluster of two. I geospatially recorded all transect mid, start, and endpoints. I split WeSl's transects into two sections due to a large area of the site being bare ground. This area was distinct from the other two halves and functioned similar to a road or site edge, and so I purposefully avoided including this in my vegetative diversity/environmental site observational measurements.

As mentioned above, quadrats were chosen from each of the 20-meter increments using a random number square. If a quadrat landed on a road (either gravel or simply compacted ground), the quadrat was moved either up or down in 1-meter increments until the roadway was avoided. All quadrats were put in on the East side of the transect line. Quadrat start and end points were designated by a single orange pin flag at the SW and NW corner of each quadrat. I geospatially recorded all quadrat center points using a Garmin 60CS handheld unit.

Understory vegetation was measured using a 1-square-meter quadrat frame constructed from PVC pipe. Understory vegetation was classified as all vegetation less than 3 meters tall. This height allowed me to include tall shrubs such as Indian plum, snowberry, and Scotch broom in these measurements, while excluding the mature trees. I recorded the presence and cover of tree saplings, seedlings, and mature trees located in quadrats but these values were not included in the analyses, since I did not define them as being part of the understory species.

Species were recorded for their genus and species. Species that I could not identify were photographed, described, and, if a sample could be found outside of the quadrat, pressed in a designated notebook to assess at a later date. Additional plant identification assistance came from University of Washington faculty (Olmstead 2016). Species that could not be identified during initial vegetation sampling periods (April and May 2016) were flagged for follow-up visits in summer 2016. A few plants of *Festuca* and *Poa* genera were not identified to species level. These varieties were included in analyses as “Poa” and “Festuca.”

Species percent cover were broken up into “bins,” or categories following Sutter's (1996) methods:

- Category 1: less than 1% cover
- Category 2: 1 - 5% cover
- Category 3: 6 -15% cover
- Category 4: 16 - 25% cover
- Category 5: 26- 50% cover
- Category 6: 51 - 75% cover
- Category 7: 76 - 100% cover

I recorded the health of each species on a scale of 0 -3. “Zero” represented a plant that was dead, while a “3” was given to vegetation that was robustly healthy. Health was determined by a plant’s signs of herbivory, foliage scorching, wilting, or discoloration of leaves and/or inflorescence of the plant.

Percent cover bins were also used to record the amount of moss, woody debris, herb litter, tree litter, and bare ground in each quadrat. Due to vegetative overlap in the understory, as well as the use of percent cover “bins,” most quadrats amounted to more than 100% cover. All data was rescaled to equal 100% cover for statistical analyses.

I also recorded primary and secondary signs of disturbance that were visually apparent at the quadrat scale, breaking this disturbance into five categorical types: animal, human, machine, vehicle, and fire, or unknown.

Canopy cover was measured using a GRS Densitometer from the center of each plot to the nearest 10%. Canopy cover was further denoted by species - oak, Douglas-fir, or a mix.

Tree measurements

I used a variation on the point-centered quarter method described by Stumberg *et al.* (2014) to choose which trees to sample (Figure 2.8). In this method, the closest tree to each of the quadrat center points in each cardinal direction was sampled. The first tree (I defined a tree as having a diameter at breast height – DBH – of 10 cm or more) that was within 1 meter (to the left or right) of that cardinal direction reading was counted. The point-centered quarter method is more commonly used in the Midwestern hardwood woodlands; however, I chose this method because oak is a hardwood. I recorded geospatial coordinates for each tree.

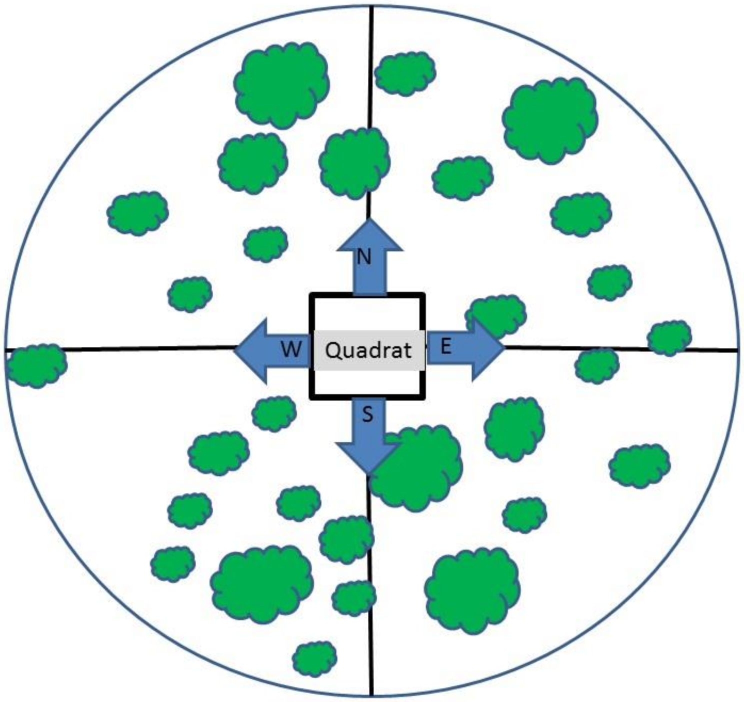

Figure 2.8: Diagram of the point-centered quarter method used to for observational tree measurements on each site. From the center of the quadrat, I walked directly north until I reached a tree (at least 10 cm in diameter). This process was repeated for east, south, and west directions, and for each quadrat.

I measured tree height with a manual Haga altimeter. I took my readings from the highest point on the tree, whether or not that was the top the trunk (N.C. Forest Service 1999). This was done because many oaks were bent toward the largest canopy openings, causing their “tops” to be below other parts of the tree. Measurements for height were rounded to the nearest 0.10 meter. All trees were measured for DBH, and were rounded to the nearest 0.25 cm. Trees with multiple trunks at breast height had all trunks measured and recorded. Trunks that split above DBH were taken at breast height, but the number of trunks were noted. Similar to understory vegetation, tree health was recorded on a scale of 0 to 3. Canopy cover beneath each tree was measured with a GRS Densitometer. Three measurements were taken around the tree perpendicular to the trunk, rather than the slope of the ground and were rounded to 5%.

Tree coring

Past research demonstrates that oak height and DBH are not always good indicators of tree age. Gilligan and Muir (2011) examined 40 different Garry oak stands in central Oregon, and found that saplings - denoted as trees with a DBH of 10 cm or less - were between 8 and 164 years old, with a mean of 83 years. During summer 2016, two members of North American Dendroecological Fieldweek (NADEF) took test cores for my field sites to age sample trees. The oldest test core was approximately 135 years old, indicating that oak trees were present in RTA 21 as early as 1881.

Main coring took place in late September and early October 2016. The objective for tree coring was to develop a timeline for oak presence on each site. Trees were purposefully selected based on visual characteristics indicative of older oaks, such as gnarled branches, "squatty" profiles, and gnarled, above-ground roots (Woodland Trust 2007). I also purposefully chose to take samples throughout the site to determine historic presence/absence of oaks site-wide. Methods for tree coring were adopted from recommendations provided by P. Dunwiddie. I used the mounting and gluing protocols recommended by Rocky Mountain Tree-Ring Research (2016).

I manually counted all tree cores' growth rings, examining them for overarching patterns of growth over time, and to develop an initial age for each core. Each record was then scanned and digitized. Cybis Coordinate Recorder (CooRecorder) software allowed me to measure each tree-ring width, both relative to neighboring rings and across the core. I then used CDendro to crossdate cores taken from within site, as well as across all sites.

Soil moisture and temperature

Three soil moisture readings were taken at each quadrat on both WeSl and SwTo. Upper Weir had a prescribed burn in July 2016 conducted outside of this study. Unfortunately, soil moisture readings were not taken prior to this burn. Three readings were taken from each UpWe quadrat that burned at low severity. Measurements for all three sites were taken once in the late summer (September) after several weeks without rain, and then again in early November, after the after wettest October in Puget Sound in recorded history, with more than 31.5 cm of precipitation in one month (Marriott 2016). I used a

HydroSense Soil Moisture probe for all measurements. I took soil temperature readings from the center of each quadrat simultaneous to my soil moisture measurements. Soil temperature was taken using an Oakton pH 5+ meter.

2.5 Human Activity Historical Analyses

Data collected around historical use of each site's vegetation and structure is limited for this project. Data from non-Native American sources can only be considered secondary in nature; the accuracy of non-Native data must be taken as partial, at best, in its ability to explain historical Native American relationships between the plants/ecosystems in question and the community that used/uses them. Because of this, and for personal reasons/beliefs on cultural appropriateness, I focused my research on identifying human activities on this landscape during the past 170 years. However, this component of the research was included in the hopes that these data be useful to groups that are interested in oak ecosystem restoration centered around cultural/heritage purposes. The following materials were used for this research:

Historic land surveys

General Land Office (GLO) Surveys from September 1853 covered all three study sites. GLO surveys were done to establish the boundaries as well as categorize lands that had recently been purchased by the United States Federal Government. These surveys were done on a township (9,323 ha) level, with details of land features documented primarily on the section (260 ha) and quarter-section level (there are 36 sections per township).

The JBLM FW digitized these surveys for geospatial analyses. Unfortunately, no field notes are available for Township 17N, Range 1E, where all three sites are located, yet the visual maps created by the surveyors were extremely helpful in determining the approximate area of each land type present across all three sites in 1853.

I also used 1908 Washington Forest Inventory Timber Cruise of Thurston County maps to define historic human activity and land types at each site. In the early 1900s, each Washington state county was required to survey its forest land for the 1910 Washington Forest Inventory. Thurston County performed this inventory in 1908. Each survey was done at the section (260 ha) level, with details recorded to the block-level of each quarter section. In addition to detailed notes on estimated board feet of timber, surveyors also indicated the quality of the timber, such as “defective,” “good” or “rotting,” as well as the quality of the land, including a recommendation for what the land may be good for, such as “grazing,” “fruit land” or a more generic “can be cultivated.” Accompanying the timber surveys were records of current land ownership in 1908.

Only physical hard copies of these maps are available in the Washington State Archives in Olympia, WA. I photographed, digitized and georeferenced all of the sections of my three observational study sites, as well as the sections that neighbored each experimental site for geospatial analyses.

I assessed landowner records for Sections 32 and 28 in Township 17N Ranger 1E (where all study sites are located) from 1825 – 1915. Maps developed by Metsker Maps (1937 and 1962) provided additional details on land ownership at study sites after 1915. Corresponding census records were consulted to examine possible land uses and disturbance types at each site over time.

For 2016 land type classification comparisons, I used the ArcGIS Spatial Analyst supervised classification tool developed by ESRI to categorize all land types. After running training samples for each land type, I used the maximum likelihood classification designation to develop final land type classifications for each section. I then created polygons around each image classification type to better quantify land type changes over time.

Fire, Logging, and Enhancement Records

Digitized fire records were used to analyze burn history for study sites from 1987 – 2015. I collected additional management history through a series of semi-formal interviews with JBLM Fish and Wildlife, Forestry, and Integrated Training Area Management (ITAM) employees, and collaborative staff from the Center for Natural Lands Management (CNLM), as well as land management prescription reports, timber sale records, and informal personal accounts. Due to this data only coming from three sites, I did not choose to look at this statistically, since the sample size of management type and frequency for each site numbered less than 10. I catalogued each of these variables, and used them to support speculations as to how different study site conditions were produced. I categorized management activities into three different groups – “Timber harvest,” “Mowing,” and “Burning.” The “Timber harvest” category included any site-wide removal of substantial woody biomass, such as an extensive thinning of oak or Douglas-fir, the removal of logs or large downed limbs, and official timber sales. The “Mowing” category includes removal or mastication of non-woody vegetation or sapling biomass from the site. Most of this removal was done via mowing. This also includes Scotch broom and Douglas-fir saplings that were hand-cut and then bone-piled. The “Burning” category includes all prescribed burns that took place at each site. One management activity – a mowing job - was localized to certain areas of Swift Tower. In this instance, I only counted those transects/quadrats that were affected by the activity were counted in the total frequency.

2.6 Statistical Analyses

I used all collected data to develop two main matrices: a site-by-species matrix and a site-by-environmental variables matrix. I used “R” software version 3.1.2 to examine potential multivariate correlations between sites and their environmental variables, as well as significant distributions of species across and within each of the three sites. Due to the high number of listed floristic species found on neighboring Weir prairies, I also examined the distribution of native, exotic, and invasive species on each site. I classified all species based on their native/exotic/invasive status for oak ecosystems. Some species that are native to Western Washington are invasive in oak ecosystems (Dorner, 1999).

Species abundance data for all 95 quadrats was converted into a site-by-species matrix. Since it is typical to remove species that are present in less than 1% of all sites, I instead chose to remove species that were found in only 1 quadrat and also were found in less than 1% (Category 1) of that quadrat’s vegetative cover – this typically meant that only one or two plants for this entire species were found at that site. This resulted in five species being removed. All data was reclassified using the midpoint of percent cover for its corresponding cover bin/category.

I developed histograms of species diversity for each site, as well as the three sites combined. Individual site histograms showed abnormal distributions, yet overall species diversity distribution for all three sites was relatively normal, so I chose to not to transform the distribution to assess the dissimilarity. Initial ordination screening showed that one quadrat was a major outlier and was skewing the results; therefore, data from this quadrat was removed.

Non-metric Multidimensional Scaling (NMDS) was used to examine the relationship between the three different sites and their recorded species. NMDS uses rank order, rather than absolute abundances, among objects in variable space (Kruskal and Wish 1978), then attempts to locate all objects in a low-dimensional ordination space. The final goal is to have inter-object distances have the same rank order as inter-object dissimilarities, or to minimize the "stress," which is the measure of the correspondence between ranked distances and ranked multivariate distances. This is done through a series of iterations, with the process being repeated under k-dimensional ordination space until the positions of the objects in the space "satisfy" the ranked dissimilarity relations between objects in the distance matrix. Unlike some ordination tests, NMDS does not assume that the underlying data is linear. The initial data analysis of species diversity demonstrated that this dataset is not linear, so NMDS works well.

The Bray-Curtis similarity index was originally developed during assessment of forest communities (Bray and Curtis 1957), and has been shown to be one of the best coefficients for community data. Because of this, I chose to use this similarity index to test my observational study data. Unlike some similarity indices, Bray-Curtis is not affected by the absence or presence of a species that does not occur in all communities (Faith *et al.* 1987). NMDS was conducted using the "vegan" package and the "metaMDS" function in R. The "envfit" function was used to assess which understory species had significant loadings. Only those species with loadings of a p value of 0.001 or better were assessed.

I used permutation-based multivariate analysis of variance (PERMANOVA) to examine potential relationships between understory species cover/diversity, environmental variables, and site location. I chose to use PERMANOVA over analysis of similarity (ANOSIM) or the Mantel tests because PERMANOVA has demonstrated to be more powerful in detecting changes in community structure (Anderson and Walsh 2013).

I used beta diversity with PERMANOVA tests because of the scale of this dataset. Beta diversity is one of the three terms originally introduced by Whittaker (1972) to define different scales of diversity: while alpha defines localized diversity, gamma is defined as regional diversity, and beta diversity is defined as the diversity of composition units of a region. Since I am examining diversity at the sampling plot, transect, and site experimental level for experimental units all within the same area, beta diversity is the most appropriate. Beta diversity was assessed using the “betadisper” function in R

3. RESULTS

3.1 Environmental and Vegetative Factors

All sites had at least four of the five disturbance categories present (Table 3.1). Ninety-six percent of Weir Slope's quadrats displayed visible signs of disturbance, with burning being the most common - burning accounted for more than 76% of all primary disturbance recorded. Ninety-one percent of Swift Tower's quadrats had at least one visible sign of disturbance, with human disturbance being the most common. Sixty-seven percent of Upper Weir's quadrats displayed signs of disturbance, with human also being the most common. Secondary disturbances were those that were present, yet less visibly so than the primary disturbance.

PERMANOVA results showed that primary and secondary disturbance were both significantly related to site. Primary disturbance was most commonly human disturbance, which included signs of trampling/ground compaction. Signs of past burning ("Fire" disturbance) was concentrated on Weir Slope. Primary disturbance had a highly ($p<0.0001$) significant relationship to fall soil moisture levels. Both primary and secondary disturbance were significantly ($p<0.01$) correlated with invasive species cover. Both disturbance factors were highly significantly related to site location.

Primary disturbance on Upper Weir and Swift Tower differed significantly from Weir Slope (p=9.5^E-9 and p=4.07^E-7, respectively), yet did not vary significantly between Upper Weir and Swift Tower. Secondary disturbance on Weir Slope and Swift Tower differed significantly from Upper Weir ($p=0.0013$ and $p=0.05$, respectively), yet Weir Slope and Swift Tower did not differ significantly from each other.

Table 3.1: Percentage of quadrats per site with visible signs of disturbance. The "Primary" and "Secondary" columns denote which disturbance category type was most visibly apparent when multiple signs of disturbance were noted. Percentages represent the number of quadrats by site with each disturbance type.

Site	**Disturbance Category**	**Primary**	**Secondary**	**Category Total**
Upper Weir	Human	26.7%	10%	**36.7%**
	Mechanical	13.3%	10%	**23.3%**
	Vehicle	16.7%	0	**16.7%**
	Animal	10%	3%	**13.3%**
	Fire	0	0	**0**
	Total	***66.7%***	***23.3%***	
Weir Slope	Human	13.3%	10%	**23.3%**
	Mechanical	6.7%	23.3%	**30%**
	Vehicle	0	6.7%	**6.7%**
	Animal	0	0	**0**
	Fire	76.7%	20%	**96.7%**
	Total	***96.7%***	***60%***	
Swift Tower	Human	34.3%	14.3%	**48.6%**
	Mechanical	28.6%	17.1%	**45.7%**
	Vehicle	11.4%	5.7%	**17.1%**
	Animal	17.1%	8.6%	**25.7%**
	Fire	0	0	**0**
	Total	***91.4%***	***45.7%***	

Canopy cover had a wide distribution across all sites (Figure 3.1). Cover ranged from 0 to 80% for Upper Weir and Weir Slope quadrats. Upper Weir had an average of 33% canopy cover, and Weir Slope had an average of 37% across the site. Swift Tower canopy cover ranged from 0 to 100% on quadrats, and had the highest average canopy cover at 43%.

