Evaluating and Monitoring the Success of Ecological Restoration Implemented by the University of Washington Restoration Ecology Network (UW-REN) Capstone Projects

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Abstract

Evaluating and monitoring the success of ecological restoration implemented by the University of Washington Restoration Ecology Network (UW-REN) capstone projects

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For every year since 2000, five to ten ecological restoration sites have been implemented in the Puget Sound region through the University of Washington Restoration Ecology Network (UW-REN) capstone program. These sites represent the integral cooperation necessary to facilitate successful restoration, as faculty, students, and community partners participate. Thirty sites were chosen for this study and evaluated for success across different parameters. I hypothesized that certain elements of restoration design and implementation, such as selected techniques for invasive vegetation suppression and removal, and the degree of site maintenance and stewardship strongly contribute to the success of these restoration sites. From the available documentation and field methods, information was gathered to conduct statistical analyses of the plant cover with respect to five explanatory variables: ownership, stewardship, initial invasive plant control technique, use of cardboard, and use of wood chip mulch. Ownership, stewardship, and control technique contribute significantly to the native composition, species richness, and species diversity of these restoration sites. Privately owned sites have greater native species composition than county and state owned sites, and city sites are more likely to have greater native species composition than state owned sites. High levels of stewardship result in greater native species composition than low stewardship, and mowing does not work as well as grubbing for initial invasive plant control technique in the outcome of native species composition. The use of cardboard and wood chip mulch is less clear. In the end, while stewardship is of the utmost importance in successful

restoration, initial control technique and the use of mulch should also be considered important in determining the resulting native species composition. The use of cardboard should be considered carefully, weighing the benefits of deploying the resources to acquire the cardboard against the only slight benefit it seems to offer the outcome of native species composition. Different vegetative layers vary in their relationship with native and non-native cover, with trees being positively correlated and tall shrubs negatively correlated to native composition.

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1.0 INTRODUCTION

In 1999 the UW-REN program was established in order to integrate students, faculty and community interests in ecological conservation and restoration (Gold et al. 2006). For every year since 2000, five to ten restoration sites have been established in cooperation with a community partner, usually a non-profit organization, private land stakeholder, or governmental agency. Many of the restoration sites lie in urban, suburban, and rural areas such as the West Duwamish Greenbelt, Union Bay Natural Area, and Licton Springs in the Seattle area, Swamp Creek in Snohomish County, and the Earth Sanctuary on Whidbey Island. They include forested wetlands, streams, and upland forest habitats. The restoration sites varied in their land use context, ecological challenges, treatments used, and expectations for restoration. Each community partner submitted a request for proposal (RFP) outlining their restoration goals. Then the students accommodated those requests by designing a restoration plan that addressed the goals suggested in the RFP, considered the ecological state of the area as determined by a site assessment, and worked within the constraints of the team expertise, time, and available resources. Each restoration plan had specific goals and objectives in order to bring the site to a state of restoration, and the capstone students performed the first stages of restoration for the community partner. Various approaches were used, as the needs, goals, and challenges of each restoration site were unique. The students compiled reports describing what they planned with goals and objectives (proposal document). Then they developed a work plan document to indicate the important steps they would take in order to implement restoration. Toward the end of the program the students submitted a document describing what they actually *did*, telling the story of how their goals and objectives were met (as-built document). I examined the available documents for projects completed in 2001-2008. As of the start of this project, no one had scrutinized the sustainability or success of these restoration efforts, and therefore a close examination of most of the UW-REN sites was in need. Palmer et al. (2007) asserted that in order to improve ecological restoration practices, it is important to evaluate and monitor restoration sites that are already in progress. Such an analysis will not only aid in the design of future restoration projects (especially in urban areas), but will also enhance the way that restoration techniques are taught.

Measuring the success of restoration sites is no easy task, but needs to be done so that restorers may utilize an adaptive approach (Palmer et al. 2007). Relatively few restoration sites are thoroughly evaluated or monitored for an appropriate length of time (Alexander and Allan 2007) due to lack of funding (Bernhardt et al. 2007) or resources. Thus the concern arises as how to define "success". Kentula (2005) states that success is an imprecise term, but that ecological restoration projects may be evaluated in terms of compliance and functional success. For instance, it can be determined whether the restoration project fulfills the original goals, and if the area of restoration fulfills a functional, ecological role. Giller (2005) and Palmer et al. (2005) discuss criteria for measuring the success of ecological restoration projects. Giller (2005) emphasizes that the success of restoration projects can be measured by whether the restored system may ultimately reach a point of self-sustainability and resilience. Palmer et al. (2005) further define the evaluation of success of a restoration site to include five important criteria:

1. Restoration should be guided by the goal of replacing a degraded system with a healthy ecosystem.
2. The ecological condition of the restored system must be measurably improved.
3. The system undergoing restoration must show signs of becoming self-sustaining.
4. During a restoration project, no further harm should be inflicted on the already degraded site.
5. A restoration project and site must be evaluated before and after project implementation.

There is no single source definitively describing how to quantitatively acquire such measurements, and since every restoration site is different it is a challenge to tailor a single method or technique of monitoring for multiple sites. The Society for Ecological Restoration defines certain parameters that are useful in monitoring restoration sites, focusing upon determining whether the original goals and objectives of the restoration design plan are fulfilled (SER 2008), such as non-native plant species suppression and ecological function. A common goal in all the UW-REN restoration sites is to reduce the cover of invasive plant species and to increase the cover of native plant species. These capstone projects are unique in that they are restoration sites undertaken in an educational context along with community partners (Gold et al. 2006). On one level, success will be determined by the group's ability to effectively translate and develop restoration goals as indicated by comparing the RFP and As-Built reports, and whether efforts resulted in stewardship of the site. Because the initiation of succession and the suppression of non-native vegetation are common goals among the projects, in this study success will further be evaluated according to the ecological goals established by the capstone groups that demonstrate a trajectory toward succession and the suppression of non-native species. I hypothesize that certain elements of restoration design and implementation, such as selected techniques for invasive vegetation suppression and removal, and the degree of site maintenance and stewardship contribute strongly to the success of these restoration sites. The key questions to be addressed in this study are

1. Do the goals and objectives laid out in the As-Built documents reflect the goals and objectives established in the RFP and attained in the implementation of restoration?
2. Does the degree of stewardship of a site affect the intended species composition and diversity?
3. Does the initial treatment and technique of invasive vegetation removal affect the coverage of native versus non-native species composition or diversity?
4. Do different vegetative layers correlate with native or non-native composition?

2.0 LITERATURE REVIEW

2.1 *Successional Trajectories*

The Society for Ecological Restoration defines ecological restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004, 2011). Clewell and Aronson (2007) and Walker et al. (2007) elaborate further stating that a fully restored site should be self-sustaining, able to withstand periodic environmental stressors, and able to recover from disturbance. Restoration efforts accomplish this by enhancing species composition that demonstrates community structure, is indigenous, and represents functional groups (Clewell and Aronson 2007), and by endeavoring to recover ecosystem composition, structure, and dynamics (Palmer et al. 2006).

The equilibrium approach to restoration involves the deliberate acceleration of succession in order to reach a goal endpoint sooner than if no intervention had occurred (Suding and Gross 2006). However, as Falk et al. (2006) states, this equilibrium is likely to be unstable, and in reality there is no steady state climax community to be reached. Instead, over long temporal scales a dynamic rather than a static view of community structure is prevailing both in restoration and succession studies (Walker et al. 2007). It is not possible to reach and maintain a steady state, as ecosystems are dynamic (Palmer 2009). Ecosystems exhibit such variation on multiple scales that there are alternative stable states to be attained in restoration (Hobbs 2007). Succession is fundamentally a change in species and substrate over time, and even though restoration projects are on shorter time scales than succession, such theories still apply to restoration practices (Walker et al. 2007). The result of succession, and therefore a worthy restoration goal, is not necessarily a climax community or specific endpoint (Suding and Gross 2006), but a sustainable ecosystem that is able to recover from disturbance (Walker and del Moral 2003). This notion broadens the goals of restoration activities to entail restoring the presence of functional groups and ecosystem functions, in addition to desired enhancements in community structure (Palmer 1997, Suding and Gross 2006).

Restoration can facilitate or inhibit changes in community structure (Suding and Gross 2006), but the goal of a full recovery of an ecosystem to a pre-disturbance state is often unrealistic (Walker et al. 2007). In order to reach the more attainable goal of sustainability where native species dominate and provide ecosystem services (Suding and Gross 2006), most projects will require at least ten years of intervention, depending on site characteristics and surroundings (Walker and del Moral 2003). Clewell and Aronson (2007) advise that in restoration practice it is preferable to introduce a variety of native species to ensure that some are well suited to the environment and will likely eventually establish, and that species appropriateness is usually based on a reference ecosystem. However, Palmer (2009) states that there is a need to identify multiple probabilities and trajectories of outcome to restoration rather than expecting the emergence of a site resembling a single reference system.

2.2 *Monitoring and Stewardship*

Reference sites can be valuable tools that demonstrate the intended paths of restoration projects (Clewell and Aronson 2007), and enhance the evaluation of success (Ruiz-Jean and Aide 2005). Although reference sites occur in a similar place on the landscape and represent the potential of species composition and community structure, they should only serve as a template and not be used exclusively to determine success (Clewell and Aronson 2007). If restoration goals are to allow for multiple trajectories to a sustainable system, then similarity to a single reference system is not necessarily the desired outcome. Another common problem is that in some circumstances a reference site does not exist. Instead historical knowledge is necessary for the determination of success of restoration (Brewer and Menzel 2009).

Restoration plans must be based on the best available science (Walker and del Moral 2003) with clear goals. The long-term success of a restoration project is greatly determined by whether the initial goals of the restoration were achieved (Clewell and Aronson 2007, del Moral et al. 2007, Hobbs 2007, Osenberg et al. 2006, SER 2008). It is also important to acknowledge the potential state of the system had restoration not taken place (Osenberg et al. 2006), and that a site can be on a successful trajectory even if a site does not meet immediate goals (Walker and del Moral 2003). It has been established that restoration projects do not necessarily have to develop to a certain endpoint in order to be successful. Success may be indicated by achieving multiple goals over time, reflecting the long temporal scale of restoration efforts. For instance, species richness or community structure may be restored first, and then the restorers may monitor for the establishment of ecological function (Palmer et al. 1997). As goals are spread out over time, all is not lost if the intended trajectory of a project is not met; if project resources allow and if determined necessary, restorers can simply go back to the site and perform more restoration (Clewell and Aronson 2007). If appropriate, the sustainability and restoration trajectory can be determined by examining the diversity, vegetation structure, and ecological processes occurring at a restoration area. Clewell and Aronson (2007) further outline nine ecological standards that may indicate the likelihood of success in restoration: species composition, indigenous species, functional groups, physical environment, normal ecosystem function, landscape context, external threats, resilience, and self-sustainability. Over time restoration projects should be monitored for these factors that contribute to a sustainable system.

Ultimately the goals of restoration determine its success, and those that are more specific such as to return a certain ecosystem process or community structure may be more easily attained than an impractical goal of completely restoring a site to an original state (Hobbs 2007). Unfortunately the progress of most restoration projects is not monitored (Palmer et al. 2006). Monitoring is critical as it can provide information as to whether action must be taken in order to keep the site on a successional trajectory (Walker and del Moral 2003). It is possible to track actual trajectories of change if such an evaluation includes but is not limited to the following: it determines species composition, invasive species potential, presence of functional groups, and the role of the site on the landscape (Clewell and Aronson 2007, Suding and Gross 2006). Monitoring ecological restoration provides an opportunity to place it into a scientific setting that provides an opportunity to test ecological and restoration theories, contributing to adaptive management and maintenance protocols (Hobbs et al. 2007, Palmer et al. 2006, Prack et al. 2007).

There are many measurements that may be included in any monitoring program, but often such assessments do not include data describing the site before restoration was implemented. Therefore, Osenberg et al. (2006) propose employing a Before-After-Control-Impact Paired Series (BACIPS) that is used in the development of environmental impact statements, where a reference site serves as the control and the restoration area serves as the impact site. Where the gathering of such BACIPS information is not possible or was not accomplished, or where reference sites do not exist, it is necessary to rely on historical knowledge (Brewer and Menzel 2009) and monitoring parameters of species cover or abundance that describe the structure of restored vegetation (del Moral et al. 2007, Walker and del Moral 2003). Ideally monitoring should include other trophic levels as well (Voigt and Perner 2004), including invertebrates or soil microbes since they are essential to sustainable ecosystems (Halle and Marzio 2004). Monitoring studies can be used to direct efforts at a restoration site to maintain a successional trajectory toward sustainability, and volunteer stewards can ensure that such maintenance occurs.