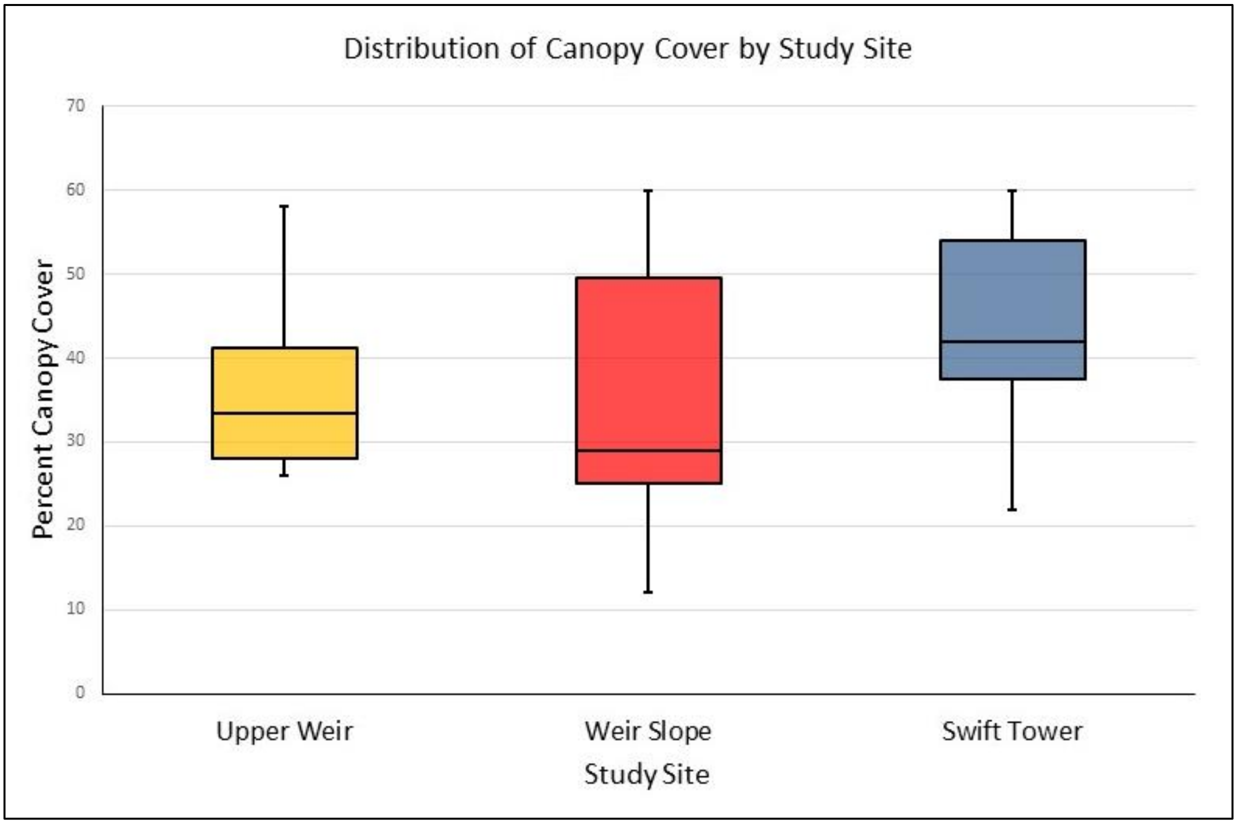

Figure 3.1: Average percent canopy cover by study site. No p-values were significant ($p<0.05$) when canopy cover was compared among study sites.

Forty-eight percent of canopy cover across all sites was due to oak trees. Since oak canopy cover changes seasonally, it is important to note that nearly half of all species diversity data from this study comes from quadrats that experience this large seasonal variation in canopy. Both Douglas-fir canopy cover and no canopy cover each account for 21% of all quadrats, and mixed oak/Douglas-fir canopy accounts for 8.4%. When tested for significant differences, all canopy cover was statistically similar at each site. PERMANOVA results echoed this finding, indicating that canopy cover means were not significantly different between study sites, and did not have significant relationships with other environmental variables.

All quadrat vegetation type data was averaged to the midpoint of its cover “bin” category. Total percent cover for each quadrat was scaled and adjusted to total 100%. Vegetation cover type was broken into the categories of bare ground, vegetation, moss, herb litter, tree litter, and woody debris (Figure 3.2). Bare ground per quadrat was highest for Weir Slope, with quadrats having an average of 13.8%. This was markedly higher than Swift Tower and Upper Weir, which had an average of 1.1% and 2.5%, respectively, per quadrat. Percent vegetation cover was similar across all three sites. PERMANOVA results indicate a significant correlation between bare ground and primary disturbance, fall soil moisture levels, and invasive species density.

Moss cover was the highest on average for Swift Tower with an average of 13.4% cover. Values ranged from 0% to 86.3% cover on quadrats across the site. Weir Slope averaged 2.8% moss cover, with the majority of quadrats (23 out of 30) having 0% moss cover. Upper Weir’s quadrats averaged a moss cover of 0.9%, or less than 1% of total quadrat cover.

Tree litter was highest on average for Upper Weir, yet all three sites had similar values. PERMANOVA results indicate that tree litter was significantly related to bare ground cover, both primary and secondary disturbance factors, and soil moisture levels in both summer and fall.

Herb litter for Weir Slope averaged only 4.2%. Swift Tower had the highest average herb litter with 17.9%, only slightly higher than Upper Weir’s average herb litter coverage of 17.9%.Woody debris included both Douglas-fir and Garry oak branches. Woody debris was, on average, highest for Weir Slope, with quadrats averaging 11.5% cover. Swift Tower had an average of 3.7% cover, while Upper Weir had an average woody debris cover of 1.5%. PERMANOVA results indicate herbaceous litter, moss, and percent vegetative cover did not have significant p-values ($p<0.05$), and were therefore unlikely to show significant differences when used to define what factors determine the overall diversity and structure at each site.

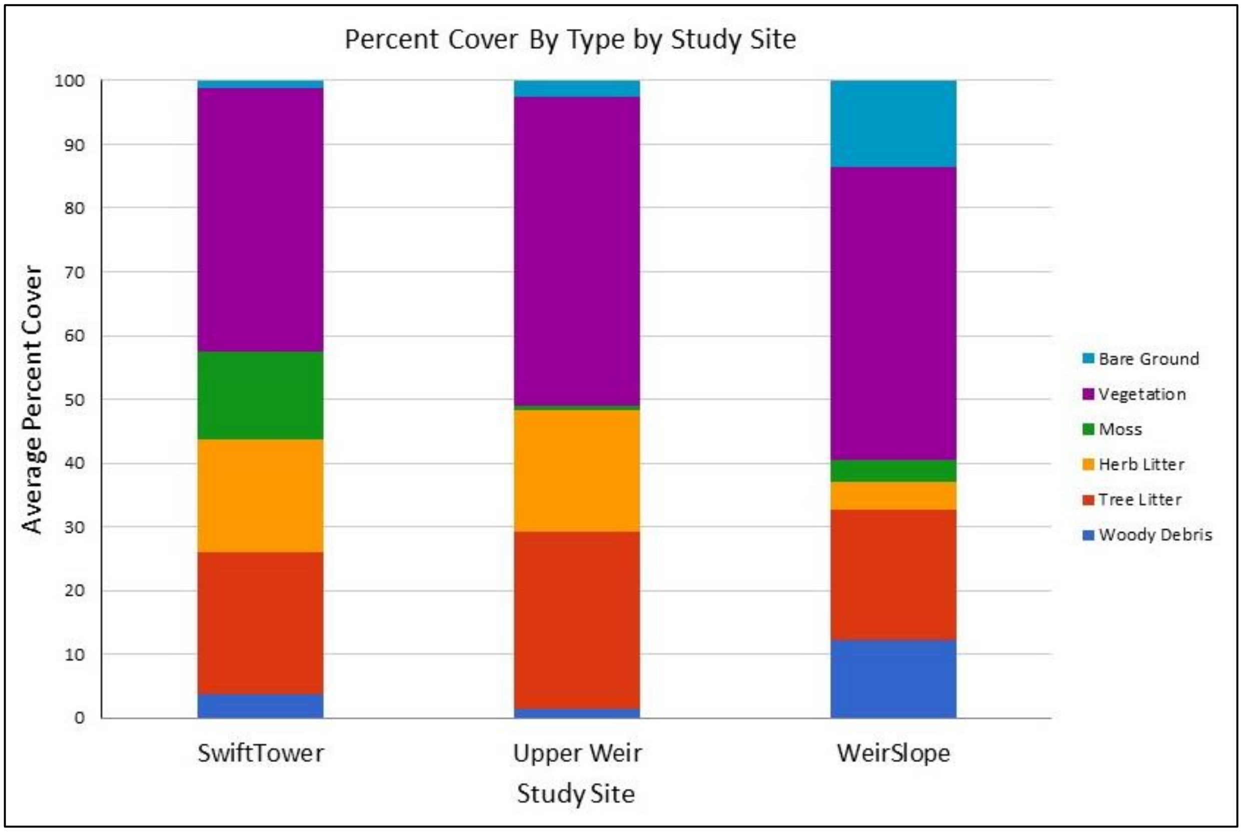

Figure 3.2: Average percent cover by type for each of the three study sites.

Weir Slope had the highest average summer soil moisture across the three sites, as well as the lowest average soil moisture in the fall (Table 3.2). Soil moisture ranged from 2.7 to 7% for Weir Slope in the summer, and 7.7 to 12% in the fall. Conversely, Upper Weir had the lowest average summer soil moisture and highest average fall soil moisture. Summer moisture ranged between 2.7 and 6% for Upper Weir and fall moisture percentages ranged between 8.7 and 19.3%. Swift Tower's soil moisture percentages ranged between 2.3 and 7% in the summer, and 6.7% and 20.7% in the fall. Average soil temperature was highest in both summer and fall for Upper Weir at 18.5 and 15.0 degrees Celsius, respectively. Upper Weir soil temperatures ranged between 17.1 and 21.8 degrees Celsius in summer, and between 11.1 and 15.7 degrees in fall. Swift Tower had the lowest average summer soil temperatures, and ranged between 14.1 and 18.3 degrees Celsius. Fall soil temps at the site ranged between 10.5 and 12.5 degrees Celsius. Weir Slope had the lowest average fall soil temperature at 11.25 degrees Celsius, and ranged between 10.7 and 11.9 degrees. Summer soil temps at the site ranged between 15.7 and 18.1 degrees Celsius.

PERMANOVA results indicate that soil moisture and soil temperature in summer were not significantly related, yet soil moisture and temperature in fall had a highly significant ($p<0.0001$) relationship. Woody debris was significantly ($p<0.01$) related to summer soil moisture and temperature measurements, but not fall measurements. Fall and summer moisture were significantly ($p<0.01$) related.

Table 3.2: Summary of soil data from all three sites and transects. All values are averages derived from quadrat-level measurements across all three sites.

	Soil Moisture Sum (%)	**Soil Temp. Sum (C)**	**Soil Moisture Fall (%)**	**Soil Temp. Fall (C)**
UpWe_Average	**4.1**	**18.5**	**14.4**	**15**
WeSl_Average	**4.7**	**16.6**	**10**	**11.3**
SwTo_Average	**4.1**	**16**	**11.3**	**11.9**

All soil moisture and temperature measurements were tested for significant differences between sites. Only fall percent soil moisture showed significant differences (Figure 3.3), with both Upper Weir and Swift Tower differing significantly from Weir Slope, yet Swift Tower and Upper Weir were not significantly different from each other.

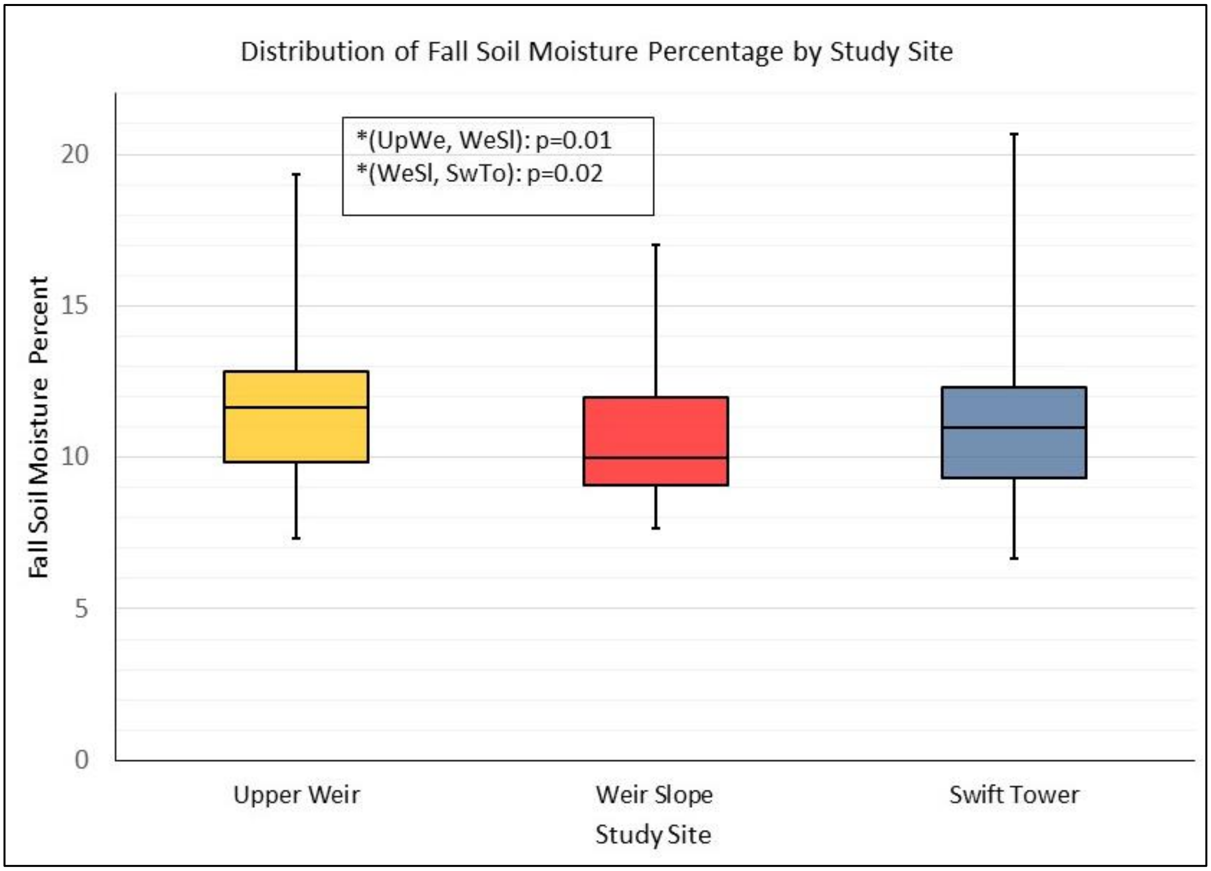

Figure 3.3: Distribution of soil percent moisture in the fall at each study site. P-values for significantly different soil moistures are labeled according to site and marked with an asterisk (*).

3.2 Vegetation diversity and cover

A total of 76 plant species were identified across 95 quadrats. Swift Tower was the most diverse, with 64 species identified (Table 3.3). Swift Tower had between 3 and 13 species per quadrat. Upper Weir and Weir Slope had a total of 46 identified species. Upper Weir had between 5 and 15 species per quadrat, and averaged 9.7 species. Weir Slope had between 3 and 9 species, and averaged 6.6. Average species health was highest for Swift Tower, with 2.9 out of 3. Upper Weir and Weir Slope averaged 2.8.

Table 3.3: Summary of species diversity and plant health at the transect- and quadrat-scale by study site.

	Transect	Total Number of Species	Average Number of Species/ Quadrat	Average Species Health (0-3)
Upper Weir	1	29	9.6	2.8
	2	23	9.8	2.8
	3	27	9.2	2.8
	4	28	10	2.7
	5	19	10	2.8
	6	25	9.6	3.0
	TOTAL	**46**	**9.7**	**2.8**
Weir Slope	1	23	7.6	2.8
	2	19	7.6	2.8
	3	20	8.4	2.9
	4	21	5.6	2.8
	5	10	4.4	2.6
	6	17	6.2	2.7
	TOTAL	**46**	**6.6**	**2.8**
Swift Tower	1	33	11	2.8
	2	21	7.8	2.8
	3	30	8.4	2.9
	4	43	10	2.8
	5	27	8.8	2.9
	6	27	7.6	2.9
	7	32	11.4	2.9
	TOTAL	**64**	**9.3**	**2.9**

The most frequent species across all three sites - nonnative or native - was common velvetgrass (see Appendix B for scientific names). Common velvetgrass was also the species most frequent at Weir Slope (Table 3.4). The most common species at Upper Weir was camas, while Swift Tower's most frequent species was cleavers.

Table 3.4: Species frequency (number of quadrats with species present) and average density (percent cover) across all three study sites – Weir Slope (WeSl), Upper Weir (UpWe) and Swift Tower (SwTo). Note that species average percent cover is averaged among quadrats with the species only, not across all quadrats at each site.

Scientific Name	Common Name	Species Code	Species Origin	Frequency All Sites	Frequency WeSl	Average % Cover WeSl	Frequency UpWe	Average % Cover UpWe	Frequency SwTo	Average % Cover SwTo
Agrostis capillaris	colonial bentgrass	ACGA5	I	23	3	11.5	17	8.8	3	8.2
Achillea millefolium	yarrow	ACMI2	N	3			3	1.5		
Aira praecox	yellow hairgrass	AIPR	E	2	2	0.5				
Amelanchier alnifolia	saskatoon	AMAL2	N	6					6	14.5
Arctostaphylos uva-ursi	kinnikinnick	ARUV	N	4			2	7	2	2
Blechnum spicant	deer fern	BLSP	N	1					1	10.5
Bromus tectorum	cheatgrass	BRTE	I	1			1	10.5		
Calandrinia ciliata	fringed redmaids	CACI2	N	1			1	0.5		
Carex inops	long-stolon sedge	CAIN9	N	41			22	10.4	19	8.3
Cardamine oligosperma	Western bitter-cress	CAOL	E	12			4	0.5	8	0.9
Camassia quamash	common camas	CAQU2	N	29			24	11.5	5	1.7
Cerastium arvense	field chickweed	CEAR	N	1			1	3.5		
Cirsium vulgare	bull thistle	CIVU	I	1	1	3.5				
Clinopodium douglasii	yerba buena	CLDO2	N	4	2	3.5			2	2
Claytonia perfoliata	miner's lettuce	CLPE	N	20	2	10.5	4	2	14	5.9
Claytonia sibirica	Siberian spring beauty	CLSIS	N	4					4	17.8
Crepis capillaris	smooth hawksbeard	CRCA3	I	2	2	2				

Scientific Name	Common Name	Species Code	Species Origin	Frequency All Sites	Frequency WeSl	Average % Cover WeSl	Frequency UpWe	Average % Cover UpWe	Frequency SwTo	Average % Cover SwTo
Cytisus scoparius	Scotch Broom	CYS4	I	30			16	9.4	14	5.4
Dodecatheon hendersonii	Henderson's shooting star	DOHE	N	3			3	4.8		
Festuca roemeri	Roemer's fescue	FERO	N	2	2	7				
Festuca rubra	red fescue	FERU2	N	4			4	22		
Fritillaria affinis	checker lily	FRAF2	N	1			1	3.5		
Fragaria vesca	woodland strawberry	FRVE	N	2			1	0.5	1	3.5
Fragaria virgniana	Virginia strawberry	FRVI	N	1					1	3.5
Galium aparine	cleavers	GAAP2	N	54	11	0.8	17	4.2	26	10.7
Geranium bicknellii	Bicknell's geranium	GEBI2	n	25	9	5.9	13	8.4	3	5.8
Geranium molle	dovesfoot geranium	GEMO	E	4	2	0.5			2	0.5
Geranium pusillum	small geranium	GEPU2	E	1	1	0.5				
Geranium robertianum	stinky bob	GERO	I	4	2		1	0.5	1	3.5
Goodyera oblonigfolia	western rattlesnake plantain	GOOB2	N	1					1	3.5
Holodiscus discolor	oceanspray	HODI	N	4					4	7
Holcus lanatus	common velvetgrass	HOLA	I	58	24	19.1	22	11.7	12	3.2
Hypericum perforatum	common St. John's wort	HYPE	I	31	6	4.2	11	3.7	14	4.2
Hypochaeris radicata	hairy cat's ear	HYRA3	I	24			17	5.4	7	10.5

Scientific Name	Common Name	Species Code	Species Origin	Frequency All Sites	Frequency WeSl	Average % Cover WeSl	Frequency UpWe	Average % Cover UpWe	Frequency SwTo	Average % Cover SwTo
Linnaea borealis	twinflower	LIBO3	N	1					1	10.5
Lonicera ciliosa	orange trumpet honeysuckle	LOCI3	N	5					5	3.1
Lomatium Triternatum	nineleaf biscuitroot	LOTR2	N	1			1	3.5		
Lotus micranthus	desert deervetch	LOMI	N	2			2	12		
Lomatium utriculatum	common lomatium	LOUT	N	1			1	3.5		
Mahonia aquifolium	tall oregon grape	MAAQ2	N	5					5	13.3
Maianthemum stellatum	false star lily of the valley	MAST4	N	3					3	25.8
Moehringia macrophylla	largeleaf sandwort	MOMA3	N	16	1	0.5			15	3.2
Myosotis discolor	changing forget-me-not	MYDI	E	3					3	1.5
Oemleria cerasiformis	Indian plum	OECE	N	2					2	2
Plantago lanceolata	narrowleaf plantain	PLLA	E	11			8	9.5	3	8.2
Dactylis glomerata	orchard grass	DAGL	I	3	3	22.5				
Polystichum munitum	sword fern	POMU	N	2					2	0.5
Pteridium aquilinum	Western brackenfern	PTAQ	N	4	3	8.2			1	10.5
Ranunculus occidentalis	western buttercup	RAOC	N	1			1	0.5		
Rosa gymnocarpa	baldhip rose	ROGY	N	1	1	3.5				