Restoration often requires more than one effort, as it is usually a series of changes that caused the land to become degraded in the first place (Palmer et al. 2006). More manipulation equals less time to achieve succession and the introduction of more functional diversity at a site (Prack et al. 2007). Without periodic maintenance and the manipulation of species composition, restoration rarely succeeds, especially in systems that require the amelioration of human impacts such as in urban areas (Clewell and Aronson 2007, Hobbs 2007, Walker and del Moral 2003). Urban and rural sites exhibit intense disturbance in that they are severed from the landscape and often have a set of non-native species that would not otherwise occur in a native ecosystem (Hobbs 2007, Walker and del Moral 2003). However, urban and rural settings may bestow citizens with a stake in restoration events. Walker and del Moral (2003) propose that partnerships be "forged between the private sector, government agencies, educational groups, and volunteer organization[s] to produce effective long-term programs (p.327)" to administer the monitoring and maintenance of restoration areas. Engaging citizens in restoration instills a sense of ownership, place and community, and produces results that improve local ecosystem functioning (Clewell and Aronson 2007, Vivek and Messer 2008). Restoration through stewardship can help people gain a better understanding of how their actions impact the environment (Vidra and Shear 2008, Vivek and Messer 2008).

2.3 *Invasive Species*

Human activities surrounding a restoration site can affect the plant community and vegetation succession, and increase the presence of non-native species that take up resources and outcompete native species (Menninger and Palmer 2006, Prack et al. 2007). Invasive plant species can change ecosystem function and halt succession by outcompeting native plant species either by competing for resources or altering nutrient cycling (Clewell and Aronson 2007, D'Antonio and Chambers 2006, Funk et al. 2008, Menninger and Palmer 2006, Prack et al. 2007, Walker and del Moral 2003). Restoration can change the impacts of invasive species that use up resources, impact the trophic structure, change the nutrient distribution of an area, damage ecosystem function, and affect successional trajectories (D'Antonio and Chambers 2006, Suding and Gross 2006). Most invasive plant species are prolific in open spaces that are high in resources such as water or nutrients, so many new restoration sites are vulnerable (Prack et al. 2007, Walker and del Moral 2003), but facilitating competition between native and non-native species later in succession becomes more important in rendering the site less susceptible to invasion (Prack et al. 2007). Many areas under consideration for restoration become overrun with a monoculture of undesirable vegetation. However, native species diversity contributes not only to succession, but also to ecosystem function by increasing resiliency in the system (Palmer 2009). The initial removal of non-native species may show an immediate reduction in such species, but subsequent removal may be necessary, too (Prack et al. 2007). Both wanted and unwanted vegetation can enter the site from surrounding areas, or be brought in through the hydrology of a site such as on a stream or river (Clewell and Aronson 2007). Sometimes an area will never return to a completely uninvaded state, and in these circumstances it becomes imperative to focus on re-establishing ecosystem services (D'Antonio and Chambers 2006), but a primary goal of restoration is usually to design a system that is resistant to invasion by undesirable vegetation (Funk et al. 2008).

Non-native, invasive plant species inhibit the growth of native vegetation that provide important ecosystem services, and should receive priority control, removal, or even eradication (D'Antonio and Chambers 2006, Prack et al. 2007). However, their removal alone is not enough to reach restoration goals (D'Antonio and Chambers 2006). Restoration sites severed from the landscape certainly have decreased native species propagule recruitment, and therefore become more difficult to restore (Suding and Gross 2006). Much time and money is spent to remove non-native species, but resources would be better accomplished by targeting only invasive plant species that pose an immediate threat to the sustainability and function of an ecosystem (Clewell and Aronson 2007). Timing in invasive plant species removal is important, for example, as they should be taken out before going to seed (Prack et al. 2007). Also, one must be careful not to harm native species during the removal of invasive plant species (Clewell and Aronson 2007).

One way to prevent the proliferation of invasive plant species is to select native species that have similar functional traits, that use greater resources, and exhibit greater ecological diversity than the monocultural invaders. Species diversity and functional richness at a local scale can reduce a restoration site's vulnerability to invasion through competitive exclusion, as niches become unavailable for the invaders. For example, reducing light availability from increased native canopy species can not only provide microhabitats for natives to establish, but it will shade out most invasive species that cannot tolerate low light levels (D'Antonio and Chambers 2006, Funk et al. 2008). Some non-native species will be outcompeted during the progression of succession (Clewell and Aronson 2007). However, native species are unlikely to replace non-natives if introduced to the site in small patches. This will not provide enough competition for the invasive plants, and eventually the native plants will be outcompeted (Walker and del Moral 2003). Successfully sustainable and resilient ecosystems with diverse native plant communities are somewhat impervious to invaders (D'Antonio and Chambers 2006).

2.4 *Ecological Function and Native Biodiversity*

Restored ecosystems should exhibit improved function (Clewell and Aronson 2007, Menninger and Palmer 2006), but the local scale of restoration is usually smaller than the regional or landscape scale of ecosystem processes (Palmer 2009). Although enhancing species diversity is a goal in many restoration projects, sometimes the goal of restoring ecological function takes priority (del Moral et al. 2007, Palmer et al. 2007, Palmer 2009). Restored ecosystems are capable of providing many economic values and services such as stormwater and pollutant amelioration, nutrient cycling, productivity, carbon sequestration, decreasing heat islands, noise reduction, habitat, recreation, and water recharge (Clewell and Aronson 2007, del Moral et al. 2007, Naeem 2006). In restoration, installing different species to conduct an ecological function ensures that role is fulfilled under varying conditions (Clewell and Aronson 2007).

Areas that provide ecosystem services are of value (Clewell and Aronson 2007). However, some indicators of ecosystem processes take a long time to recover, and may not be determined in the first few years of monitoring, and even then measurements may not be feasible within the constrained budgets of smaller restoration projects (Ruiz-Jaen and Aide 2005). Measurements of vegetation cover can provide inferences of ecosystem function (Clewell and Aronson 2007). Vegetation structure and cover are often used to measure a species function at a site, because it is assumed that with the recovery of vegetation follow re-establishment of habitat and ecological processes (Halle and Marzio 2004, Ruiz-Jaen and Aide 2005). So that costs may be weighed against benefits, it is necessary to consider the functional groups and amounts of species necessary for providing ecosystem functions (Palmer et al. 1997).

Ecologically, a functional group is the categorization of life forms that "consist of the species that perform a particular role in an ecosystem or respond to a given stressor or driver in an adaptive manner" (Clewell and Aronson 2007, p.63), such as light requirements, growth speed, or lifespan. It has already been established that restoration goals should not strive for an unpredictable endpoint, but setting goals based on ecosystem function is more compatible with the purpose of restoration. Using functional groups helps achieve ecosystem function and resilience (del Moral 2007, Menninger and Palmer 2006), but urban restoration projects cannot be expected to recover all functional groups or ecological roles (Clewell and Aronson 2007). In order to achieve ecosystem functionality, restoration can install dominant species to quickly return function to the system (Sullivan et al. 2009). Although this could enhance the stability and function of a system, diversity would be low. Over time more species could be introduced to enhance diversity at the site, which will further enhance ecosystem function (del Moral et al. 2007). Although select degrees of specific ecosystem functions may be reached with the introduction of a single native species, the site will not be as ecologically fit and is less resilient than if several species represent a function, since having several species for a particular function ensures that the function is carried out (Naeem 2006).

An increase in species diversity increases resistance to disturbance and intact ecological communities have higher ecological function and higher stability (Menninger and Palmer 2006, Palmer 2009). The ability of species to provide function to an ecosystem is at least as important as the number of species in an ecosystem (Hooper and Vitousek 1997). As the number of plant species increase, in some ecosystems so does net primary productivity (NPP) (Hooper and Vitousek 1997). In fact in less than three years vegetation manipulation can alter the nutrient dynamics of urban soil for the better (Vauramo and Setälä 2010), but nitrogen retention remains the same even if productivity is decreased (Symstad et al. 1998). Biotas govern ecosystem processes (Naeem 2006), and soil microbial communities are important indicators of function (Menninger and Palmer 2006). Also important is how species fit together (Naeem 2006). Clewell and Aronson (2007) maintain that the greater the variety and diversity of species the greater the chance that a system will be restored and will have ecological function. And increasing variety in plant species installed attracts species from higher trophic levels and helps to reestablish those populations as well.

3.0 METHODS

3.1 *Site Selection*

At the time this study was implemented, restoration had been ongoing for at least one year at 47 capstone sites. Ultimately 30 sites were chosen according to their location, available documentation, access, and ecosystem type (Table 1). In order to accommodate limited resources, the study was limited to sites that occurred within a 35 mile radius from the University of Washington Botanical Gardens and the Center for Urban Horticulture building in Seattle, Washington (Figure 1). From these sites all efforts were made to acquire the capstone student work plans, as-built reports and client RFP's, and sites were excluded if documentation could not be obtained. Sites were further eliminated if access to the restoration area was not possible, either because the restoration area no longer existed or permission to access the site was not granted during the field season. From the remaining group of restoration sites, only forested ecosystems were chosen for the purpose of comparing ecological factors across sites.

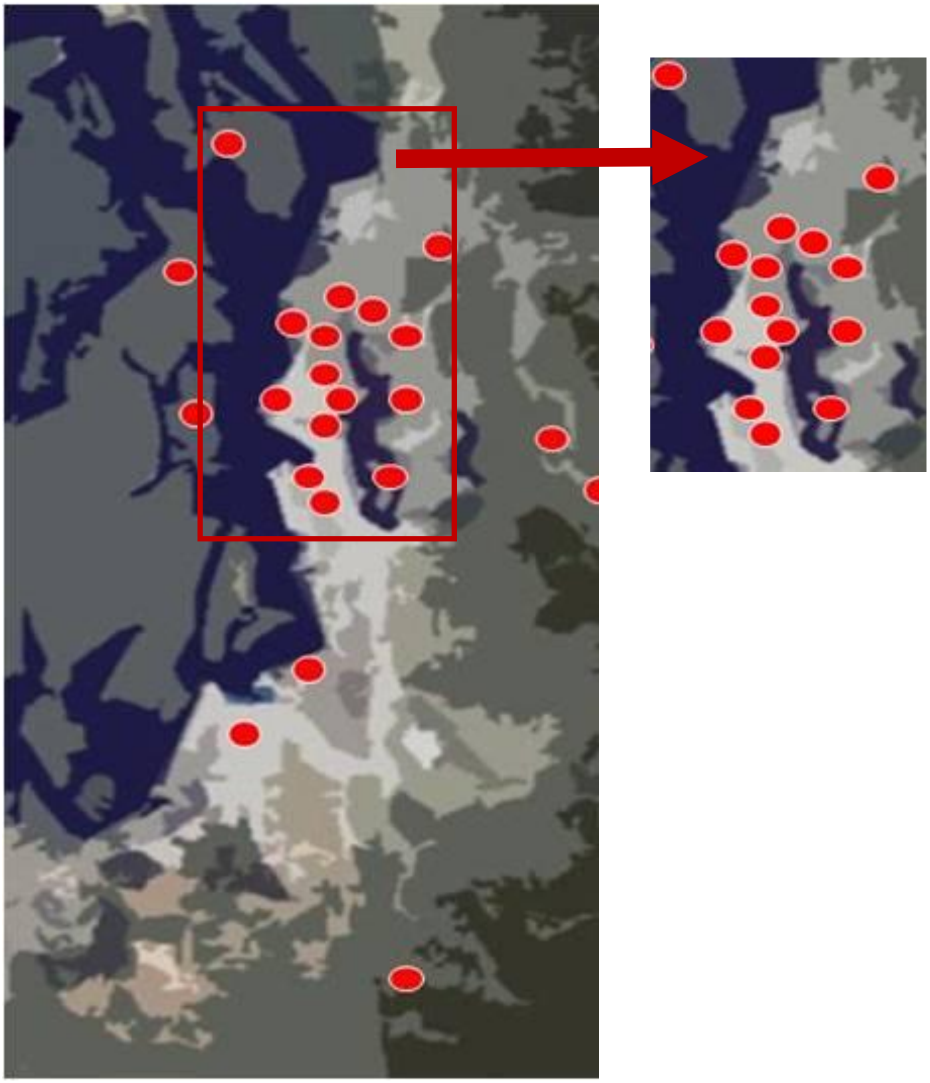

Figure 1: Map of the UW-REN capstone restoration sites in the Puget Sound region. Insert shows the capstone sites and projects that were ultimately examined for this study.

3.2 *Document Review*

From the documentation, management and explanatory variables including type of ecosystem, invasive plant control techniques, mulch techniques, the use of cardboard or fabric, identification of the community partner, and age of restoration were determined (Tables 1 and 2). Invasive plant control techniques included mowing, grubbing, and ivy pull. Mowing is simply the cutting back of invasive species, with no regard to removing the roots. Grubbing and ivy pull include removal of roots of the invasive plant species. The application of wood chip mulch was considered and divided into three categories: sites that did not use mulch, those that used less than six inches, and those projects that used greater than or equal to six inches. The use of cardboard included the technique whereby invasive plant species are removed using one of the methods described above, then a layer of corrugated cardboard is laid on top of the soil, then wood chip mulch is placed over the cardboard, and plants are installed through the cardboard. Fabric is the application of landscape fabric. The degree of stewardship was decided both from the documents and confirmation by the community partner. Sites were determined to have a value of high stewardship if they were maintained by an established group of volunteers or other entity beyond the first year of restoration implementation. Low stewardship was assigned to those sites that are maintained less than once per year, or only once by a subsequent capstone group. Furthermore, the goals and objectives outlined in the as-built documents were compared with those in the client RFP's.