Scientific Name	Common Name	Species Code	Species Origin	Frequency All Sites	Frequency WeSl	Average % Cover WeSl	Frequency UpWe	Average % Cover UpWe	Frequency SwTo	Average % Cover SwTo
Rumex acetosella	sheep sorrel	RUAC3	E	17	7	3.36	6	3.67	4	8.75
Rubus armeniacus	Himalayan blackberry	RUAR9	I	1	1	63.5				
Rubus ursinus	Pacific blackberry	RUUR	N	23	8	24.1			15	13.6
Sanicula crassicaulis	Pacific blacksnakeroot	SACRT	N	21	8	1.6	1	0.5	12	3.5
Schedonorus arundinaceus	tall fescue	SCAR7	E	5	1	3.5	1	10.5	3	3.5
Sonchus arvensis	field sowthistle	SOAR2	E	19	19	2.8				
Stellaria media	common chickweed	STME2	E	15	2	2	4	4.5	9	1.8
Symphocarpos albus	common snowberry	SYAL	N	33	10	16	10	23.5	13	7.9
Symphocarpos mollis	trailing snowberry	SYMO	N	2	1	0.5			1	3.5
Synthyris reniformis	snowqueen	SYRE	N	15					15	5
Taraxacum officinale	common dandelion	TAOF	E	31	18	3.4	12	2.8	1	0.5
Teesdalia nudicaulis	barestem teesdalia	TENU	I	35	10	2.1	17	7.6	8	2.4
Thalictrum occidentale	western meadow-rue	THOC	N	1			1	0.5		
Trientalis borealis	starflower	TRBO2	N	4					4	3.8
Trifolium dubium	little hop clover	TRDU	E	12	1	0.5	9	13.7	2	2
Trillium ovatum	Western trillium	TROVO2	N	4					1	3.5
Veronica arvensis	common speedwell	VEAR	E	7			5	3.1	2	2
Vicia cracca	bird vetch	VICR	E	7	7	9.2				

Scientific Name	Common Name	Species Code	Species Origin	Frequency All Sites	Frequency WeSl	Average % Cover WeSl	Frequency UpWe	Average % Cover UpWe	Frequency SwTo	Average % Cover SwTo
Viola glabella	common yellow violet	VIGL	N	1					1	0.5
Vicia sativa	common vetch	VISA	E	45	18	9.6	20	4.7	7	1.8

I assessed species cover for the *Festuca/Poa* vegetation I was unable to identify to species. Unidentified *Festuca/Poa* species comprised 4.2% of total species cover for Swift Tower, yet were only 0.24% of Weir Slope cover and 0.29% of Upper Weir species cover.

All plant data were broken into one of three categories based on species origin: native, exotic, or invasive (USDA 2016). These categorizations were for oak ecosystems, not necessarily regional species origin. Therefore, some species that are considered native to the Pacific Northwest were labeled as “invasive” or “exotic” for this study (Table 3.4). Plants that are nonnative to oak ecosystems but are not large threats to ecosystem diversity (they do not dominate interspecific competition for ecosystem resources) are classified as “exotics,” while nonnative plants to oak ecosystems that do prompt large threats to ecosystem diversity are classified as “invasive.”

A total of 43 native oak ecosystem species was recorded across all three sites, and accounted for 50.2% of total cover. Swift Tower had the highest average native cover among all three sites, with 68.1% native cover across the site (Figure 3.4). Two Swift Tower quadrats had 100% native vegetation and four had 99% native plant cover. Upper Weir had an average of 51.6% native cover, while Weir Slope had an average of 31%. Eighteen of the 20 quadrats for highest native vegetation cover were on Swift Tower. The quadrats with the lowest percent of native vegetation, however, came from all three sites: 14 from Weir Slope, four from Upper Weir, and two from Swift Tower. Five quadrats on Weir Slope had 0% native vegetation.

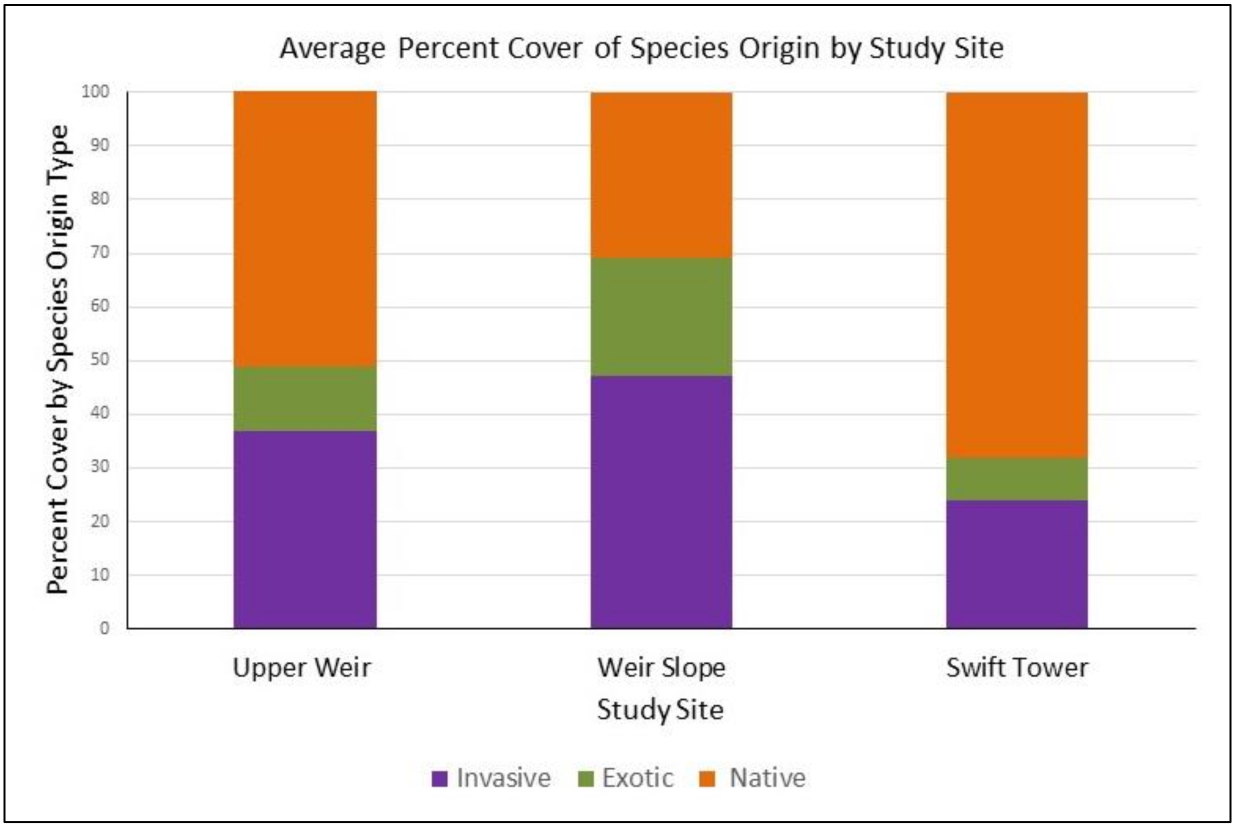

Figure 3.4: Breakdown of average percent vegetative cover by species origin. Species were assessed as being invasive, exotic, or native to oak ecosystems.

Distribution of percent native vegetation across all three study sites varied significantly (Figure 3.5). Both Upper Weir's and Swift Tower's native species cover differed significantly from Weir Slope, yet Upper Weir and Swift Tower did not vary significantly from one another.

Site-by-species data was further analyzed through NMDS. I chose to use a 3-dimensional solution to ordinate my sample plots. The 3-dimensional solution brought the final stress to a best of 18.7, below the recommended threshold of 20 (Clarke 1993), which achieves ordination results that are meaningful enough to make strong inferences about the underlying data, yet still retain a low number of dimensions. The data ordination from 4 to 3 dimensions did not reduce the final stress significantly, but moving the data from 2 to 3 dimensions reduced stress by more than 8. The R-squared values for the calculated dissimilarities and plotted values was 0.97 for a non-metric fit, and 0.73 for a linear fit.

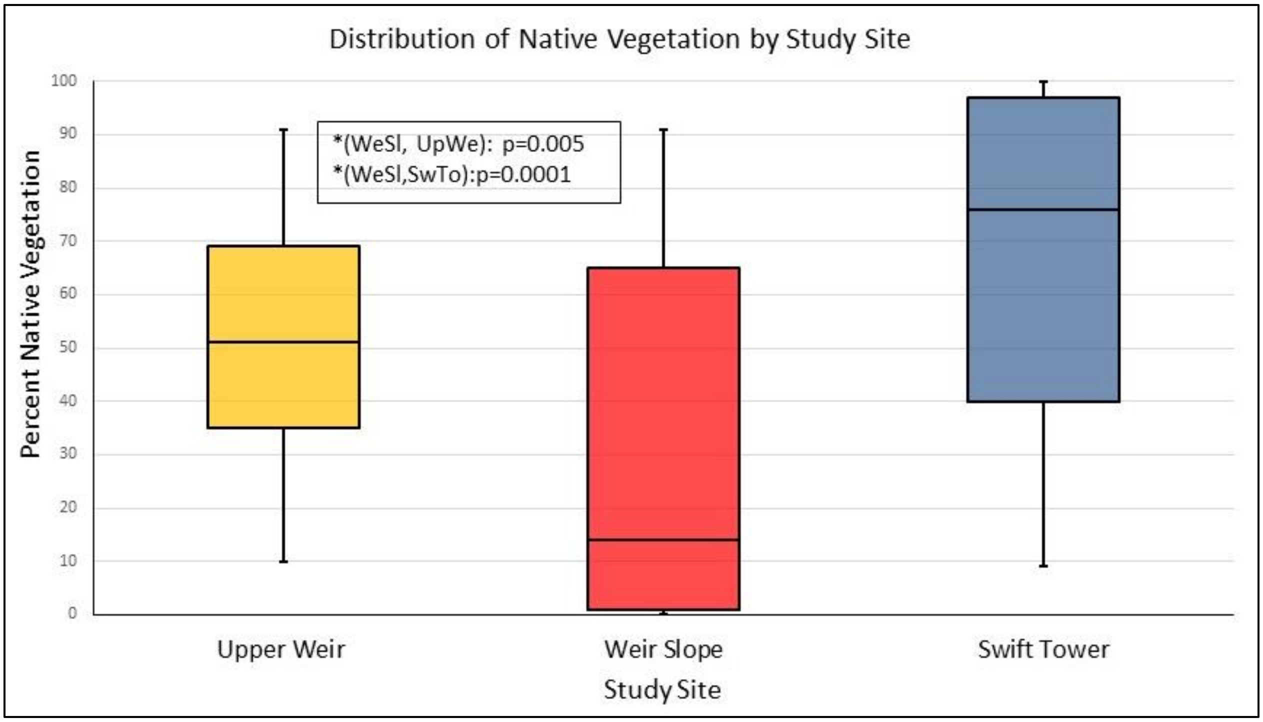

Figure 3.5: Distribution of percent native vegetation at the quadrat scale by study site. P-values for significantly different percent native vegetation are labeled according to site and marked with an asterisk (*).

Ordination results from NMDS show a correlation between species abundance and location. The ordination grouped points for Swift Tower largely in one dimension, visualized to the right of Axis 1 and 2 (since this is a two-dimensional diagram) in Figure 3.6. These quadrats had a higher density of six species: two native shrubs – oceanspray and trailing blackberry; and four native herbaceous species - snowqueen, cleavers, largeleaf sandwort, and false star lily of the valley (see Appendix B for scientific names). Oceanspray and is a plant widely used by Pacific Northwest Native Americans, with its inner bark used medicinally and its wood used to make a variety of tools (Moerman 1998). Trailing blackberry fruit was traditionally eaten fresh, dried, or mashed into cakes by a number of Native Americans in the region (Moerman 1998).

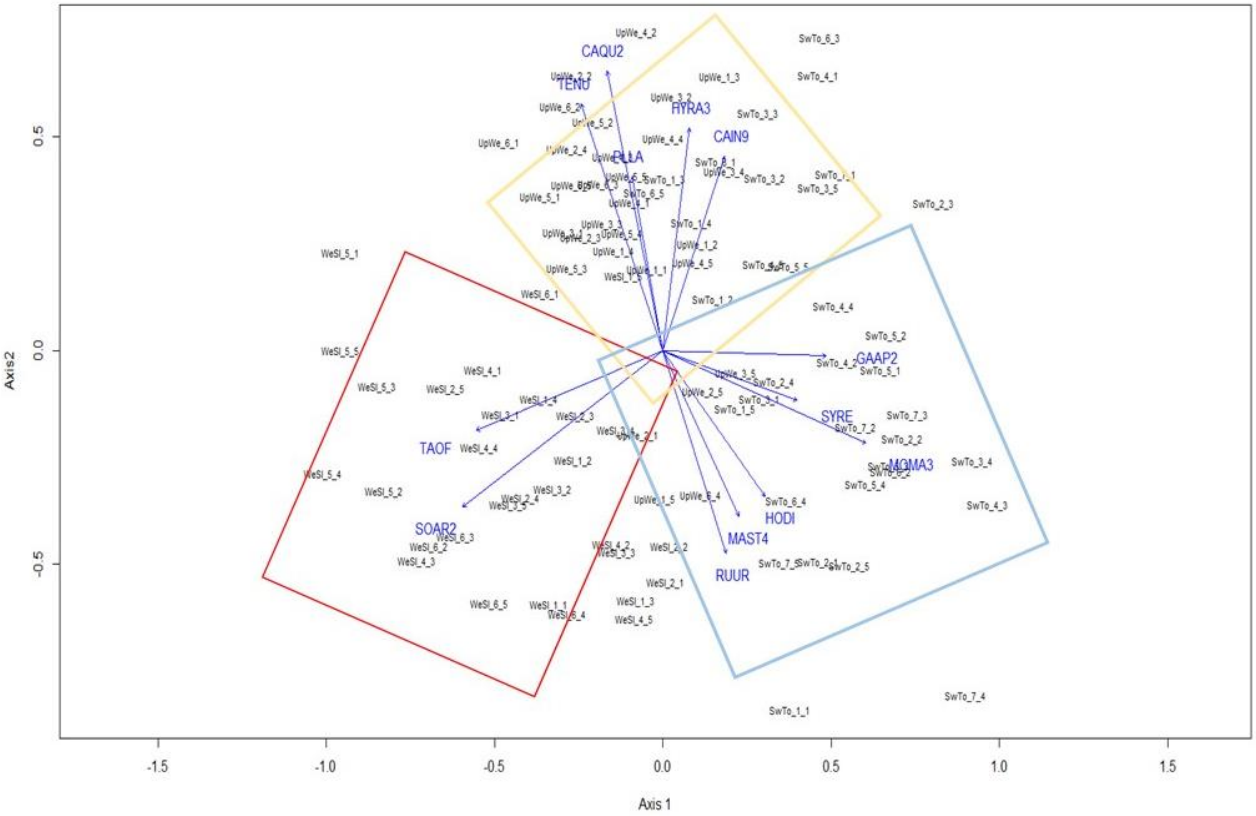

Figure 3.6: Non-metric Dimensional Scaling for site-by-species data. Species with highly significant ($p<0.001$) loadings are indicated in blue (see Appendix B for species codes) and are drawn toward their dimensional loading. Each point represents a quadrat, and is labeled by its site location, transect and quadrat number. Groupings (dimensions) are outlined by the colored squares. Please note that axes are arbitrary, and have been rotated to their current position to optimize the presentation of this three-dimensional ordination.

NMDS ordination grouped most Weir Slope points in a second dimension. Two invasive herbs have significant loadings for Weir Slope: field sow-thistle; and common dandelion. Dandelion is a common green and medicinal plant. The majority of Upper Weir points were centralized in a third dimension, visualized along Axis 1 in Figure 3.6, and had higher densities of five species: one native herb - common camas; one native graminoid – long stolon sedge; and three invasive herbs - English plantain, barestem teesdalia, and hairy cat’s-ear. Common camas is a traditional food for a number of Native Americans in the Pacific Northwest (Turner 2014, Storm and Shebitz 2006).

I further examined vegetative diversity by site by looking at the adaptive characteristics species with significant loadings have (Table 3.5), as these characteristics can suggest how a plant reacts to various types of ecological disturbance (Maslovat 2002).

Table 3.5: Adaptive characteristics of species with significant loadings by study site.

Site	Species	Fire adapted?	Dormancy	Soil	Sun level	Climate	pH range	Notes
UpWe	long-stolon sedge	Yes, sprouts back	Unknown	Often nutrient deficient	All	Not tolerant of extended drought	4.8 to 5.8	Common in early seral stages
	common camas	Yes, sprouts back	Partial	All soil types	Full	Moist in spring, dry in summer	Basic to acidic	Often found near vernal pools
	hairy cat's-ear	Yes	No	All soil types	Full to partial	Moist, cold or warm climates	Basic to acidic	Often found on thinned, disturbed sites
	English plantain	Yes	Yes	Well-drained	Full to partial	Dry to moist	Basic to acidic	Grows in disturbed sites.
	barestem teesdalia	Yes, survives fire in seedbank	No	Well-drained		Wet, but well-drained	Acidic	Grows well on disturbed sites
WeSl	field sow-thistle	Yes, sprouts back	Yes	Mesic	Full sun	Moderately wet	Basic to acidic	Prefers disturbed areas
	common dandelion	Yes	Seeds can remain in soil for 5 years	Most, but not high clay content	All	Dry to moist	Basic to acidic	Cannot compete in climax ecosystems
SwTo	false star lily of the valley	moderate resistance	Some	Shallow	All	Moist sites	Neutral to acidic	Dies when fire heats mineral layer.
	largeleaf sandwort	Yes	Some	Often rocky	Partial to none	Moist sites	5.2 to 7.4	
	oceanspray	Yes, sprouts back	Yes	Often nutrient deficient	Full to partial	Low moisture	5 to 7.5	
	snow queen	No	No	Forest soil types	Partial to none	Low moisture	Unknown	Minimal recovery after burning and logging
	cleavers	Killed if actively growing	Yes, when seed is partially buried	All soil types	Partial	shady and moist	5.8 to 7	Thrives in disturbed areas
	Pacific blackberry	Yes, sprouts back	Yes, when seed is partially buried	Often nutrient deficient	Full to partial	Moderately wet	Basic to acidic	Tolerant of periodic flooding

Species with significant loadings on Upper Weir displayed an ability to grow on either nutrient-deficient soils or those that are well-drained, as well as on a range of soil pH levels. Some species are also able to grow near sites with seasonal flooding and “maritime” conditions. Weir Slope species are able to thrive in most soil pH conditions, as well as in post-disturbance environments. Species with significant loadings on Swift Tower are fire-adapted and prefer moist climate conditions.

3.3 Tree Data

A total of 318 trees across all three sites were used for analyses: 108 from Upper Weir, 107 from Weir Slope, and 103 from Swift Tower. Trees that were counted twice had their second recording removed from the analyses. Both Weir Slope and Swift Tower had a relatively similar mix of oak and Douglas-fir trees recorded, while 100% of the trees recorded on Upper Weir were oak (Table 3.6).

Table 3.6: Overview of tree data for all study sites. Data is the average of all tree measurements by species and study site.

Site	Type	Total Type	Relative density	Dominant (%)	Codominant (%)	Suppressed (%)	Height (m)	DBH (cm)	Canopy cover (%)	Basal Area (m^2 ha^{-1})	Density (trees ha^{-1})
Upper Weir	QUGA	108	1	53.7	33.3	13	17.1	27	42.5	6.8	100
	Total	108	1	53.7	33.3	13	17.1	27	42.5	6.8	100
Weir Slope	QUGA	69	0.64	29.0	47.8	21.7	12.1	24.4	53.2	5.6	800
	PSME	38	0.36	47.4	36.8	18.4	23.3	49.4	53.2	25.2	300
	Total	107	1.00	35.5	43.9	20.6	16.1	32.4	53.2	13	500
Swift Tower	QUGA	67	0.64	26.9	49.3	23.9	10.1	30.8	41.0	4.5	100
	PSME	35	0.34	34.3	42.9	22.9	25.8	53.1	65.1	27	1000
	ALRU	1	0.01	0	0	100	14	11	90	1.0	0.00
	Total	103	0.01	29.1	46.6	24.3	15.3	20.6	20.6	12	500

Both Swift Tower and Weir Slope had similar percentages of oak to Douglas-fir tree measurements. Weir Slope had 64.5% oak and 35.5% Douglas-fir, while Swift Tower had 64.4% oak and 34.3% Douglas-fir, while. Swift Tower had the highest average tree height for Douglas-fir at 25.8 meters, while Upper Weir had the tallest oaks, on average, with a mean height of 17.1 meters. Both average oak and Douglas-fir DBH were largest at Swift Tower, with average DBH being 30.8 and 53.1, respectively.

Upper Weir had the lowest overall tree density among all three sites, yet Swift Tower had the lowest density of oak trees. However, oaks on Swift Tower are about 1/10 the density of Douglas-fir on the site. Weir Slope had the highest density of oaks at 800 trees per hectare, which was much higher density than the Douglas-fir on this site.

Tree density differed significantly between sites for Garry oak, but did not vary significantly for Douglas-fir density (Figure 3.7). Both Upper Weir's and Swift Tower's oak density was significantly lower than Weir Slope, yet Upper Weir and Swift Tower did not vary significantly from each other in terms of oak density.

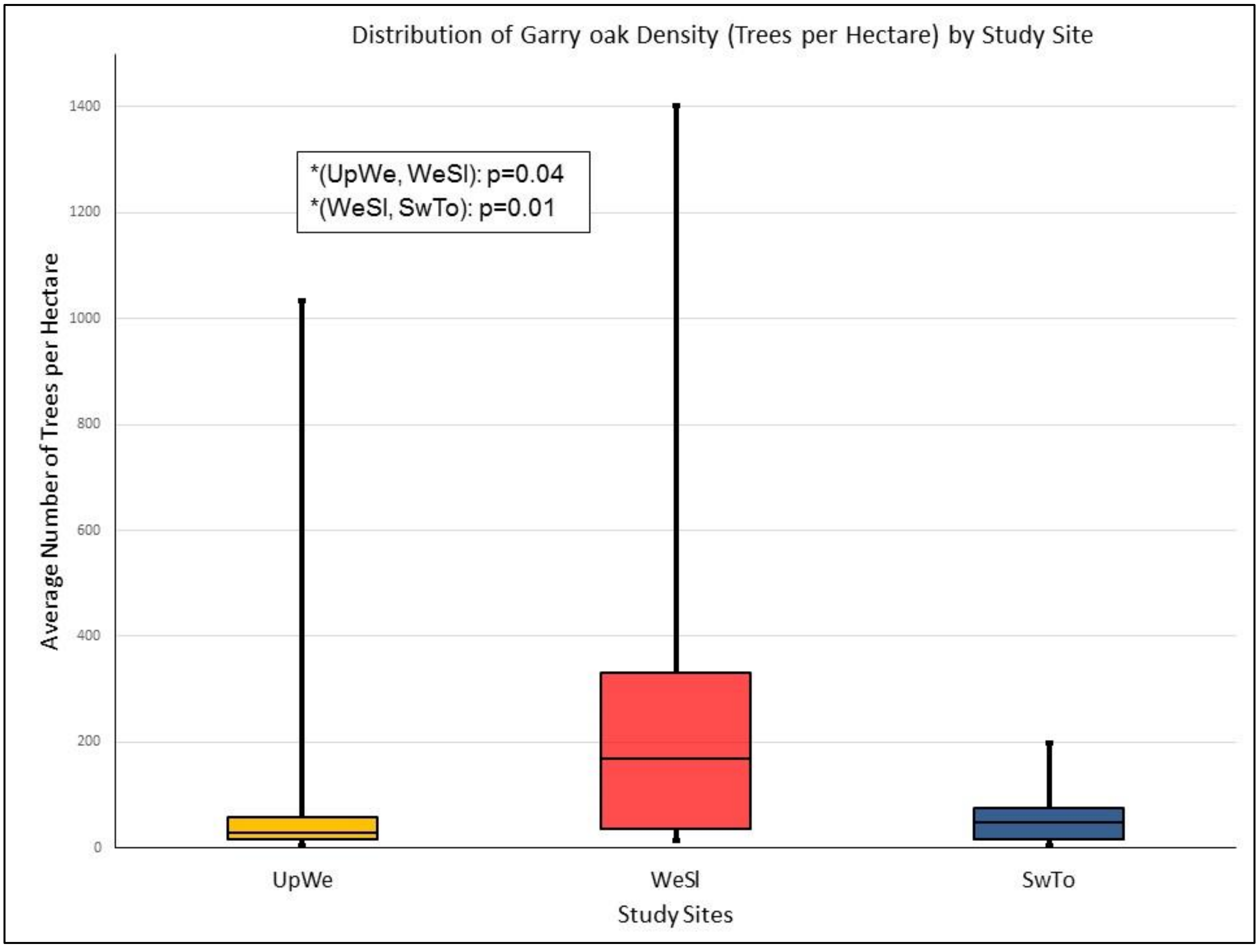

Figure 3.7: Distribution of oak density measurements by study site. P-values for significantly different distributions of oak density are labeled according to site and marked with an asterisk (*).

Tree variance across each site was further assessed geospatially to examine geographic patterns in the data.

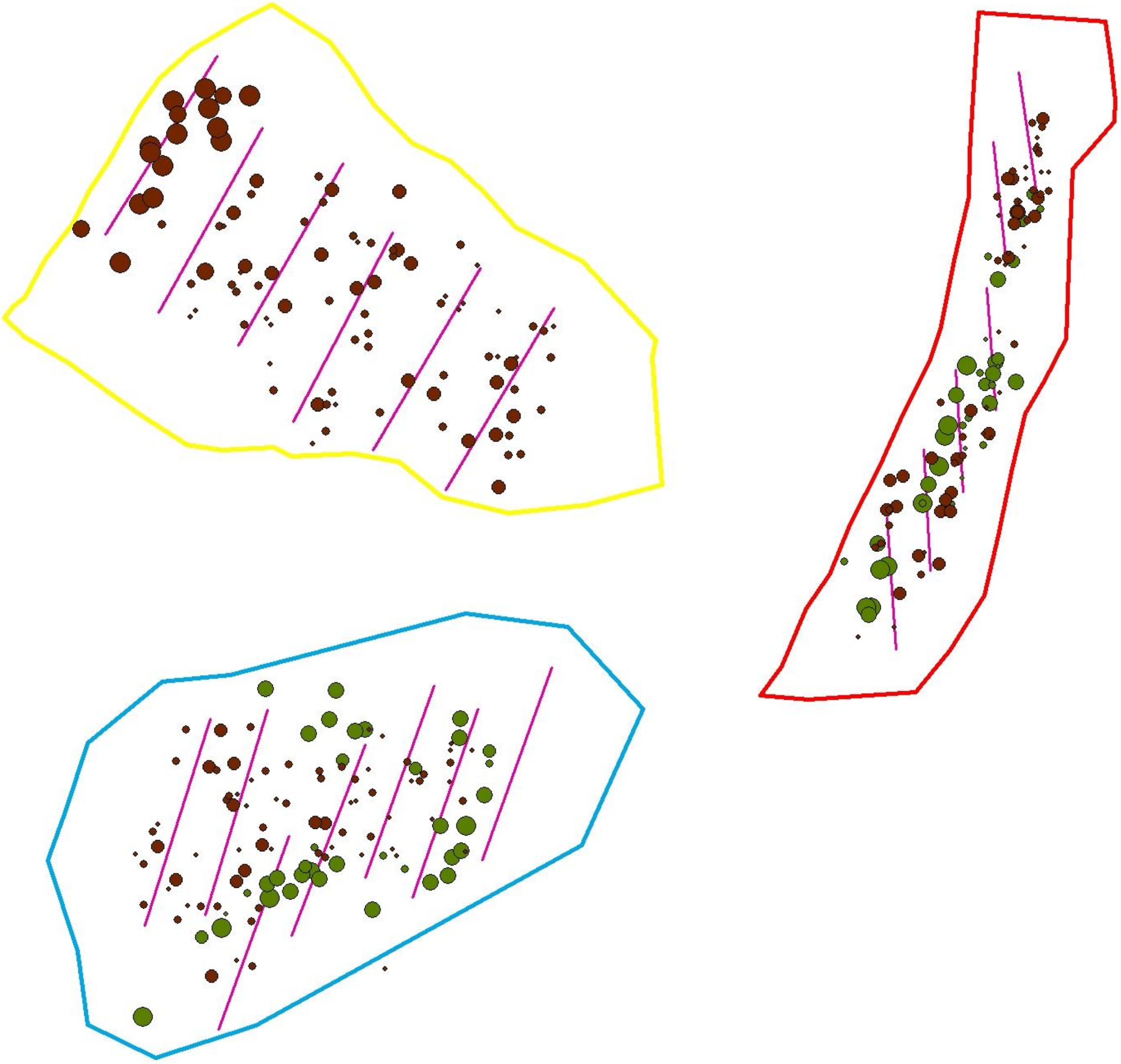

Figure 3.8: Comparison of tree heights by study site. Upper Weir's borders are outlined in yellow, Weir Slope is outlined in red, and Swift Tower is outlined in blue. All sites are oriented north in this figure. The largest circles denote trees between 35.1 - 53.9 meters tall.

Figures 3.8 and 3.9 show the locations of oak trees in brown, with Douglas-fir denoted in green. Heights and DBH are expressed through a size gradient, with the largest circles denoting the tallest and widest trees. Upper Weir's tallest trees are predominantly clustered along the northwest edge of the site, which faces Lower Weir and a large slope (Figure 3.8). Weir Slope's largest trees, both for Douglas-fir and oak, are concentrated on its southern edge, which has a much steeper slope than the site's northern half. Swift Tower's tallest Douglas-firs are concentrated on the north and south edges of the site, which border a Douglas-fir stand and part of Weir prairie, respectively.

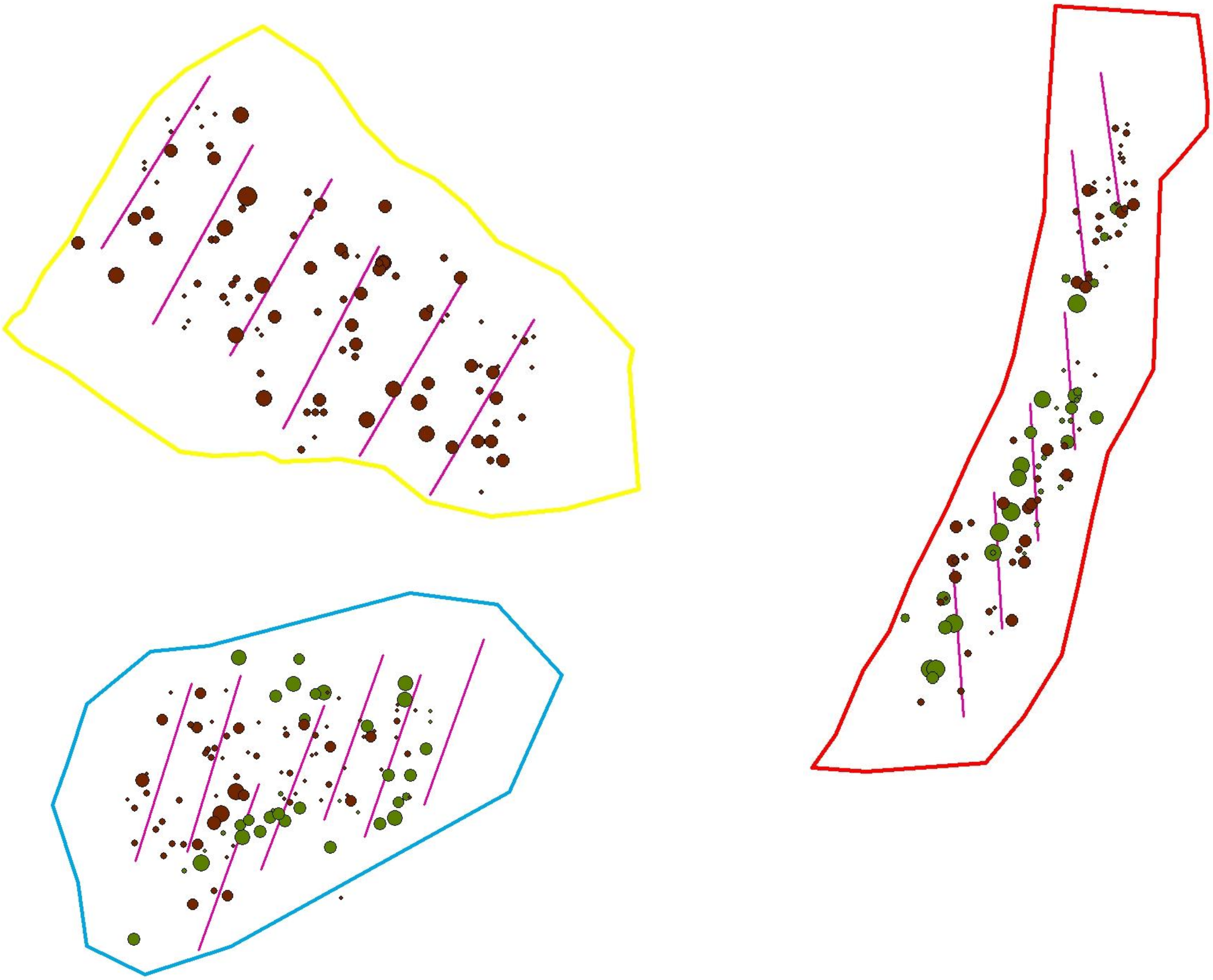

Figure 3.9: Tree DBH measurements by study site. DBH is expressed through a size gradient, with the largest circles denoting trees of between 89 and 113 centimeters.

DBH patterns across all sites were similar (Figure 3.9). Predominantly wider trees are in two clusters on Swift Tower, both on the north and south edges of the site. Trees with the largest DBH on

Weir Slope, similar to height measurements, are concentrated on the southern end of the site, where there is a much steeper slope.

However, on Upper Weir, the pattern of height and DBH are strikingly different - large-diameter trees are much more spread out across the site. As shown in Figures 3.8 and 3.9, both Weir Slope and Swift Tower's large DBH and tall height clusterings are strongly positively correlated.

I also assessed the growth morphology/number of trunks per tree across each site. Oaks have a tendency to sprout after being cut, being burned, or undergoing a similar disturbance, which can lead to multiple seedlings sprouting out of a former seedling/sapling/tree (Gucker 2007). This can eventually grow into a larger, multi-trunked tree. Sites that have a higher percentage of multi-trunked oak trees are more likely to have undergone some type of cutting/logging, so examining this on each site provides details as to the history of logging on that site.

Weir Slope had the highest number of trees with single trunks, with 88.5% of trees having single trunks. Only 11.5% were multi-trunked, and of these, all of them were had two trunks. Upper Weir had 79.6% of its trees being solitary trunks, while 20.4% of its trees were multi-trunked. Swift Tower had a similar breakdown, with 79.1% of its trees being single trunks and 20.9% being multi-trunked. When tested, both Upper Weir and Swift Tower's trunk data varied significantly from Weir Slope (p-values of 0.005 and 0.006, respectively), yet did not vary significantly from each other (Figure 3.10).

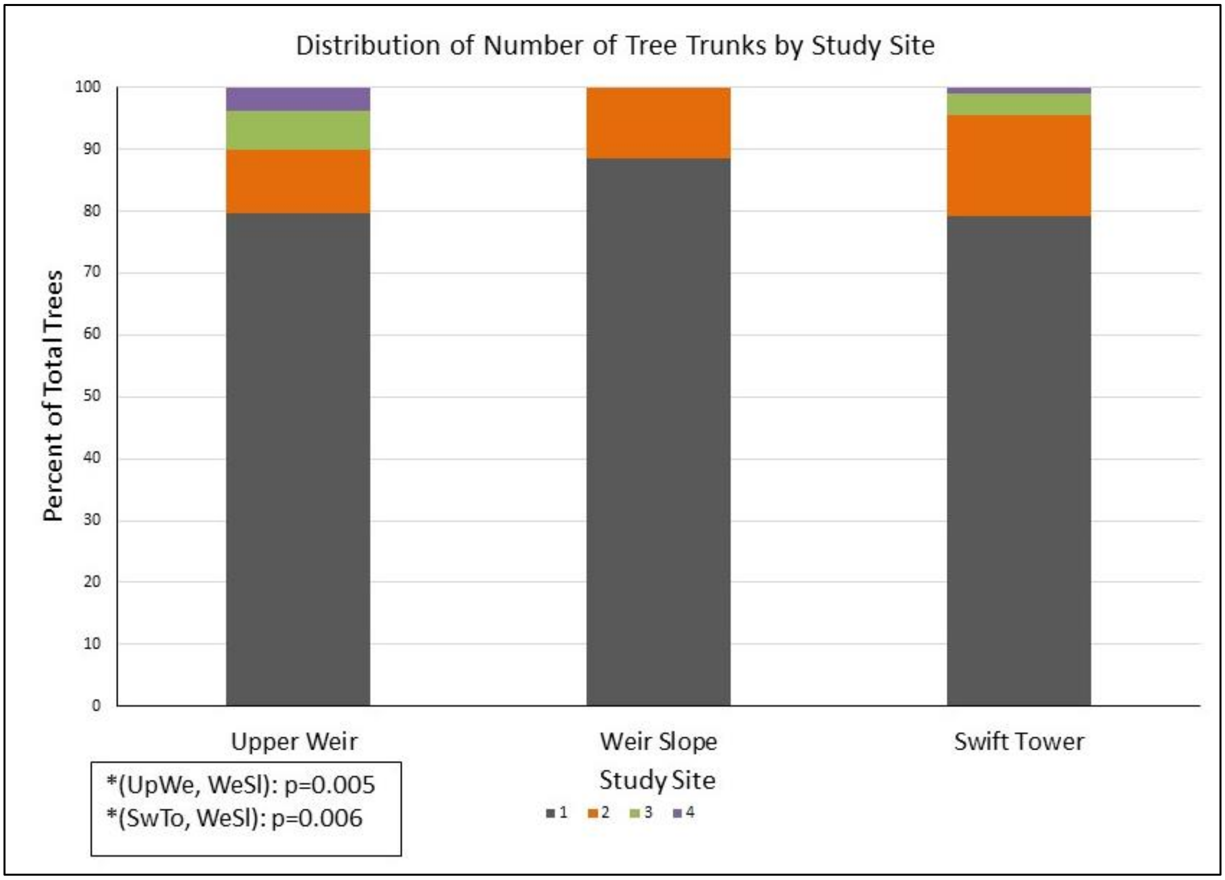

Figure 3.10: Distribution of the number of trunks per tree by study site. P-values for significantly different frequencies of number of tree trunks are labeled according to site and marked with an asterisk (*).