Table 1: Summary table of the 30 capstone restoration sites that ultimately were selected for this study.

Site Name	Year Completed	Community Partner	Ecosystem Type
Arboretum	2006	University of Washington Botanical Gardens (UWBG)	Riparian lowland
Arboretum	2007	UWBG	Riparian lowland
Earth Sanctuary	2004	Earth Sanctuary	Forested upland
Earth Sanctuary	2005	Earth Sanctuary	Forested upland
Earth Sanctuary	2006	Earth Sanctuary	Forested upland
Earth Sanctuary	2008	Earth Sanctuary	Forested upland
Evergreen	2001	Evergreen School	Forested wetland
Fern Hollow	2001	Rita Moore	Forested wetland
Frink Park	2002	Friends of Frink Park & City of Seattle Department of Parks and Recreation (CSDPR)	Riparian lowland
Grass Lawn Park	2003	City of Redmond	Forested upland
Lawton Park	2002	CSDPR	Forested wetland
Licton Springs	2002	Licton Springs Community Council & CSDPR	Forested wetland
Licton Springs	2004	Friends of Licton Springs & CSDPR	Forested wetland
Licton Springs	2005	Friends of Licton Springs & CSDPR	Forested wetland
Mosher Creek	2008	Snohomish County	Riparian lowland
Rotary Park	2004	City of Woodinville	Riparian lowland
Swamp Creek	2005	Snohomish County	Forested upland
Swamp Creek	2006	Snohomish County	Forested upland
Swamp Creek	2007	Snohomish County	Forested upland
Thrasher’s Corner	2002	City of Bothell	Forested upland
Union Bay Natural Area (UBNA)	2006	Center for Urban Horticulture (University of Washington, UW)	Forested upland
UBNA	2001, 2003	Center for Urban Horticulture (UW)	Forested upland
UBNA	2002,2004	Center for Urban Horticulture (UW)	Forested upland
UBNA	2004,2005	Center for Urban Horticulture (UW)	Forested upland
West Duwamish Greenbelt	2004	The Nature Consortium	Forested upland
West Duwamish Greenbelt	2005	The Nature Consortium	Forested upland
West Duwamish Greenbelt	2006	The Nature Consortium	Forested upland
White Center	2008	King County	Forested upland
Yesler Creek	2007	Friends of Yesler Creek & CSDPR	Riparian lowland
Yesler Creek	2008	Friends of Yesler Creek & CSDPR	Riparian lowland

Table 2: The explanatory variables (i.e. factors) and number (n) of sites for each factor examined in this study.

Explanatory Variable (i.e. Factors)	Value	n	Factor	Value	n
Ownership	Private	6	**Use of Cardboard**	Yes	14
	City	15		No	14
	State	5		Fabric	2
	County	4	**Age of restoration**	1	4
Stewardship	High	17		2	3
	Low	13		3	5
Invasive Plant Control Technique	Mow	4		4	5
	Grub	23		5	5
	Ivy pull	3		6	2
Use of Mulch	None	4		7	4
	<6"	12		8	2
	≥6"	14			

3.3 *Field Measurements*

The vegetation monitoring protocol used in this study was developed by Seattle Urban Nature (SUN 2009), now the science team at Earthcorps, for restoration sites maintained in the Green Seattle Partnership within the City of Seattle Parks and Recreation system (see Appendix C). This graduate student along with one to three invaluable field assistants collected data during the 2009 summer season by establishing a 0.1 acre circular plot that best represented the implementation of restoration on each site. In smaller sites where a 0.1 acre plot could not be created, a 0.05 acre plot was established and final calculations were adjusted accordingly. In order to facilitate ease and accurate estimates of plant cover, each circular plot was divided into four quadrats. Collected were averaged estimates of the cover of all plant species occurring in each quadrat. Plant cover was determined recording the average estimate from all field members. Species that were present in trace amounts were given a value of 0.1% (SUN 2009). Also collected were tree height and diameter at breast height (dbh) again averaging the observed estimates of height from each field member, and verifying dbh measurements with calipers or dbh tape. Such tree data was originally collected during the 2009 field season, and verified during the summer of 2010. Site descriptors such as slope, aspect, soil surface stability, moisture, and texture, coarse woody debris (CWD) cover, and seral stage were observed. Soil characteristics were determined using the ribbon test for texture.

3.4 *Canopy Cover*

Canopy cover was measured at each site, usually on overcast days during the three weeks from 22 July to 11 August 2010. Using a hemispherical lens, a digital photograph was taken facing directly upward from the center point of each plot from a vertical five feet, and analyzed using the open source imaging software Gap Light Analyzer Version 2.0 (Frazer et al. 1999). Digital images were uploaded to the software and configured(Figure 2). The contrast threshold of each image was adjusted to further differentiate between sky and non-sky pixels. The software then divided each image into grids for measuring the percent of light infiltrating the canopy. The resulting data indicated the percent of canopy openness, and this number was subtracted from 100 to indicate the percent of canopy cover which was of interest in this study.