3.4 Analyses of Historical Land Type and Use

The 1853 GLO Land Survey for Township 17N, Range 1E shows both Upper Weir and Weir Slope sites were categorized as exclusively residing in the "Tenalcot Plains" (Figure 3.10). Tenalcot is the former name of this area prior to it being referred to as "Weir." Cross-references with other area GLO surveys of nearby areas that have survey notes attached indicated that many "plains" were the ecosystem categorized today as prairies (Bureau of Land Management 1853). Due to the lack of field notes attached to this particular township's survey, it is unclear how many and what types of trees were present here in 1853.

Swift Tower falls within the boundaries of a large swath of land labeled as "Land Rolling Hills, Timber Fir. Dense undergrowth of Hazle, Fern, Salal" (Bureau of Land Management 1853). Swift Tower's southern edge borders the Tenalcot Plains. While broad, the clear distinction between "plains" and "timber" with a "dense undergrowth" demonstrates that Swift Tower had a much higher density of Douglas-fir trees than Upper Weir and Weir Slope in 1853. At the section level of Township 17N in 1853, Section 32 (where both Upper Weir and Weir Slope are located) had 259.01 hectares outlined as prairie, and less than one (0.99) hectare classified as timber fir/cedar in the far northwest corner. Section 28 (where Swift Tower is located) had 31.84 hectares designated as prairie, and 228.16 hectares designated as timber (fir/cedar).

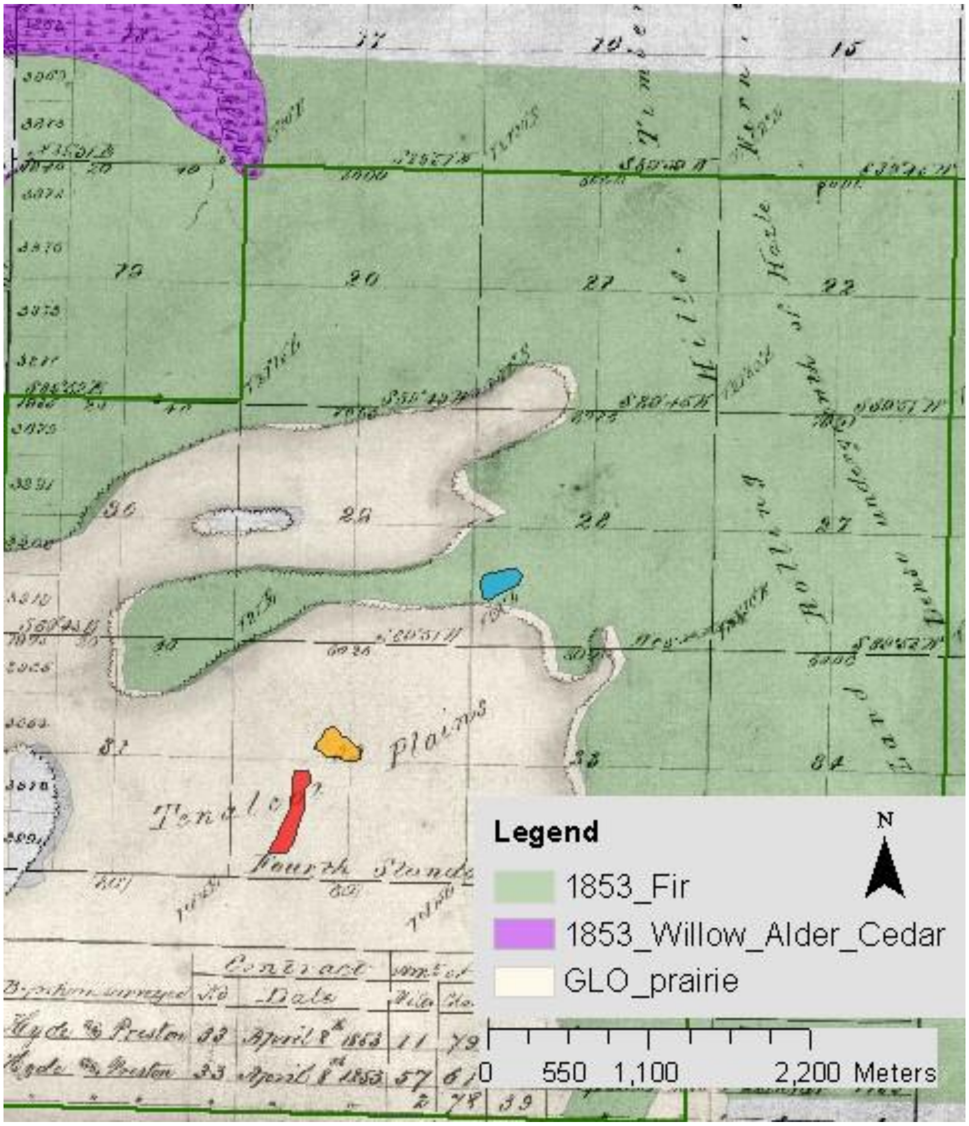

Figure 3.11: Land types of study sites, 1853. Land areas noted as "plains" are marked in beige, areas of "timber" with dense underbrush are highlighted green. Surrounding "Cedar, Alder Swamps" are denoted in purple. ESRI, 2015.

The smaller scale of the 1908 timber survey provide additional details about historic conditions for each site. According to the official instructions given to timber cruisers by the commissioners of the 1910 Timber Cruise Inventory, they were to “Examine only those tracts [sections] that contain two hundred thousand feet of timber or a sufficient amount of merchantable timber to justify a close cruise, but make a brief report on all tracts of forty acres coming under your observation” (Washington State Archives 1908).

Both Upper Weir and Weir Slope sites are located on Section 32, Township 17N, Range 1E. Section 32’s brief report, which starts with the line, “All prairie” includes only one estimate of timber for the Section in the NWNW block with a measurement of “20m of fir timber.” The “m” in this era’s surveys stood for “mille” or “thousand,” board feet (Wilderman and Major 2016), so 20m would be 20,000 board feet, or 47.19 cubic meters. Timber cruiser A.B. Smith noted that timber on this section was “2nd grade,” with about “2m of fir per tree.” Assuming Douglas-firs in 1908 with this volume had similar dimensions to trees with this volume in 2016, Section 32 had approximately 10 trees, 30 -37 m tall, with a 60-70 cm DBH. Comparing that to current average Douglas-fir height on Weir Slope, which is 23.3 meters tall with an average DBH of 49.5cm, the average size Douglas-fir tree on this section were much larger in 1908. Comparing 1908 land type to 1853, it makes sense that all Douglas-fir land type would be in the NWNW block of the section, where most “Timber fir” land type was in 1853. Both Upper Weir and Weir Slope are found exclusively on the “prairie” land type in 1908.

Swift Tower is located in Section 28 of Township 17N Range 1E (Figure 3.11). This site had more than the 200,000 feet of timber threshold, and so includes estimations of timber in 1/16 blocks. These timber estimates range from 2465.9 to 236 cubic meters of fir per block. Trees in the NW, NE, and SW quarters are characterized as being “mostly young and of a poor quality.” No estimates of average cubic meters of timber per tree are indicated for these young trees, yet neighboring sections note about 4.7 cubic meters per tree, so I used this figure for my estimations.

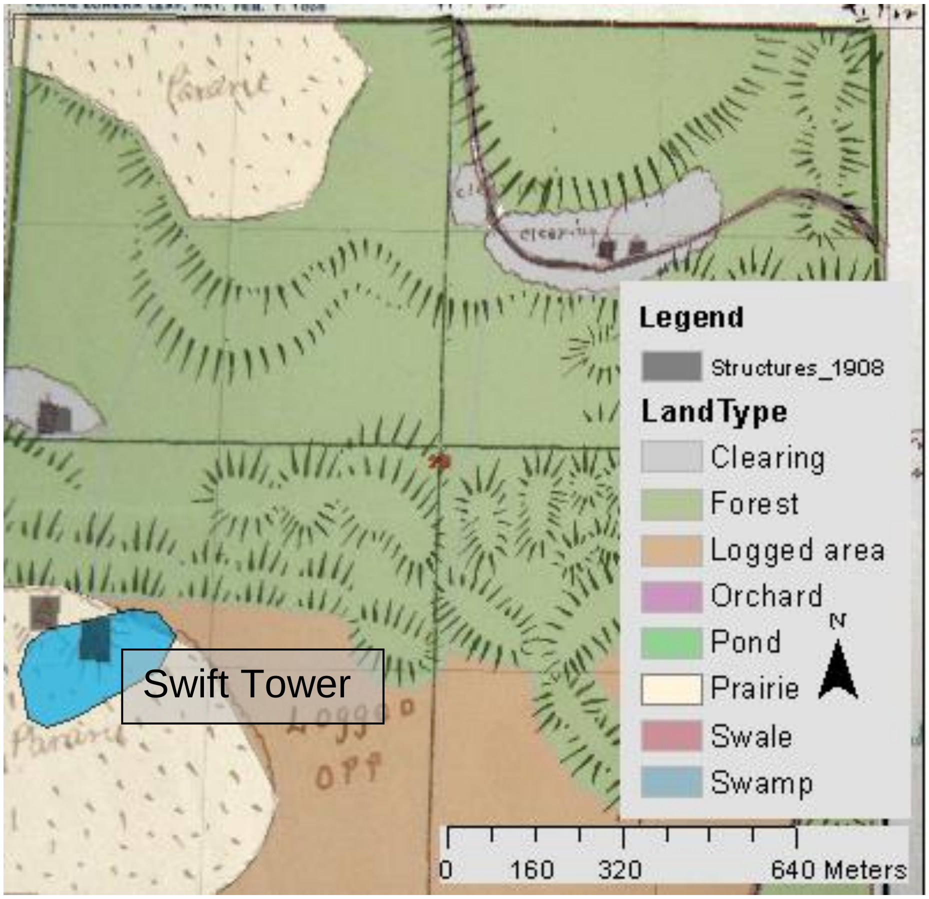

Figure 3.12: Land types outlined for Section 28 in 1908. Location of Swift Tower study site is highlighted in blue. Note the location of a structure – likely a house or barn – in the northern half of Swift Tower in 1908. ESRI, 2015.

Section 28 had 164.5 hectares of forest at a density of approximately 31 trees per hectare, based on the areas outlined on the surveyor's 1908 maps as well as the rough timber density (19,540 cubic meters total) recorded across the site. Section 28 also has 41.18 hectares of prairie, and 41.96 hectares of logged land and 12.3 hectares of clearings. These estimates were made from measurements taken from the georeferenced timber cruise map (Figure 3.11) with land types outlined. Approximately 3.88 hectares of Swift Tower is "prairie," with 0.16 hectares in the NE side of the site designated as a "clearing" in 1908. Surveyor Smith provided no notes for how these clearings were established, yet the etymology for "clearings" during this time period indicates that the word was used exclusively in relation to land that had recently had its timber, grass, or shrubs removed for the express purpose of homesteading (OED Online 2016). Therefore, it's likely that these open spaces were created shortly before the 1908 timber cruise. Smith also notes that the NE quarter of Section 33, directly south of Section 28, had signs of an "old burn into willow, hazel, and small fir" (Washington State Archives 1908).

Surveyor records on trees in the SE quarter of Section 28, while noted as primarily old growth, indicate that many of these trees are "rotten." The timber cruiser notes that this section would make "good grazing land," demonstrating that timber quality and density here are likely not high enough to develop a timber sale. Lack of merchantable timber – or at least a recent reduction in timber – is further indicated by the area marked as "logged off" by the 1908 surveyor (Figure 3.11). This figure shows greater detail than depicted in the 1853 survey map, in part due to it being conducted at a much finer scale. The GLO was done on the township level, or approximately 9,300 hectares, the 1908 timber cruise was conducted on the section scale, or in 260 hectare areas. Two well-worn trails are shown on the map in this section, as well as several houses and/or barns. Two substantial prairies do not correspond to the prairie boundaries shown in the 1853 GLO survey map. Based on this visual interpretation of Section 28, Swift Tower has a history of logging, as well as intensive human activity during the early 1900s.

Land types for Sections 32 and 28 in 2016 are markedly different than 1908 and 1853 (Tables 3.7 and 3.8). Image classification done through ESRI geospatial software created a guided land categorization for all three study sites as well as the two sections (32 and 28) the sites occupy.

In 2016, Section 32 had 205.02 hectares of prairie – a 54.97 hectare decrease from 1908. Douglas-fir, or timber land type, increased by 13.7 hectares between 1908 and 2016 (Table 3.7). The "new" land type classifications of oak savanna and oak woodlands accounted for 2.64 and 38.63 hectares, respectively, in 2016. Upper Weir is completely classified as oak woodland in 2016, while 85.6% of Weir Slope is classified as oak woodland – the remaining 14.4% is classified as Douglas-fir type (Table 3.8).

Section 28 has 205.6 hectares of Douglas-fir land type, an increase of 41.1 hectares from 1908, yet a decrease of 22.59 hectares between 1853 and 2016 (Table 3.7). Prairie decreased by 28.7 hectares between 1908 and 2016, and decreased by 19.4 hectares from 1853. Clearings increased by 7.6 hectares, and the new land types of oak savanna and oak woodland accounted for 10.7 and 11.4 hectares, respectively. Less than 1% of Swift Tower is classified as prairie in 2016, with the new land types (for 2016) of oak woodland and Douglas-fir forest making up 2.9 and 1.1 hectares, respectively (Table 3.8).

Table 3.7: Land type change over time at the section scale. Areas are based on geospatial calculations through ESRI software. Years were chosen based on available surveyor representations (1853 and 1908) and aerial photographs of the areas (2016).

	Section 32			Section 28		
	1853	**1908**	**2016**	**1853**	**1908**	**2016**
Prairie (in ha)	259.01	259.99	205.02	31.84	41.18	12.45
Clearings (in ha)	--	--	--	--	12.3	19.92
Logged Area (in ha)	--	--	--	--	41.96	--
Oak Savanna (in ha)	--	--	2.64	--	--	10.7
Oak Woodland (in ha)	--	--	38.63	--	--	11.38
Douglas-fir Forest (in ha)	0.99	0.003	13.71	228.16	164.46	205.57

Table 3.8: Land type change over time at study sites. Areas are based on geospatial calculations through ESRI software. Years were chosen based on available surveyor representations (1853 and 1908) and aerial photographs of the areas (2016).

	Upper Weir			Weir Slope			Swift Tower		
	1853	**1908**	**2016**	**1853**	**1908**	**2016**	**1853**	**1908**	**2016**
Prairie (in ha)	4.32	4.32	--	6.17	6.17	--		3.88	0.031
Clearings (in ha)	--	--	--	--	--	--		0.16	--
Oak Savanna (in ha)	--	--	--	--	--	--		--	--
Oak Woodland (in ha)	--	--	4.32	--	--	5.28		--	2.9
Douglas-fir Forest (in ha)	--	--	--	--	--	0.89	4.04	--	1.11

Landowner records and corresponding census records for Section 32 and 28 from 1825 – 1915 show a quick succession of different owners and land uses. The Treaty of Medicine Creek, which limited access to areas like RTA 20 and 21 occurred in 1854. All blocks of Section 32 and 28 in Township 17N were bought from the United States Government between 1897 and 1899 – more than 40 years after the treaty was signed.

Table 3.9 outlines the number and variety of landowners that Section 28 and 32 were owned by between 1897 and 1943, when JBLM bought both sections from the current owners. All of Section 32's land patents were purchased by Andrew Chambers in 1899, who was a farmer by occupation. The 1908 timber cruise notes that some or all of Section 32 were previously George Huggins's ranch, which he sold in 1907 (Washington State Archives 1908). Additional historical records (Washington State Historical Society 1922) indicate that Mr. Huggins owned the Woodland Driving Park (a race track) in Lacey. Due to this, both Upper Weir and Weir Slope sites may have experienced heavy grazing, ground compaction and high inputs of horse excrement between the time G. Huggins purchased the site - sometime after 1898 - and 1907, when he sold the site. However, this would not have necessarily been the first time horses were present on the landscape – the Native Americans in southwest Washington were classified as "equestrian" (Gibbs 1855) people, with Chief Leschi owning more than 50 horses (Meeker 1905). The treaty of Medicine Creek directly specifies the right of Native Americans to allow their horses to roam on lands unclaimed by settlers (Stevens 1854). It is likely that all sites had some history of horse activity, yet this additional, concentrated horse activity in the early 1900s on Upper Weir and Weir Slope is worth noting as a different type, or at least frequency, of disturbance.

Table 3.9: Land ownership by site over time. Land ownership sales are noted by year, name of new landowner and land use.

Site	Year	Landowner	Use
Upper Weir	1899	Chambers	Farm
	1908	Mulhall and Weir	Farm or Dairy
	1937	Phillion	Timber
Weir Slope	1899	Chambers	Farm
	1908	Mulhall and Weir	Farm or Dairy
Swift Tower	1898	Neilson	Unknown
	1902	Troller	Farm
	1903	Ostrauder	Farm
	1908	Weyerhaeuser	Timber
	1908	Mulhall and Weir	Farm or Dairy

In 1908, Upper Weir and Weir Slope (as well as sections of Swift Tower) were both owned by Mulhall and Weir, who according to records were a "general" farmer and a dairy farmer, respectively. Mulhall and Weir split up these landholdings sometime between 1915 and 1937, when records indicate that Weir was the sole owner. Both Upper Weir and Weir Slope likely had trees cut down by different owners, yet only Upper Weir has a record of logging activity, when the western half of the site was sold to an owner for logging purposes. These timber harvest(s) occurred between 1915 and 1937.

Section 28 went through a succession of several landowners starting in 1897. All blocks of Section 28 had land patents secured between 1897 and 1901. Swift Tower was purchased by the Neilsen family in 1898. Records of the head of household's occupation could not be found, but it is likely that they were homesteading on the site. Troller bought the land in 1902, followed by Ostrauder in 1903. Both Troller and Ostrauder were farmers according to census records. Weyerhaeuser and Mulhall and Weir owned the north and south half, respectively, of Swift Tower, until the land was purchased by JBLM in 1943, with Mulhall took sole ownership of the block sometime between 1915 and 1937. Due to Weyerhaeuser owning part of the site, it is likely that Swift Tower had timber harvests between 1908 and 1943.

3.5 Tree Ring Data

Tree ring data provided additional details that assisted in identifying land changes and uses on the site. I used a total of 40 oak cores (between 12 and 15 cores for each site) for my final analyses. Cores taken from oaks with severe heart rot were not dated and analyzed due to many pieces being too fragmented for me to properly date and examine ring width. The oldest tree cored across all three sites was 208 years old (dating back to 1808) on Weir Slope (Figure 3.13). Trees cored on Weir Slope dated back to between 1808 and 1904, with an average age of 144 years. Oaks cored on Upper Weir ranged between a starting year of 1870 and 1944, with an average age of 112 years. Swift Tower had the youngest trees, with starting years ranging between 1883 and 1949, with the average tree cored being 94 years old. Swift Tower had two distinct age classes, with six cores dating back to between 1936 and 1949, and six oaks dating between 1883 and 1914.

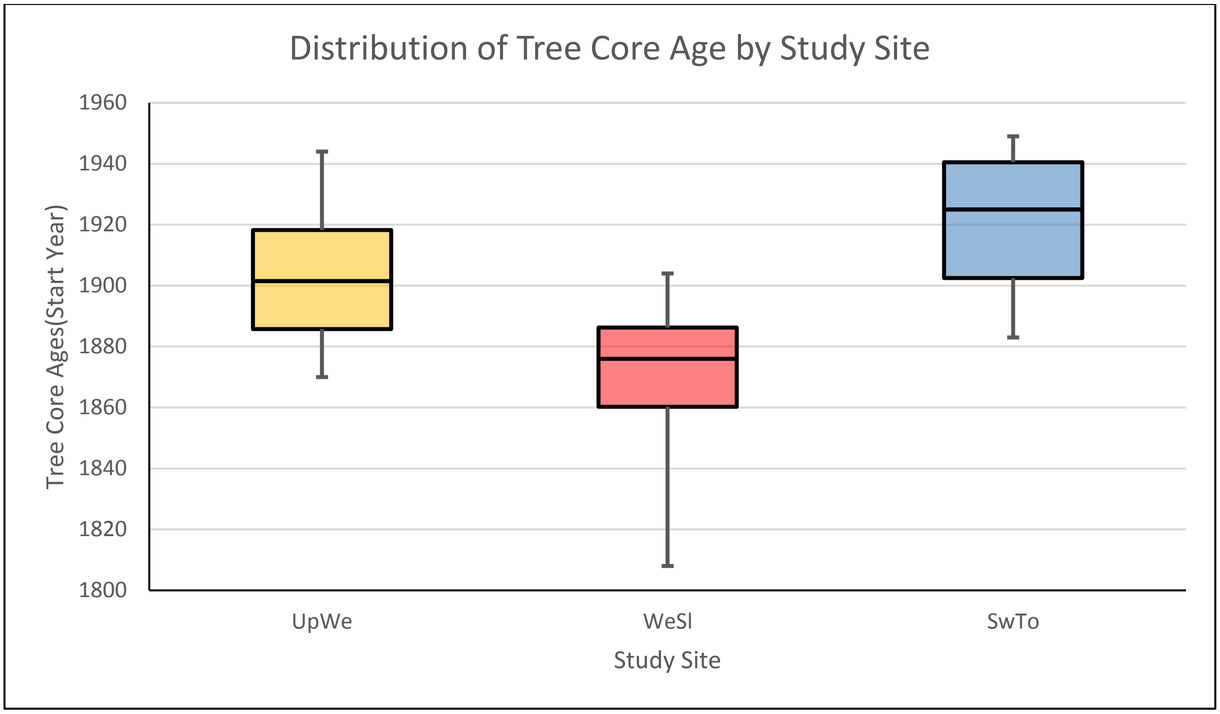

Figure 3.13: Box-and-whisker plot summarizing the distribution of tree ages for trees cored on all three study sites.

CDendro software found appropriate reference curves for most cores in Upper Weir and Weir Slope sites; however, Swift Tower cores were difficult to correlate with the other two study sites. All cores and their adjusted ring width values were tested for significance using T-tests. I used the results from these T-tests to build master reference curves for each study site and across all sites. Samples added to a master reference curve had to correlate to the reference curve by at least 0.35 (correlation values range from -1 to 1) and overlap with the reference curve on at least 50 points. Using this criteria, I was able to create reference curves with 10 Weir Slope cores, 9 Upper Weir cores, but only 4 Swift Tower cores. Due to many Swift Tower cores being much younger, and therefore having fewer “points,” I adjusted the reference curve conditions to have cores overlap by 20 points; however, no additional cores met this criteria, so I kept the final correlation at 4 cores for Swift Tower.

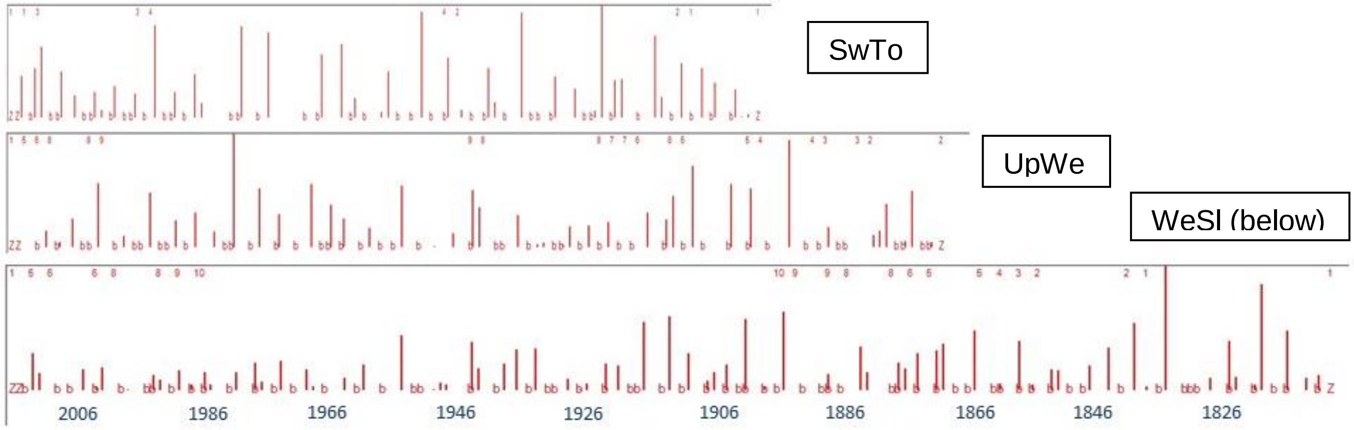

Figure 3.14: Composite of skeleton plot averages by site. Swift Tower's composite is the top skeleton plot, followed by Upper Weir and Weir Slope. Long red lines indicate narrow rings – the longer the line, the more narrow the ring was relative to its neighboring tree rings. Particularly wide rings are indicated by the letter "b." The youngest rings (2016) are indicated as "ZZ," while the oldest ring dated for each site is indicated by a single "Z." Skeleton plots have been scaled to match the timeline of dates shown at the bottom of the figure.

Data between 1855 and 1808 are only available for one tree (on Weir Slope), so these data were not included in the overall analysis of the tree cores, yet provide a detail as to when the earliest trees showed up on Weir Slope – 45 year prior to the 1853 GLO survey. Both Upper Weir and Weir Slope have narrow rings site-wide around 1896 (Figure 3.14). All three sites have narrow rings around 1942 to 1943 and 1955 to 1956. Both Upper Weir and Swift Tower have particularly narrow rings around 1980. Oaks across all three sites had wider rings around 1930 to 1932, as well as around 2007 to 2009.

Rings for 1900, 1945 and 1980 were all particularly narrow on Weir Slope, indicating periods of suppressed growth on the site (Figure 3.14). A period of wider rings occurred between approximately 1885 and 1895, indicating conditions on the site were more conducive to tree growth. Another period of wider rings occurs between approximately 1925 and 1935, as well as between 1990 and 2005. Many tree cores taken in the upper slope/eastern half and the northern section of the site have a pattern of tree rings in the early 1980s (1983-1985) that go from wide, then narrow rings, to wide, then narrow, yet this pattern was not present across the site, and did not show up as strongly in the composite skeleton plot for Weir Slope.

The narrowest growth rings on Upper Weir occur on the site on 1895 and 1980, with narrow rings also occuring around 1910 and 1967 (Figure 3.14). Year 1895 had narrow growth rings across Upper Weir, but specifically in oaks along the western edge/upper slope of the site. Year 1980 was a thin ringed year across the site, yet 1981 -1983 were wider rings. Periods of wide rings occur on Upper Weir between 1888 and 1900, 1929 and 1935, as well as between 1958 and 1970.

The narrowest ring for Swift Tower occurred around 1900, with additional years only slightly more narrow than other neighboring years. Swift Tower had a pattern of extremely thin rings (little growth) across the site between 1976 and 1980. While this pattern was very apparent when I was manually dating the cores, this pattern did not show up as strongly when I digitized the core results in CDendro. Periods of wide rings on the study site are found between approximately 1950 and 1962, as well as 1990 and 1994. Trees cores taken from the southeast section of the site (tree cores 7, 13, and 14) have markedly similar tree ring patterns, with the strongest patterns in 2004-2006, 1994-2000, 1975, and 1959-1962. I could not verify any fire scars on the tree cores.

4. DISCUSSION AND CONCLUSION

4.1 Patterns in Species Distribution and Environmental Variables

Native species cover differed significantly from one site to another, and all three sites contained species that were used traditionally as food or medicine. However, Upper Weir's most common species – common camas – is well-known as a traditional food, so its significant loading and high frequency across the site provide some evidence that this particular area may have been cultivated for the plant. Other areas may have also been cultivated for camas; however, the effects of different forms of disturbance may have affected those sites' abilities to retain camas. For example, while camas readily propagates in post-fire environments, it may be excluded on sites with a high level of shade. Although canopy cover was not significantly different between sites, tree density (see discussion below) can prompt additional shading on a site, and may have limited any camas from reproducing on sites like Weir Slope or Swift Tower. Upper Weir has also had twice as many prescribed burns as Weir Slope and 8 times as many prescribed burns over the last three decades as Swift Tower. A lack of burning, or less burning frequency since 1987 could have affected camas frequency – or other species frequencies - on both sites. The lack of fire on Swift Tower also may explain the presence of shrub species with significant loadings at this site, while both Upper Weir and Weir Slope have only forb and graminoid species with significant loadings.

Both Upper Weir and Swift Tower have significantly lower oak density than Weir Slope. Looking at the environmental variables that had significant p-values, I found that many of them could be related to density. Primary disturbance, on Upper Weir and Swift Tower was significantly different than it was on Weir Slope. Weir Slope most frequently had signs of fire disturbance. However, as mentioned above, Upper Weir has had twice as many prescribed burns as Weir Slope, and both Weir Slope and Upper Weir had their most recent burn (at the time of observation) in 2014. Weir Slope's visible signs of fire disturbance were primarily burned branches and logs, which display signs of a burn much longer than non-woody vegetation and organic litter would. Weir Slope's quadrats, compared to Upper Weir, also had a much higher percentage of woody debris. Woody debris, of course, comes mainly from on-site trees, and would show up in the site's understory more frequently with a higher density of trees.

Observations of visible signs of quadrat-level disturbance provide a localized, quadrat-scale measurement of effects of site enhancement activities and past site use, and were highly correlated with species composition at each site. Secondary disturbances, which had considerably more variability across each site than primary disturbances, were significantly related to invasive species cover (more so than primary disturbance factors). This demonstrates that all categories of disturbance have a strong effect on species composition, and contribute to native species presence and density on a site. However, these effects are likely both positive and negative. Thom and Seidl (2016) found that site disturbance in temperate and boreal forests, while resulting in positive increases in species richness and overall habitat quality, simultaneously decreased carbon storage and overall ecosystem carbon.

Frost *et al.* (1997) found that dense canopies suppress understory productivity in oak systems that receive more than 50 cm of precipitation per year. All three sites receive an average of 101.6 - 127 cm per year – far beyond 50 cm. Although differences in canopy cover between sites were not statistically significant, these measurements only recorded canopy cover directly overhead. A higher density of trees creates more multi-directional shading at different times throughout the day, and therefore affects which plants are able to adequately establish on-site. Weir Slope also had the highest average percentage of bare ground per quadrat, which provides some indication as to how few species can readily establish with the site's current conditions. While this is likely not all due to tree density (see section 4.3 below for further discussion), it is one of the driving forces behind study site differences in vegetation. Interestingly, both species with significant loadings on Weir Slope prefer full sun, which seems to contradict the fact that Weir Slope's added tree density would create additional shading on the site. It may be that these species are thriving in microsites throughout Weir Slope, rather than across the site as a whole. This overarching microsite-level plant suitability could also partially explain the higher percent of bare ground across site-wide quadrats.

Soil moisture levels, and correlating plant suitability on Weir Slope soil, could also be tied to tree density. A higher density of trees means that the trees would be taking up more water across the site, leaving less for other vegetation types. Although both species with significant loadings on Weir Slope prefer moist conditions, both are also able to remain dormant in the soil for long periods of time, which allows them to propagate on-site primarily when conditions are most suitable.

Additional soil measurements – such as deep soil cores – would provide details into the levels and types of disturbances across the site and within each quadrat. Soil measurements for nutrient levels, nutrient ratios, and filtration rates are recommended to further define the effects the soil has on species composition.

4.2 Tree Core Analyses and Land Patterns

Tree ring patterns on Weir Slope and Upper Weir between 1885 and 1900 are very similar, with both showing a period of wider rings. This period is when both of the sites were homesteaded. It is likely that larger trees at both sites may have been selectively cut down at this time, creating additional canopy openings and stimulating growth of the remaining trees on the site. Narrow growth rings around 1895 to 1900 for all three sites are likely all due to the same force. Although I could not find weather records for the area prior to 1934, I did find a report that stated 1900 was the year that Frederick Weyerhaeuser purchased 900,000 acres in Washington state, mostly, if not all, for timber harvesting purposes. There was a lot of logging activity in and around all three sites during this period – several lumber and timber companies came to the area, and may have purchased the wood from many homesteaders. Although I found only two records of logging during this time – one on Swift Tower and one on Upper Weir – the reduction in timber across all three sites is highly likely. Therefore, it’s also likely that each site had a new “normal” in terms of growth following intensive timber operations, so growth rings for 1900, by comparison, would be comparatively much more narrow after logging had allowed trees to be “released.”

Narrow tree rings on Weir Slope around 1945 are likely due to the drought in the Puget Sound between February 1938 and April 1942, when conditions ranged between -4.1 and -4.7 of normal precipitation (King *et al*. 1977) on the Palmer Drought Index (which spans between -10 for dry and +10 for wet). Conditions of prolonged periods below -1 on the index constitute a drought. While tree rings in 1945 are a few years post-drought, reduction in tree growth can often occur after a drought, due to the tree's loss of roots and root hairs, and thereby the tree's ability to absorb nutrients and water (Kujawski 2011).

Narrow rings around approximately 1980 across Upper Weir and Swift Tower are likely due to the May 1980 eruption of Mount St. Helens. Volcanic eruptions often affect tree growth negatively (Pieper *et al*. 2014, Mann *et al.* 2012). This narrow ring could have also been due to the 1976 and 1977 drought, considered the worst in Pacific Northwest recently recorded history, when precipitation averaged -4.7 of normal on the drought index (King *et al*. 1977). The thin rings for Swift Tower between 1976 and 1980 support the latter drought as the culprit; however, it is likely a combination of both the drought and eruption that caused limited growth.

Swift Tower's maximum tree age lines up well with information from the 1908 timber cruise surveys. Areas that are marked as "logged off" on 1908 maps line up well with the establishment dates for the oldest trees on the site (dated to 1883). Although Swift Tower is west of the area marked as "logged off" in 1908 timber cruise surveys, additional "clearings" throughout Section 28 demonstrate that much of the area was highly altered around this time. The presence of two distinct age classes – between 132 and 101 years old and between 79 and 66 years old – also makes sense. The younger age class dates from between 1936 and 1949, which is close to the time that Weyerhaeuser and Mulhall sold their portions of Swift Tower to JBLM (in 1943). It's likely that both parties wanted to acquire as much value from the land prior to selling, so each probably harvested timber from the site shortly before selling it in 1943.

Examining oak core results alongside tree morphology/trunk data provides additional information about the history of each site. Oak trees that survive a logging event that removes larger, dominant Douglas-fir trees, for example, will often show signs of being released after the stand's canopy has opened up. Conversely, root and root crown sprouting is common after a logging episode in which the oaks are cut, or following a particularly severe fire that results in the topkill of mature trees (Gucker 2007). Such resprouting is often evident in stands for decades or centuries, as it results in numerous multi-trunked oaks. The significantly higher presence of multiple-trunked trees on Upper Weir and Swift Tower compared to Weir Slope indicates that both of these sites likely had more logging in their past than Weir Slope. Land ownership records suggest this, with both Upper Weir and Swift Tower being owned by individuals or companies for the purposes of logging in their past (Table 3.9. Weir Slope's significantly lower number of multi-trunked trees and significantly higher density, further support this lack of historic timber sales on the site. The site's significant slope is one likely reason for this lack of logging – taking any trees off of the site would have likely required more intensive labor than a timber harvest on flat sites like Upper Weir or Swift Tower. On Weir Slope, the encroachment of Douglas-fir and the high density of Garry oak is likely heavily influenced by a lack of burning or logging on the site prior to 2006. Douglas-fir encroachment is likely very recent, as no Douglas-fir trees were indicated on the site – or at least any of substantial size – in the 1908 timber cruise surveys. However, additional coring data is recommended to confirm the age range of current Douglas-fir on Weir Slope. Finally, Douglas-fir encroachment at this study site appears to be very rapid, particularly when considering that more than 220 cubic meters of Douglas-fir were logged off of Weir Slope in 2006.

Tree core data shows that oaks on all three sites are relatively young. Garry oaks can reach 300 years old or more (Gucker 2007), yet the oldest tree on these study sites is 208 years old, and most are much younger. This could also indicate a widespread infection (Swiecki and Bernhardt 2006), that the trees were cut down, or that there was another force that wiped oaks out in the area. 1908 surveyor records for Swift Tower indicate that many trees are "rotten," which provides some evidence of widespread disease (Washington State Archives 1908). Some types of fungi that produce rot in oaks have been identified north of Weir Slope (Foster 2016), yet are currently a localized issue. Trees that were cored in this study could have been much younger than the site average as well – aging estimates for each site are likely limited.

Tree core results provided good indications for how past surveyors categorized lands as well. Weir Slope was categorized as "prairie" in 1853 and 1908, yet oak were undoubtedly present at this site during both surveys. Although the density of oaks in 1853 and 1908 is unknown, it is clear that oak-based ecosystems were not seen as distinct from prairies during this time. This failure to distinguish between prairie and oak systems is at least partially attributable to the lack of merchantable value of oak (Dunwiddie *et al.* 2011).

The lack of burn scars on the cores does not by itself indicate lack of fire in these environments. Many early burns at these sites would have been low severity, so burn scars would only be present on the lower parts of the tree. Most current visible burn damage from recent fire activity on Weir Slope and Upper Weir is less than 1 meter high on the trunks. I recommend taking future tree cores at a much lower point on the tree trunk than 1.3 meters (standard breast height) to capture a higher number of burn scars.

Additional tree coring is also recommended to follow-up on the health of the oak populations at each site. Pedersen (1998) found that dead oak trees in oak-hickory forests in the Midwestern United States were, on average, growing 18% more slowly than neighboring living trees. Pedersen concluded that mortality in trees is often a decades-long process that can have visual signals in tree rings, so management regimes could be adjusted to minimize the environmental stresses currently negatively affecting Garry oak at these sites.

The CDendro software used to cross-date all of the oaks only accepted a limited number of cores, which limited my analyses for tree cores, particularly on Swift Tower. CDendro was only able to cross-date 4 of the 12 full cores that I prepared for Swift Tower, and so my analysis is very limited in its scope and ability to make any inferences about site history and land changes over time. Manual cross-dating often uses most, if not all oak cores from an area/site. This was not the case with CDendro. Additionally, CDendro was unable to pick up on clear patterns of narrow or wide rings that I could see when manually counting the rings of each oak core. Because CDendro acknowledges particular rings as being “narrow” or “wide” relative to neighboring rings, a series of narrow or wide rings would only show up in a digitized record as one line denoting when the series of narrow rings starts, followed by a “b” denoting a series of wider rings. This does not provide as apparent of a visual cue in terms of overarching patterns in the cores. Therefore, I recommend cross-dating oak cores both manually and digitally to capture the widest breadth of patterns across a study site or area.

4.3 Land Categorization, Use, and Management

Land categories used by surveyors quantifying RTA 20 and 21 in 1853 and 1908 did not include oak ecosystems as a separate land type category; however, oak cores demonstrate the oaks were present on these sites, both in 1853 and in 1908. We know that Swift Tower had a much higher density of Douglas-fir than either Weir Slope or Upper Weir, due Swift Tower being labeled as “timber fir” in 1853 and for its noted amounts of Douglas-fir in 1908. This provides some indication of historic Douglas-fir presence on the site. However, the DBH of Weir Slope and Swift Tower Douglas-firs are not significantly different, indicating that trees on both sites may be of similar age. Swift Tower’s history of ownership by timber companies, as well as its distinct age classes of oak, provide data to indicate that the site had its timber regularly harvested, so Douglas-fir encroachment was disrupted due to human activity, providing opportunities for oak release and additional growth on the site, as well as openings for oak saplings to thrive.