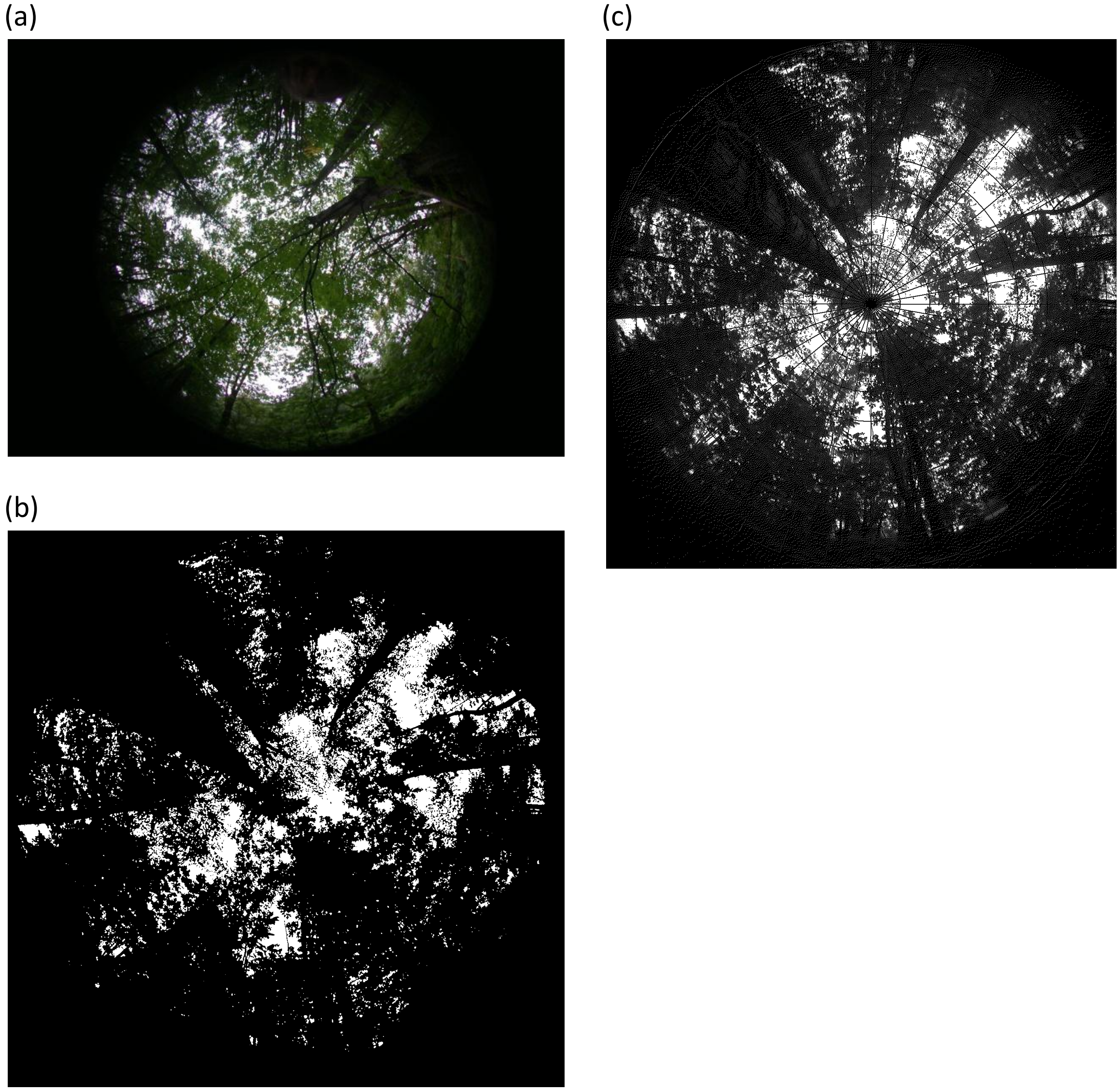

Figure 2: Pictures used in the determination of canopy cover. (a) is the original picture taken with the hemispherical lens, (b) is the image after uploading into the GLA software, and (c) is the image overlaid with the grid to measure the amount of light infiltrating the canopy.

3.5 *Data Analysis*

Total plant cover was estimated and then calculated for each 0.1 acre plot. For this study, trees with a dbh less than five inches were considered to be regenerating, and their abundance was calculated as stems per tenth of an acre multiplied by ten to estimate the average stems per acre (SUN 2009). Different vegetative layers were of interest in this study. Therefore, categorization of tall shrubs and short shrubs were determined using the University of Washington herbarium database (WTU 2010), and tall shrubs were regarded as those that can grow more than 3m in height. Nomenclature for plants species was derived from the USDA plants database (USDA 2010). Variables for the explanatory and species matrices were recovered from these data. All cover data was entered into a Microsoft Access database provided by the science team at Earthcorps (SUN 2009). Spreadsheets were then derived for further data management both in Excel and in the open source software R (version 2.10.1 (2009-12-14)). All statistical tests were run in R.

Barplots were created to demonstrate trends in the explanatory variables in relation to differences in native and non-native cover. The native and non-native cover composition data were found to have a binomial distribution, as is common with percentage or proportional data (Zar 1999). Therefore an arcsine square root transformation was implemented on the cover composition data to attain normality (McCune and Grace 2002, Zar 1999), which was confirmed with a Shapiro-Wilkes test. Single factor analysis of variance (ANOVA) tests were conducted to evaluate whether differences were significant in native and non-native cover across the explanatory variables of ownership, stewardship, control technique, use of cardboard, use of mulch, and age; and a Tukey's Honestly Significant Difference (HSD) test was employed to examine multiple mean comparisons.

Pearson correlation tests were enlisted to examine the presence or absence of significant correlations of non-native cover and the various life form vegetative layers of trees, tall shrubs, short shrubs, and the herbaceous layer. Several community analysis techniques were employed to quantitatively describe the relationships between plant community composition and the explanatory variables and vegetative layers. R was used to generate a multivariate regression tree (MRT), and non-metric multi-dimensional scaling (NMDS) ordination using Bray-Curtis distance measure (Ruiz-Jaen and Aide 2005) of species composition, vegetative layers, and explanatory variables of data taken at the 30 sites.

Data were relativized to avoid the pitfall of the analyses emphasizing the effect of only a few species (McCune and Grace 2002). Since relative cover was of interest in these analyses, species composition data were relativized by species maxima, and site composition totals were relativized by totals. Rare species were not eliminated from the data since it was important to include species even if they were only present as a trace.

Diversity measures can be used to indicate the ecological integrity of a system, although sites may still display integrity even with low diversity measurements. In order to fully interpret diversity, it is useful to examine both richness and evenness (Magurran 1988, Whittaker 1972). Species richness and alpha diversity indices were run to determine the extent to which the restoration sites exhibit species richness, abundance, and evenness. Therefore, in order to show the relationship of diversity across explanatory variables, from the species composition matrices, native and non-native species richness was determined, and diversity evenness was calculated using the Shannon Index (Magurran 1988). Native species richness and diversity were then analyzed using ANOVA and Tukey's HSD in comparison to the explanatory variables ownership, stewardship, invasive plant control technique, use of cardboard, use of mulch, and age.

4.0 RESULTS

4.1 *Project Goals*

A comparison was made of the client RFP's and the student As-Built documents for the thirty capstone projects (Table 3). All groups endeavored to follow the outlined goals from the RFP, and thirteen groups enhanced the requested goals and/ or added more goals. The most common goal occurring in all projects was to remove invasive plant species and to restore native plant species and/ or diversity. Promoting succession was the most common way of accomplishing this. Where relevant, eleven clients asked that previously implemented restoration projects adjacent to the sites be maintained, and while only eight groups made this task a goal, all capstone groups included maintenance of previous plantings as part of their work. Nine RFP's laid out plans to enhance wildlife habitat, but eleven student projects prioritized the enhancement or creation of wildlife habitat as a main goal. The capstone groups incorporated an educational context for the projects with ten groups identifying it as a major goal, while only four RFP's specifically asked for it. Limiting or reducing erosion, and stabilizing slopes was another common goal occurring in eight RFP's and nine as-built documents. Evident in all the documents was the objective of the return of ecosystem function to a site, with ten RFP's and ten relevant as-built documents even outlining it as a major goal. Ecosystem function ranged from ameliorating pollution to retaining stormwater or enhancing stream water quality through native plantings. While all the capstone groups attempted to promote community involvement and public awareness of their restoration activities, only twelve groups specifically outlined it as a goal.

Table 3: List of the number of explicit project goals as stated in the RFP and As-Built documents.

Project goals	RFP documents	As-Built documents
• Decrease invasive plant species • Increase native plant species &/ OR • Increase native plant diversity	30	30
• Promote succession	9	4
• Maintain previous restoration	11	8
• Enhance or create wildlife habitat	9	11
• Provide educational opportunities	4	10
• Reduce erosion • Stabilize slope	8	9
• Enhance ecosystem function	10	10
• Involve community	2	12

4.2 *Ecological Evaluation Results*

4.2.1 Plant cover

A total of 109 vegetative species were found and recorded at the 30 UW-REN capstone project restoration sites (Table 4). There were 96 Pacific Northwest native species and 13 non-native species identified across the project sites (SUN 2009, USDA 2010, WNPS 2008). The most abundant native species was *Alnus rubra* (red alder), occurring in twenty sites with an average cover of 30% (at sites where it was present). Other trees in abundance across the sites included *Acer macrophyllum* (bigleaf maple) occurring on twelve sites with an average cover of 31%, *Populus balsamifera* ssp. *trichocarpa* (black cottonwood) on eleven sites with 17% average cover), and *Pseudotsuga menziesii* (Douglas-fir) on fifteen sites with 8% average cover. *Thuja plicata* (Western redcedar) was present on twenty-six sites at an average cover of 5%.

Among the tall shrubs, *Salix* species were also found in abundance across the sites occurring on four sites with an average cover of 20%. *Salix lucida* (Pacific willow) and *Salix scouleriana* (Scouler's willow) were found on nine sites with an average cover of 15% each. More tall shrubs were utilized across the sites such as *Physocarpus capitatus* (Pacific ninebark) found on six sites at an average cover of 6%, and *Lonicera involucrata* (twinberry) on fourteen sites with an average cover of 5%.

Several short shrubs were located across the project sites including *Rubus spectabilis* (salmonberry) found on 22 sites with an average cover of 15%, *Rubus ursinus* (trailing blackberry) on fifteen sites with an average cover of 23%, *Rosa nutkana* (Nootka rose) on eleven sites with an average cover of 11%, *Oemleria cerasiformis* (Indian plum) on sixteen sites with 4% average cover, and *Symphoricarpos albus* (snowberry) on 21 sites with 2% average cover.

The herbaceous layer across sites included *Polystichum munitum* (sword fern) occurring on 22 sites with an average cover of 9%, *Athyrium filix-femina* (lady fern) on eleven sites at 4% average cover, and *Oenanthe sarmentosa* (water parsley) on seven sites with an average cover of 10%. The most common non-native species were *Rubus armeniacus* (Himalayan blackberry) occurring in 27 sites, and *Phalaris arundinacea* (reed canarygrass) in 15 sites with average covers of 14%. Other common non-native species were *Convolvulus arvensis* (field bindweed) on fifteen sites at 12% average cover, and *Ranunculus repens* (creeping buttercup) on thirteen sites and *Hedera* sp. (English ivy) on eight sites with an average cover of 9% each.

Table 4: Common native and non-native vegetative species and their abundance at the restoration sites.

Native species	**Common name**	**Growth form**	**# of sites**	**Average % cover**	**Standard Deviation**
Alnus rubra	red alder	Tree	20	30	23
Acer macrophyllum	bigleaf maple	Tree	12	31	22
Athyrium filix-femina	lady fern	Herbaceous	11	4	5
Lonicera involucrata	twinberry	Tall shrub	14	5	3
Oemleria cerasiformis	indian plum	Short shrub	16	4	3
Oenanthe sarmentosa	water parsley	Herbaceous	7	10	10
Physocarpus capitatus	Pacific ninebark	Tall shrub	6	6	10
Polystichum munitum	sword fern	Herbaceous	22	9	12
Populus balsamifera ssp. *trichocarpa*	black cottonwood	Tree	11	17	12
Pseudotsuga menziesii	Douglas-fir	Tree	15	8	11
Rosa nutkana	Nootka rose	Short shrub	11	11	12
Rubus spectabilis	salmonberry	Short shrub	22	15	14
Rubus ursinus	trailing blackberry	Short shrub	15	23	24
Salix lucida	Pacific willow	Tall shrub	9	15	15
Salix scouleriana	Scouler's willow	Tall shrub	9	15	7
Symphoricarpos albus	snowberry	Short shrub	21	2	2
Thuja plicata	western redcedar	Tree	26	5	7

Non-native species	**Common name**	**Growth form**	**# of sites**	**Average % cover**	**Standard Deviation**
Convolvulus arvensis	field bindweed	Vine	15	12	10
Hedera spp.	English ivy	Vine	8	9	8
Phalaris arundinacea	reed canarygrass	Herbaceous	15	14	17
Ranunculus repens	creeping buttercup	Herbaceous	13	9	7
Rubus armeniacus	Himalayan blackberry	Short shrub	27	14	22

4.2.2 Canopy cover

Canopy openness was measured at each site and converted to canopy cover (100 - openness) (Figure 3). Twenty-two of thirty sites had measured canopy covers of 80% or more. The Arboretum (2007), Earth Sanctuary (2005), Rotary Park/ Little Bear Creek (2004), and Swamp Creek (2006) had canopy covers in the 70-80% range. Earth Sanctuary (2004) and Mosher Creek (2008) had canopy covers in the 50% - 69% range. Two UBNA sites had the lowest canopy cover with UBNA (2001,2003) at 18% and UBNA (2006) at zero.