Written records of land use history provide some additional details about types and timelines of disturbances on each site. Grazing activity was likely more concentrated on Upper Weir and Weir Slope due to both being part of the Huggins ranch, where they likely had much higher levels of horse-associated disturbance, such as grazing. Upper Weir and Weir Slope’s categorizations as “plains” and “prairies” provide some evidence that these environments may have been more open than Swift Tower historically, and so would have been more suitable for animal grazing as well. Again, this animal activity may be tied to tree density. Grazing activity often coincides with increasing tree density (Romme et al. 2009), due to most ungulates preference to eat non-woody greens like grasses and forbs on each site. This added herbivory on grasses and forbs reduces the interspecific competition on the site for tree seedlings, thereby making it easier for a higher number of them to establish, increasing overall site tree density. Weir Slope’s significantly higher density than Upper Weir may partially indicate that Weir Slope had a much higher intensity of historic grazing activity/herbivory than Upper Weir.

While land use records provide some indication of who or what may have occurred, these are not exhaustive in scope, and do not encapsulate the true range of use for each site, even during the time periods when they were surveyed. As Rindfuss *et al.* (2004) explain, a land parcel "may change ownership or tenure, be borrowed or rented by distant households, [or] have multiple users adhering to different rules of use." For example, Andrew Chambers, who bought all land patents for Section 32 in 1899, was a farmer according to census records (Washington State Archives 1890), yet historical records from other sources of the time indicate that Chambers was also very active in the Puget Sound and Columbia River Railroad Company (Bancroft 1890). Many timber companies of the era were active in and around all three study sites (Hannum 2012), yet this study did not delve into these timber records enough to verify what frequency and intensity of disturbance local timber companies had on each site. Additional land history studies should examine the intensity and types of land disturbance by timber companies.

Although I originally planned to use past management data to examine environmental variables statistically, these data were difficult to quantify. Each site's number and frequency of active management activities since 1987 numbered less than 10, which was too small a sample size to generate a statistical model to test significance. I do expect that burning, mowing, timber harvests, and other intentional management has a significant effect on each site, yet these relationships between vegetative diversity and structure require more quantitative data to be adequately analyzed. Records of management by JBLM often outline the areas where certain enhancement activities will take place, yet do not necessarily provide quantitative details. For example, there are excellent map records of where JBLM and CNLM staff have burned since 1987, yet burn severity at these sites has not been tracked. Removal of invasive species, when it is not timber, is not quantified. Some records of land activities do not have paper records. This lack of details is usually due to lack of time and funding for these different types of management, and so poses a difficult hurdle for more thorough records of enhancement activity details in the future.

In addition, the number of site enhancement activities collected from my data is not complete – additional partners and researchers have worked at these sites, particularly Upper Weir and Weir Slope, yet no one has kept official records of these additional activities. This prompts additional difficulty in determining the effect each enhancement activity has on site composition.

4.4 Data Inconsistences, Gaps, and Future Research

The effects of a number of unvarying site conditions – such as slope and aspect – can also prompt significant changes in an oak ecosystem's vegetative diversity and environmental variables. Slope and aspect can both affect the amount of solar radiation that a site's vegetation receives compared to neighboring ecosystems that may be flatter or slope in a different direction. As shown in Figure 4.1, taken from Stathers (1998), an oak site like Weir Slope, whose aspect is primarily southwest and has approximately a 40 percent slope, would receive around 1.15 times the amount of solar radiation as a similar flat site like Upper Weir. Solar radiation is often negatively correlated with soil moisture (Stearns and Carlson 1960), and could have played a large part in why Weir Slope's fall soil moisture was significantly lower than soil moisture at Upper Weir and Swift Tower.

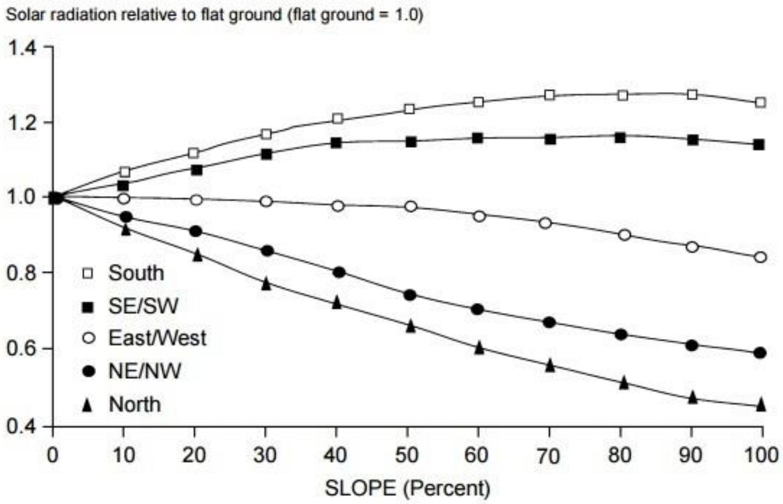

Figure 4.1: Average amount of solar radiation an area receives based on slope and aspect 50 degrees north latitude. Figure drawn by Stathers (1998). Due to Weir Slope being located at 46 degrees latitude, these effects of slope and aspect will be slightly less.

Supporting the importance of solar radiation affecting plant growth is the fact that Weir Slope's tallest and widest trees were predominantly on its steeper southern half. Higher levels of solar radiation provide more energy for trees and plants to grow. This pattern on Weir Slope may partially demonstrate how important slope and aspect are in terms of site structure, particularly in mixed oak/Douglas-fir ecosystems. Additional research must acknowledge the constant site features of an area first and hypothesize how these constant site features may affect site conditions and vegetation.

Disturbance was measured largely at the quadrat level for this research, which greatly affected the amount and type of disturbance measured for each site. Although Weir Slope had the highest visible signs of fire disturbance among the three sites at the quadrat scale, Upper Weir has site-wide signs of its recent fire disturbance, predominantly on many oak trees and stumps. Although my data indicate that small spatial scale fire disturbances on Weir Slope and Upper Weir are different, site-wide fire disturbance for Weir Slope and Upper Weir may be very similar. Additionally, there are a number of disturbance types that were not included in this research. White (1979) found that up to 20% of tree mortality may be wind-related in dry-type forests like Garry oak ecosystems. Quantitative measurements of weather-related disturbance over time were not directly included in this study, but likely play a substantial role in determining site structure and vegetation. Large-scale events such as volcanic eruptions are also often spatially heterogeneous (Turner *et al.* 1997), and can have uneven effects on a region or an ecosystem. For example, although I saw a clear pattern of oak growth suppression on Upper Weir and Swift Tower around the time of the 1980 Mount St. Helens eruption in oak core data, I did not see as clear of a pattern of this growth reduction/suppression in Weir Slope. Underlying reasons for why certain large-scale disturbances like volcanic eruptions affect sites differently remains unclear (Turner *et al*. 1997), yet the fact that large-scale disturbances often have heterogeneous effects both regionally and locally should be acknowledged in future research.

Some of the instruments and types of measurements observed and recorded at each study site may also be inappropriate to gauge how each site's environmental variables significantly affect each site's vegetative diversity and structure. Many changes occur on timescales that are much longer than human lifetimes (Parminter 1998), and are therefore difficult to recognize (Magnuson 1990), especially using instruments and techniques designed specifically to record changes on annual, seasonal, or decadal timescales.

Orientation data of tree cores was not included in my analyses, but could have played a large role in the width of the tree rings. For example, on Weir Slope, 13 out of 15 samples used for coring analyses had an orientation between 200 and 310 degrees – I was facing West, or downslope, for most of these samples. Hardwoods like oak form “tension” wood, or wood that forms due to the force of gravity, on the upper side of the tree (University of Florida 2015). Most samples were taken from this upper side of the slope due to better footing, so most of my cores had bigger rings due being taken on the “tension wood side,” than the same rings on the downslope side of the tree. This skews tree ring results across Weir Slope, and so may have obscured patterns that would have otherwise been more apparent in respect to the other two study sites.

Land was officially bought on Section 28 and 32 in 1897 and 1899, respectively, yet this is not an indication that all three study sites had no human activity between 1854 (the time of the Treaty of Medicine Creek) and 1897. If Native Americans customarily pastured their horses at these sites, they would have had the right to do so throughout this time period, which would mean that all sites had much more horse-related disturbances - such as grazing, organic matter inputs from excrement, and ground compaction – than was assumed for this work. To better understand potential or recorded land use by Native Americans for these and other oak ecosystems, more direct partnerships with local tribes like the Nisqually are necessary.

Land types and land use are somewhat obscured for study sites in this research due to record discrepancies. For example, in 1908, land records for Section 29 (due west of Section 28, where Swift Tower is located) in Township 17N indicate that J.B. Powles and Company owned the property in the southeast block of the northeast quarter. Figure 4.2 provides a close-up of my georeference of the block that J.B. Powles owned in 1908, shown in the upper-right corner. However, during the 1908 timber cruise, surveyor A.B. Smith mapped the sawmill owned by the Powles in the northeast block of the southwest quarter (shown in pencil markings on the left-hand side of Figure 4.2).

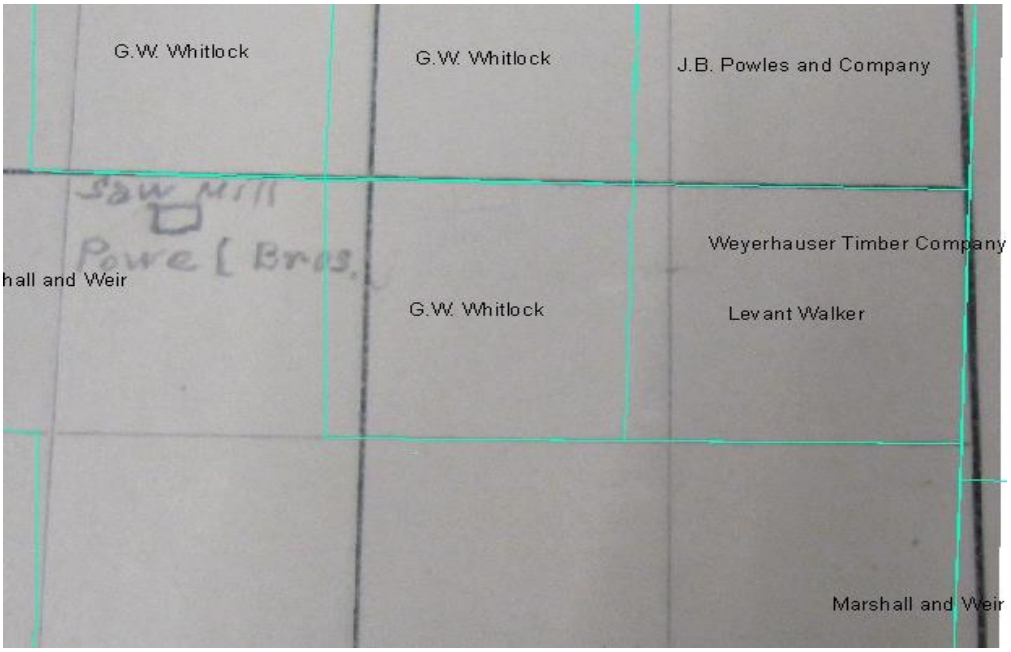

Figure 4.2: Close-up of digitized 1908 land ownership records for J.B. Powles on T17N R1E overlaying georeferenced 1908 timber cruise survey maps from 1908.

Similarly, Figure 4.3 shows the boundaries of Mr. Filman's property labeled and outlined in blue in the lower-right corner. Again, we see that the surveyor drew Mr. Filman's property boundary incorrectly, in the north half of the northeast quarter of Section 33.

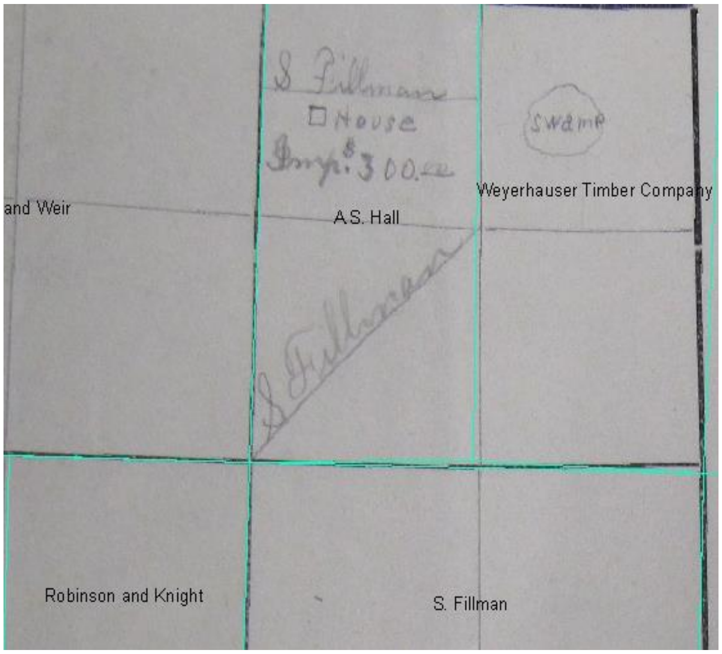

Figure 4.3: Close-up of digitized 1908 land ownership records for S. Filman on T17N R1E overlaying georeferenced 1908 timber cruise survey maps from 1908.

These inconsistencies between indications of use/ownership and location amount to around 1.8 hectares, and are also not seen across all land records of the time period. In a project on a much larger scale, these discrepancies would make little difference in assessing patterns of overall land use change over time. However, 1.8 hectares is up to 45% of a research site in this study, and could dramatically change any data quantifying land type change and use over time. Study of census data and ecological correlations found that patterns that exist in data at an aggregated level do not necessarily exist at a disaggregated level - data patterns at a county-level, for example, may not exist at a household level (Robinson 1950). To make conclusions about possible relationships and patterns in the data, researchers must use data that have been collected at that same scale. Similarly, the scale of errors must be examined in regards to how much of an effect it may have on resulting conclusions.

A number of land records also have names spelled differently. The 1908 timber cruise denotes "Marshall and Weir" as owning many blocks in Section 32 and 28, yet separate Thurston County records indicate these family names as both "Mulhall" and "Weier." While these differences are not large, other land records could have had much greater differences in spellings of names, to a point that they may falsely be identified as a new and/or multiple landowners.

These issues of misplacement and misspelling in this small of an area show that these types of errors likely occurred across historic surveys, likely prompting a number of modern-day miscategorizations of historic land types and associated land use. While many oak ecosystems that remain are fragmented vegetative communities that span a few hectares, the scale of many of these errors is also around this size, making a land map or land record to use as a standalone reference for site history. Using a variety of sources – historic maps, land records, local news reports of the time period, and tree cores – allows researchers to more aptly define what incongruences exist in data for a study site or region.

Mattingly *et al.* (2015) found that while historic agricultural use has significant effect on the plant diversity in fire-maintained ecosystems, these impacts from historic agriculture both positively and negatively affect beta diversity on the site. These findings echo Thom and Seidl's (2016) conclusions on site disturbance, even though the latter focuses on recent disturbances/land use. Mattingly *et al.* further conclude that localized factors are often more of a determinant. Extremely fire-suppressed environments are most likely to incur these negative effects. All three study sites probably had no prescribed burning for approximately 130 years, and missed between 13 and 40 burn cycles (Regan and Agee 2004, Kertis 1986), and likely fall into the category of extremely fire-suppressed. Again, partnerships with local Native American tribes may provide more details as to the deep history of these sites and their types of human activity.

While conducting semi-formal interviews with current JBLM FW and collaborative staff, the aspect of “personal preference” in site enhancement was mentioned multiple times (Zuchowski *et al.* 2016). For example, one land manager implementing a prescriptive oak release may decide to retain all Douglas-fir snags for bird habitat, while a second land manager may decide to cut most fir snags down. Although both land prescriptions may state the same management objectives on paper, they can result in highly divergent sites, with different tree densities, amount of woody debris, and animal use –which, as shown in the results above, can all be highly significant in determining species composition.

Data on historical land use is replete with personal and cultural biases of its time period. Additional research examining interpretations of land for that time period must be conducted simultaneously with historic landscape cataloguing to gain an accurate depiction of this historic data. To facilitate further analysis, I recommend that all researchers who work with historic datasets continually develop modern-day definitions of historic land terms.

Additionally, land managers today must record their own land enhancement practices in finer detail. Due to the various unforeseen circumstances and variables encountered with field work, land managers must remain flexible in site prescriptions. This often forces pre-established management plans to become more like guidelines. However, land prescriptions must be recorded when they are prescribed, and should be followed-up with records of how each prescription was actually implemented. None of us knows what data will be the most important in the future. Recording these details is necessary for us to continue to improve our processes and awareness of what drives landscapes change.

Additional vegetative surveys over several years are recommended for all three sites. Due to the limited time frame (spring season only, one year) for vegetative measurements, a number of species present on each site were likely missed. For example, in quadrat SwTo0704, I found a trillium species that was not flowering. I originally identified it as *T. ovatum*, or western trillium; however, without a flower, it is possible this plant was the rare *T. parviflorum* (small-flowered trillium). *T. parviflorum* was "discovered" as a new taxon on Joint Base Lewis-McChord in 1980 (Soukup 1980).

Furthermore, research conducted on JBLM by Thysell and Carey (2001) found that Garry oak species-area curves were not asymptotic, even after 171 species had been collected. Species-area curves, which determine when species diversity is no longer increasing with increasing sampling area, were used to define this study's extent and design. In light of these results, however, it's likely that each of the three study sites did not reach its species-area curve "true" asymptote, and will need more exhaustive vegetative surveys over multiple years. Specific attention should be directed at Swift Tower's species diversity, and how this could likely impact management. The small cluster of rare plants due northeast of Swift Tower (Zuchowski *et al.* 2016) makes it a good candidate site for possible in-situ restoration or natural dispersal of these plants. Additional surveys may verify the presence or absence of several listed species.

4.5. Final Thoughts

Weir Slope's many significant differences from Upper Weir and Swift Tower indicate distinct differences not necessarily in the level of disturbance, but the amount of human activity that the site has had since 1853. Both through data collected on the sites themselves (tree cores, tree density, tree growth forms) and through paper records of each site, we can see evidence of higher amounts of human activity on Upper Weir and Swift Tower (the flat sites), then on Weir Slope. It is likely that all underwent levels of animal (ungulate) disturbance/activity, but overarching results indicate that human activities may play a larger role in shaping these significant site differences. Garry oak ecosystems are environments that were highly and frequently altered through human activity for millennia. Although human activity has changed over time, these environments are likely well adapted to human-related disturbance. On these sites, the presence of human activity on these sites produced ecosystems that have higher native vegetative cover, which is a metric used by many to indicate oak ecosystem health.

Some of the main driving forces behind site differences were environmental variables tied, at least in part, to oak tree density. This research did not assume that density would play a large role in defining site characteristics and vegetative diversity, yet future studies examining underlying driving forces of oak ecosystem structure and vegetation should hypothesize this. Density measurements in oak ecosystems of the Puget Sound likely provide great baseline data that can help define research studies to concentrate on the significant forces behind ecosystem differences more directly.

Foster *et al.*'s (2003) research on land-use legacies outlines the importance of examining the history of land activity when trying to determine the dynamics affecting structure in an ecosystem. While most restoration work today is built around the premise of restoring ecosystems to a “reference” site, Maslovat (2002) concluded that Garry oak ecosystems do not have these sites. Traditional Garry oak ecosystems, or what would have been the best example of a “reference” site, would have included regular alteration. Garry oak areas that are “preserved” in the traditional sense, or without human disturbance, would directly inhibit any reference conditions from continuing. A better way to arrive at what these key site environmental variable differences are is through cataloguing how these disturbances (both in type and frequency) have changed. Examining the effects of each disturbance, or lack thereof, on an ecosystem provides a better key to how oak ecosystems functioned in the past.

JBLM staff outlined the primary objective of maintaining current oak systems by preventing invasive species such as Scotch broom and invasive grasses from dominating understory vegetation, and retaining native species cover (Fort Lewis 2005). However, the desired species composition (all species desired, as well as density/percent vegetative cover) for each Garry oak community type on JBLM have not been defined. Although an increase in native plant establishment at each site is a clear objective, quantitatively outlining what these species assemblages will look like may prompt more methodical, intentional management based around the specific needs of each site.

The current management plan also outlines the need for all management and treatment to protect sites with significant cultural or historic importance (Fort Lewis 2005). While this provides some direction, similar to quantitative species assemblages, what makes a site culturally or historically significant have not fully been defined in this plan, and requires additional research into each oak ecosystem's history. However, paper records of sites will likely date back only 200 years or less. To gain a more holistic understanding of the deep history (and driving forces) of oak ecosystems, more direct examination of the traditional ecological knowledge held by local Native American tribes and individuals is advisable.

Due to the many current unknowns of Garry oak systems, defining the critical features and components of remaining Garry oak sites is key to their survival. The pressures of urban growth and habitat fragmentation with continue to constrain Garry oak in the Puget Sound. As ecosystems that have rich cultural and natural histories, considering both is required for these ecosystems to survive.

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APPENDIX A: REFLECTIONS ON ORIGINAL THESIS PROJECT

This thesis work originally centered around a project that was developed with the support of members of the Leschi Heritage Foundation. In February 2016, the tribe decided that more robust protocols were needed for work done around cultural purposes by non-tribal members on the Nisqually Reservation. This decision also halted all current work by non-tribal members on the reservation, which included the research I was conducting at the time on an oak ecosystem on reservation. *Please note that I am choosing to keep my terms around this vague, as a sign of respect for Nisqually people and the privacy they may wish to maintain around the lands on their reservation.*

Due to timelines – both for my masters, as well as for the Nisqually tribe writing these protocols, it only made sense that I would take on a different site for my work. In an effort to possibly collect some data that could be useful for the tribe, I wanted to have study sites close to the reservation that likely had similar site histories.

Although I was disappointed to not continue my research as directly with the Nisqually tribe and on the reservation, the tribe's decision to halt this on-reservation research project taught me a lot about cultural considerations that need to take place in project partnerships, in particular between Native Americans and non-natives. I've developed this appendix as a short reflection on some of the lessons I've learned through this experience.

Lessons learned

Limited Understanding

As a white woman, there are limitations on how much I am allowed to know, as well as how much I can comprehensively understand about Native American cultural practices. Gary Morishima, co-founder of the Intertribal Timber Council, told me during a conversation in March 2016 that sharing a cultural practice is similar to sharing a millennia-old family recipe. As the daughter of a chef, this metaphor rang particularly true to me. My father would not teach me how to make his legendary marinara sauce until I knew how to properly mince garlic, sweat onions, or simmer tomatoes. Even when I felt ready to make the sauce, my dad still would not teach me. Wanting to know and being ready to fully understand a process are two very different things. Knowledge on activities and practices that Native Americans used in Garry oak ecosystems can be sacred, and experts on these activities may feel I am never ready to know what these practices were.

Coming from a Western mindset, there are many limitations to how deeply I can understand these practices. Fossett's "Mapping Inuktut: Inuit Views of the Real World," provides a great example of this lack of awareness and depth of understanding. Fossett explains that most maps in Canadian Inuit societies were stored in memory - impermanent maps were drawn in the sand, snow, or dirt, with pebbles and dirt or sand used to represent islands, hills, and riverbeds. These surveyors, "trained in the European tradition of scientific geography which made representations of actual terrain the goal of cartography," concentrated erroneously on the objects on the map, and failed to understand the link between on-the-ground representations and verbal instructions. Many Canadian Inuit individuals would adjust map distances to match the difficulty of the route, adjusted for the age, health, and size of the party using the map. Fossett adds, "dioramic maps on the ground were four-dimensional, incorporating information about distance, difficulty of travel, travel time, and location of necessary resources." Two-dimensional paper maps could never provide all of these details, or provide the richness of understanding of the area that these four dimensional maps provided. Similarly, I have been taught to think about certain topics in a specified number of "dimensions," so to speak. I perform land assessments by taking tree measurements, probing soil for its temperature and moisture, and examining diversity of vegetation. These methods in turn limit my range of knowledge for that landscape. As someone who is rightly limited to information about Native American cultural practices, can I collect meaningful data? What dimensions am I missing? What ways am I misinterpreting information?

Western science has a tendency to display data as factual, and not an opinion largely supported by the cultural bias and ethos under which western society is built. Cultural biases have a tendency to feel like truths, and it's often easier to function and operate in a society when one assumes they are truths. Tom Andrews' (2012) paper, What is Social Constructionism? argues that

> any frequently repeated action becomes cast into a pattern, which can be reproduced without much effort…the meaning of the habitualization becomes embedded as routines, forming a general store of knowledge. This is institutionalized by society to the extent that future generations experience this type of knowledge as objective.

The way in which we share knowledge becomes such an ingrained part of how we function in our society that we begin to regard it as objective, rather than its true subjective nature. However, acknowledging these subjective beliefs as such is the first step in developing open, honest, and successful partnerships with groups and individuals that live in a different paradigm or cultural structure.

Always a Guest

While on a Native American reservation, I was always a guest. I am a guest in different houses, buildings, community centers, and even when I am driving or walking on the land. There were several encounters where I did not understand the proper way to be a guest, and offended and angered different individuals. I made my biggest blunder at the senior center, when I assumed I knew the right way to approach an elder while they were eating. My advice to anyone is: learn about the proper ways to act as a guest on that reservation or on tribal land by asking. Ask multiple people to gain a clearer sense of the customs, since these tend to vary from person to person. Take time to learn what is expected of you as the type of guest you are trying to be. Are you a guest researcher? Then learn how researchers are expected to behave. Are you a guest volunteering for a restoration project? Then learn how the tribe likes their restoration volunteers to act. And in the end, if I am not welcome by one of the residents, the only fair thing to do is leave. No matter what.

Considerations for future Native/non-native partnerships

Many researchers have acknowledged - some even note in their research - the need for traditional/indigenous knowledge in management practices surrounding ecological projects, (Huntington 2000, Kimmerer 2002), including Pacific Northwest prairie-oak ecosystems (Dunwiddie and Bakker 2011). However, research around traditional and indigenous knowledge is most developed in the fields of educational programs, general ecological restoration, and ecological interpretation, while only a small subset of this research has focused on forestry and forests specifically (Hummel and Lake 2015). For example, while JBLM adheres to the regulations outlined by the Integrated Cultural Resources Management Plan, this plan only asks that Tribal Historic Preservation Officers have a chance to comment on different actions on base – not necessarily that these comments will have any bearing on the final decision. Additionally, the plan itself was approved only by individuals who are part of the military – not a single tribal member was given the right to be a signatory on this lengthy document.

Research into the social dynamics between these two groups have shown that both often have biased assumptions of the others objectives and criteria (Russo 2011), which can limit the amount of trust and understanding, and therefore the success, of these partnerships. After a handful of failed partnerships, individuals can be discouraged, wary, and even distrustful of similar partnership offers in the future - this is the case for any relationship. Developing successful relationships must start from a place of understanding.

Considerations for literature reviews

One of the main things that academics tend to do for research is read past literature on the subject. However, a great deal of literature on traditional land management is written by non-natives and/or outsiders. Even scholars who have spent many years within a community will only be able to grasp a limited range of the knowledge at hand. As Standing Rock Sioux scholar Karen Gayton Swisher (1998) explains,

> How can an outsider really understand life on reservations, the struggle for recognition, sovereignty, economic development, preservation of language and culture? Perhaps they can gain a high degree of empathy and act as 'brokers' of sorts, but it takes American Indians and Alaska Natives themselves to understand the depth of meaning incorporated in Indian education to ask appropriate questions and find appropriate answers.

White scholars who may share aspects of native knowledge will only be sharing the answers to the questions they answered, the questions that came about from their own cultural bias and background. Swisher continues by citing an example in which "just three non-Indian authors have written more than

30 articles and books about Indian education since 1985" (1998). These individuals, although taking their research from experts, are still cited more often than any of the experts from which they gathered this information from (Swisher 1998). In Western society, academic thought and intellectual exchange of ideas has a long history of being done and communicated through written formats. Western academics, who have grown up in this system, will present their work this way, in a way that feels more comfortable, and therefore will be more likely to be used for information - for these academic "truths" than the true experts.

I have limited the amount of non-native research that I have included in this reasearch on the ethnobotanical history and current relationships of oak ecosystems and humans. I tried to bracket information I did include from non-native sources in language that exuded the fact that these are partial truths, at most, and are largely limited by the questions which the individual anthropologist chose to ask – which, of course, may not have been enough to attain the root of the meaning. When found, I used Native American authors for citations and sourcing. It is unfair, and sometimes incorrect, in my opinion, to share any secondary or tertiary observations on Native American life as fact in this research.

Hopeful use for this data in the future

Nisqually historian Cecilia Carpenter (2008) wrote that the transfer of well-maintained land "signifies an unacknowledged transfer of wealth from one nation to another." This wealth has never been repaid. The tendency for Westernized U.S. society to deem National Parks as land that is "'virgin' uninhabited land has always been especially cruel when seen from the perspective of the Indians who had once called the land home. Now they were forced to move elsewhere, with the result that tourists could safely enjoy the illusion that they were seeing their nation in its pristine, original state" (Cronon 1995) Cronon's quote demonstrates this unacknowledged transfer in a very tangible way, and has many examples, even today. In 2011, the Ogalala Lakota Sioux refused a $1 billion payment for the loss of the Black Hills region of South Dakota, because the land was never for sale - it was taken. What the tribe wants is the land, not the money (Uenuma and Fritz 2011). Many researchers acknowledge that many of the remaining oak ecosystems, as well as their associated and neighboring cultural/spiritual spaces. No tribe or Native American should need to explain why these spaces are important – this is knowledge that is sacred, and, as mentioned above, outsiders may not be able to fully understand the importance of these systems even after given an explanation. Partnerships must become more active on the important cultural landscapes of the Puget Sound. This will require time to build trust between parties, and will likely have to function on a timeline that many land managers are not used to. As this research shows, while we can examine the written historic records of nonnative human activity in oak ecosystems, this data is limited, and provides a small sliver of the types and timeline of human activity. To truly understand how these ecosystems function, how they can thrive, what the definition of a healthy Garry oak community is, we need to develop a more holistic understanding and a wider knowledge of humanity in the region, both historically and today.

APPENDIX B: SPECIES FREQUENCY AND AVERAGE VEGETATIVE COVER BY STUDY SITE

Table B.1: Frequency and average percent cover of species recorded on Upper Weir

Scientific Name	Common Name	Species Code	Frequency All Sites	Frequency UpWe	Average % cover
Agrostis capillaris	colonial bentgrass	ACGA5	23	17	8.9
Achillea millefolium	yarrow	ACMI2	3	3	1.5
Arctostaphylos uva-ursi	kinnikinnick	ARUV	4	2	7.0
Bromus tectorum	cheatgrass	BRTE	1	1	10.5
Calandrinia ciliata	fringed redmaids	CACI2	1	1	0.5
Carex inops	long-stolon sedge	CAIN9	41	22	10.4
Cardamine oligosperma	Western bitter-cress	CAOL	12	4	0.5
Camassia quamash	common camas	CAQU2	29	24	11.5
Cerastium arvense	field chickweed	CEAR	1	1	3.5
Claytonia perfoliata	miner's lettuce	CLPE	20	4	2
Cytisus scoparius	Scotch Broom	CYS4	30	16	9.4
Dodecatheon hendersonii	Henderson's shooting star	DOHE	3	3	4.8
Festuca rubra	red fescue	FERU2	4	4	22
Fritillaria affinis	checker lily	FRAF2	1	1	3.5
Fragaria vesca	woodland strawberry	FRVE	2	1	0.5
Galium aparine	cleavers	GAAP2	54	17	4.2
Geranium bicknellii	Bicknell's geranium	GEBI2	25	13	8.4
Geranium robertianum	stinky bob	GERO	4	1	0.5
Holcus lanatus	common velvetgrass	HOLA	58	22	11.7
Hypericum perforatum	common St. John's wort	HYPE	29	11	3.7
Hypochaeris radicata	hairy cat's ear	HYRA3	24	17	5.4
Lomatium dissectum	fernleaf biscuitroot	LODI	1	1	3.5
Lotus micranthus	desert deervetch	LOMI	2	2	12
Lomatium urticulatum	common lomatium	LOUT	1	1	3.5
Plantago lanceolata	narrowleaf plantain	PLLA	11	8	9.5
Ranunculus occidentalis	western buttercup	RAOC	1	1	0.5

Scientific Name	Common Name	Species Code	Frequency All Sites	Frequency UpWe	Average % cover
Rumex acetosella	sheep sorrel	RUAC3	17	6	3.7
Sanicula crassicaulis	Pacific blacksnakeroot	SACRT	21	1	0.5
Schedonorus arundinaceus	tall fescue	SCAR7	5	1	10.5
Stellaria media	common chickweed	STME2	15	4	4.5
Symphocarpos albus	common snowberry	SYAL	33	10	23.5
Taraxacum officinale	common dandelion	TAOF	31	12	2.8
Teesdalia nudicaulis	barestem teesdalia	TENU	35	17	7.6
Thalictrum occidentale	western meadow-rue	THOC	1	1	0.5
Trifolium dubium	little hop clover	TRDU	12	9	13.7
Veronica arvensis	common speedwell	VEAR	7	5	3.1
Vicia sativa	common vetch	VISA	45	20	4.7

Table B.2: Frequency and average percent cover of species recorded on Weir Slope

Scientific Name	Common Name	Species Code	Frequency All Sites	Frequency WeSl	Average % cover
Agrostis capillaris	colonial bentgrass	ACGA5	23	3	11.5
Aira praecox	yellow hairgrass	AIPR	2	2	0.5
Bromus hordaceus	soft brome	BRHO2	3	3	22.5
Cirsium vulgare	bull thistle	CIVU	1	1	3.5
Clinopodium douglasii	yerba buena	CLDO2	4	2	3.5
Claytonia perfoliata	miner's lettuce	CLPE	20	2	10.5
Crepis capillaris	smooth hawksbeard	CRCA3	2	2	2
Festuca roemeri	Roemer's fescue	FERO	2	2	7.0
Galium aparine	cleavers	GAAP2	54	11	0.8

Scientific Name	**Common Name**	**Species Code**	**Frequency All Sites**	**Frequency WeSl**	**Average % cover**
Geranium bicknellii	Bicknell's geranium	GEBI2	25	9	5.9
Geranium molle	dovesfoot geranium	GEMO	4	2	0.5
Geranium pusillum	small geranium	GEPU2	1	1	0.5
Geranium robertianum	stinky bob	GERO	4	2	0.5
Holcus lanatus	common velvetgrass	HOLA	58	24	19.1
Hypericum perforatum	common St. John's wort	HYPE	29	6	4.2
Moehringia macrophylla	largeleaf sandwort	MOMA3	16	1	0.5
Pteridium aquilinum	Western brackenfern	PTAQ	4	3	8.2
Rosa gymnocarpa	baldhip rose	ROGY	1	1	3.5
Rumex acetosella	sheep sorrel	RUAC3	17	7	3.4
Rubus armeniacus	Himalayan blackberry	RUAR9	1	1	63.5
Rubus ursinus	Pacific blackberry	RUUR	23	8	24.1
Sanicula crassicaulis	Pacific blacksnakeroot	SACRT	21	8	1.6
Schedonorus arundinaceus	tall fescue	SCAR7	5	1	3.5
Sonchus arvensis	field sowthistle	SOAR2	19	19	2.8
Stellaria media	common chickweed	STME2	15	2	2
Symphocarpos albus	common snowberry	SYAL	33	10	16.0
Symphocarpos mollis	trailing snowberry	SYMO	2	1	0.5
Taraxacum officinale	common dandelion	TAOF	31	18	3.4
Teesdalia nudicaulis	barestem teesdalia	TENU	35	10	2.1
Trifolium dubium	little hop clover	TRDU	12	1	0.5
Vicia cracca	bird vetch	VICR	7	7	9.2
Vicia sativa	common vetch	VISA	45	18	9.6

Table B.3: Frequency and average percent cover of species recorded on Swift Tower

Scientific Name	Common Name	Species Code	Frequency All Sites	Frequency SwTo	Average % cover
Agrostis capillaris	colonial bentgrass	ACGA5	23	3	8.2
Amelanchier alnifolia	saskatoon	AMAL2	6	6	14.5
Arctostaphylos uva-ursi	kinnikinnick	ARUV	4	2	2
Blechnum spicant	deer fern	BLSP	1	1	10.5
Carex inops	long-stolon sedge	CAIN9	41	19	8.3
Cardamine oligosperma	Western bitter-cress	CAOL	12	8	0.9
Camassia quamash	common camas	CAQU2	29	5	1.7
Clinopodium douglasii	yerba buena	CLDO2	4	2	2
Claytonia perfoliata	miner's lettuce	CLPE	20	14	5.9
Claytonia sibirica	Siberian spring beauty	CLSIS	4	4	17.8
Cytisus scoparius	Scotch broom	CYS4	30	14	5.4
Fragaria vesca	woodland strawberry	FRVE	2	1	3.5
Fragaria virgniana	Virginia strawberry	FRVI	1	1	3.5
Galium aparine	cleavers	GAAP2	54	26	10.7
Geranium bicknellii	Bicknell's geranium	GEBI2	25	3	5.8
Geranium molle	dovesfoot geranium	GEMO	4	2	0.5
Geranium robertianum	stinky bob	GERO	4	1	3.5
Goodyera oblonigfolia	Western rattlesnake plantain	GOOB2	1	1	3.5
Holodiscus discolor	oceanspray	HODI	4	4	7
Holcus lanatus	common velvetgrass	HOLA	58	12	3.2
Hypericum perforatum	common St. John's wort	HYPE	31	12	4.2
Hypochaeris radicata	hairy cat's ear	HYRA3	24	7	10.5
Linnaea borealis	twinflower	LIBO3	1	1	10.5
Lonicera ciliosa	orange trumpet honeysuckle	LOCI3	5	5	3.1
Mahonia aquifolium	tall oregon grape	MAAQ2	5	5	13.3
Maianthemum stellatum	false star lily of the valley	MAST4	3	3	25.8

Scientific Name	**Common Name**	**Species Code**	**Frequency All Sites**	**Frequency SwTo**	**Average % cover**
Moehringia macrophylla	largeleaf sandwort	MOMA3	16	15	3.2
Myosotis discolor	changing forget-me-not	MYDI	3	3	1.5
Oemleria cerasiformis	Indian plum	OECE	2	2	2
Plantago lanceolata	narrowleaf plantain	PLLA	11	3	8.2
Polystichum munitum	sword fern	POMU	2	2	0.5
Pteridium aquilinum	Western brackenfern	PTAQ	4	1	10.5
Rumex acetosella	sheep sorrel	RUAC3	17	4	8.8
Rubus ursinus	Pacific blackberry	RUUR	23	15	13.6
Sanicula crassicaulis	Pacific blacksnakeroot	SACRT	21	12	3.5
Schedonorus arundinaceus	tall fescue	SCAR7	5	3	3.5
Stellaria media	common chickweed	STME2	15	9	1.8
Symphocarpos albus	common snowberry	SYAL	33	13	7.9
Symphocarpos mollis	trailing snowberry	SYMO	2	1	3.5
Synthyris reniformis	snowqueen	SYRE	15	15	5.0
Taraxacum officinale	common dandelion	TAOF	31	1	0.5
Teesdalia nudicaulis	barestem teesdalia	TENU	35	8	2.4
Trientalis borealis	starflower	TRBO2	4	4	3.8
Trifolium dubium	little hop clover	TRDU	12	2	2.0
Trillium ovatum	Western trillium	TROVO2	4	1	3.5
Veronica arvensis	common speedwell	VEAR	7	2	2
Viola glabella	common yellow violet	VIGL	1	1	0.5
Vicia sativa	common vetch	VISA	45	7	1.8