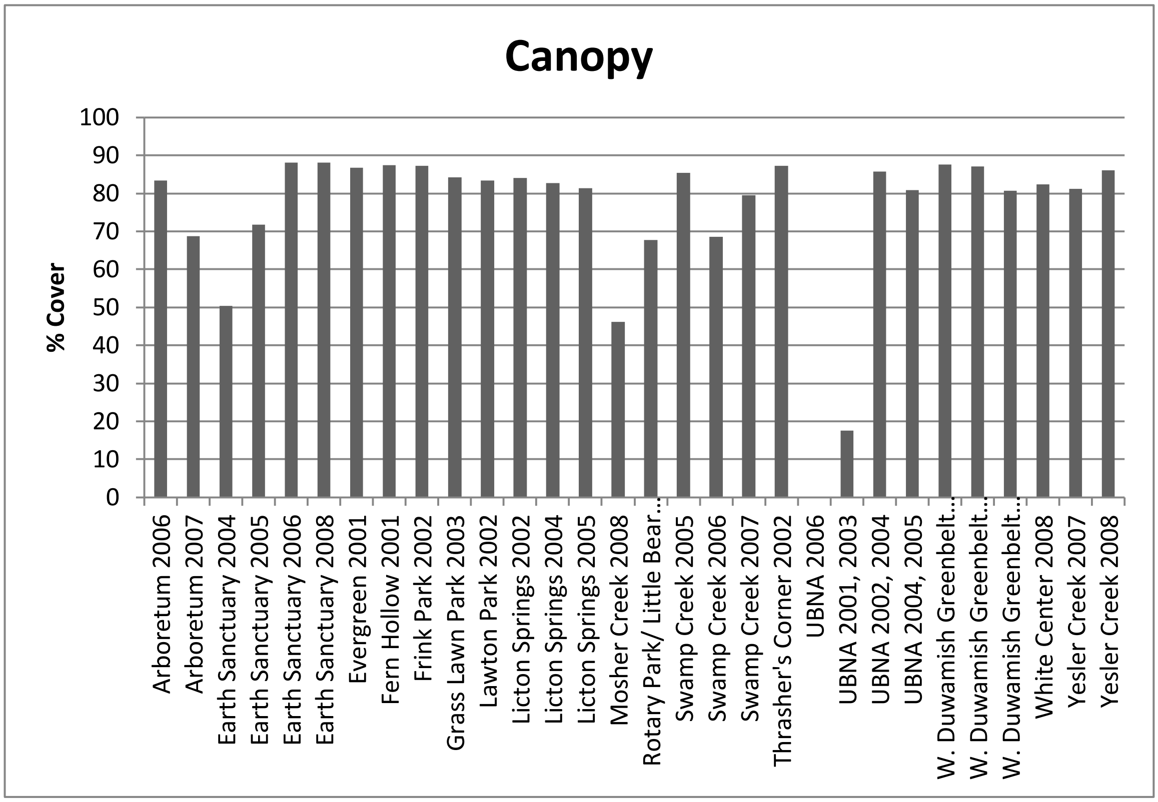

Figure 3: Canopy cover by capstone restoration site.

4.2.3 Tree regeneration density

In order to measure efforts by capstone students to introduce species that will eventually reach canopy height, provide shade, and promote forest succession, regenerating trees were recorded (Table 5). Twenty regenerating tree species were found across the thirty site projects. Fifteen of these species were native trees found in Pacific Northwest forested ecosystems. Five species were non-native, and four of these species are considered invasive. Regenerating conifer species included *Abies grandis* (grand fir) occurring on four sites at an average of 30 stems per acre, *Picea sitchensis* (Sitka spruce) occurring on nine sites at an average of 37 stems per acre, *Pinus contorta* (shore or lodgepole pine) on eight sites at an average of 18 stems per acre, *Pseudotsuga menziesii* (Douglas-fir) on fifteen sites at an average of 35 stems per acre, *Taxus brevifolia* (Pacific yew) on two sites at an average of 15 stems per acre, *Thuja plicata* (western red cedar) on twenty-three sites at an average of 83 stems per acre, and *Tsuga heterophylla* (western hemlock) on ten sites at an average of 24 stems per acre. Regenerating deciduous species were *Acer macrophyllum* (bigleaf maple) occurring on six sites at 45 stems per acre, *Alnus rubra* (red alder) on nine sites at 39 stems per acre, *Arbutus menziesii* (Pacific madrone) on one site at ten stems per acre, *Frangula purshiana* (cascara) on seven sites at an average of 30 stems per acre, *Fraxinus latifolia* (Oregon ash) on three sites at 20 stems per acre, *Populus balsamifera* spp. *trichocarpa* on five sites at 22 stems per acre, *Populus tremuloides* (quaking aspen) was found on one site at 10 stems per acre, and *Prunus emarginata* (bitter cherry) on two sites at 57 stems per acre. Non-native species that were found in the capstone sites include *Crataegus monogyna* (hawthorn) on two sites at an average of 10 stems per acre, *Ilex aquifolium* (English holly) on three sites at an average of 23 stems per acre, *Prunus laurocerasus* (cherry laurel) on one site at 10 stems per acre, *Prunus* sp. (horticultural cherry species) on one site at 20 stems per acre, and *Sorbus aucuparia* (European mountain ash) on two sites at 10 stems per acre.

Table 5: Regenerating tree species measured in stems per acre, with the standard deviation. Note the high variability among the sites.

Evergreen tree species		# of sites	stems/ acre	Standard Deviation
Abies grandis	grand fir	4	30	8
Arbutus menziesii	Pacific madrone	1	10	10
Picea sitchensis	Sitka spruce	9	37	41
Pinus contorta	shore pine	8	18	10
Pseudotsuga menziesii	Douglas-fir	15	35	26
Taxus brevifolia	western yew	2	15	7
Thuja plicata	western red cedar	23	83	94
Tsuga heterophylla	western hemlock	10	24	24

Deciduous tree species		# of sites	stems/ acre	Standard Deviation
Acer macrophyllum	bigleaf maple	6	45	34
Alnus rubra	red alder	9	39	45
Frangula purshiana	cascara	7	30	30
Fraxinus latifolia	Oregon ash	3	20	0
Populus balsamifera ssp. *trichocarpa*	black cottonwood	5	22	8
Populus tremuloides	aspen	1	10	0
Prunus emarginata	bitter cherry	2	57	81

Non-native tree species		# of sites	stems/ acre	Standard Deviation
Crataegus monogyna	oneseed hawthorn	2	10	0
Ilex aquifolium	English holly	3	23	23
Prunus laurocerasus	cherry laurel	1	10	0
Prunus sp.	horticultural cherry species	1	20	0
Sorbus aucuparia	European mountain ash	2	10	0

4.3 *Site Management and Initial Restoration Technique*

Ownership and stewardship were significantly associated with native percent composition ($p=0.0016$ and $p<0.001$ respectively). Initial control techniques were less significant ($p=0.02$). The use of wood chip mulch, sheet mulch (cardboard), and the time since the restoration project was completed were not significantly associated with native or non-native plant cover (Figure 4, Table 6).

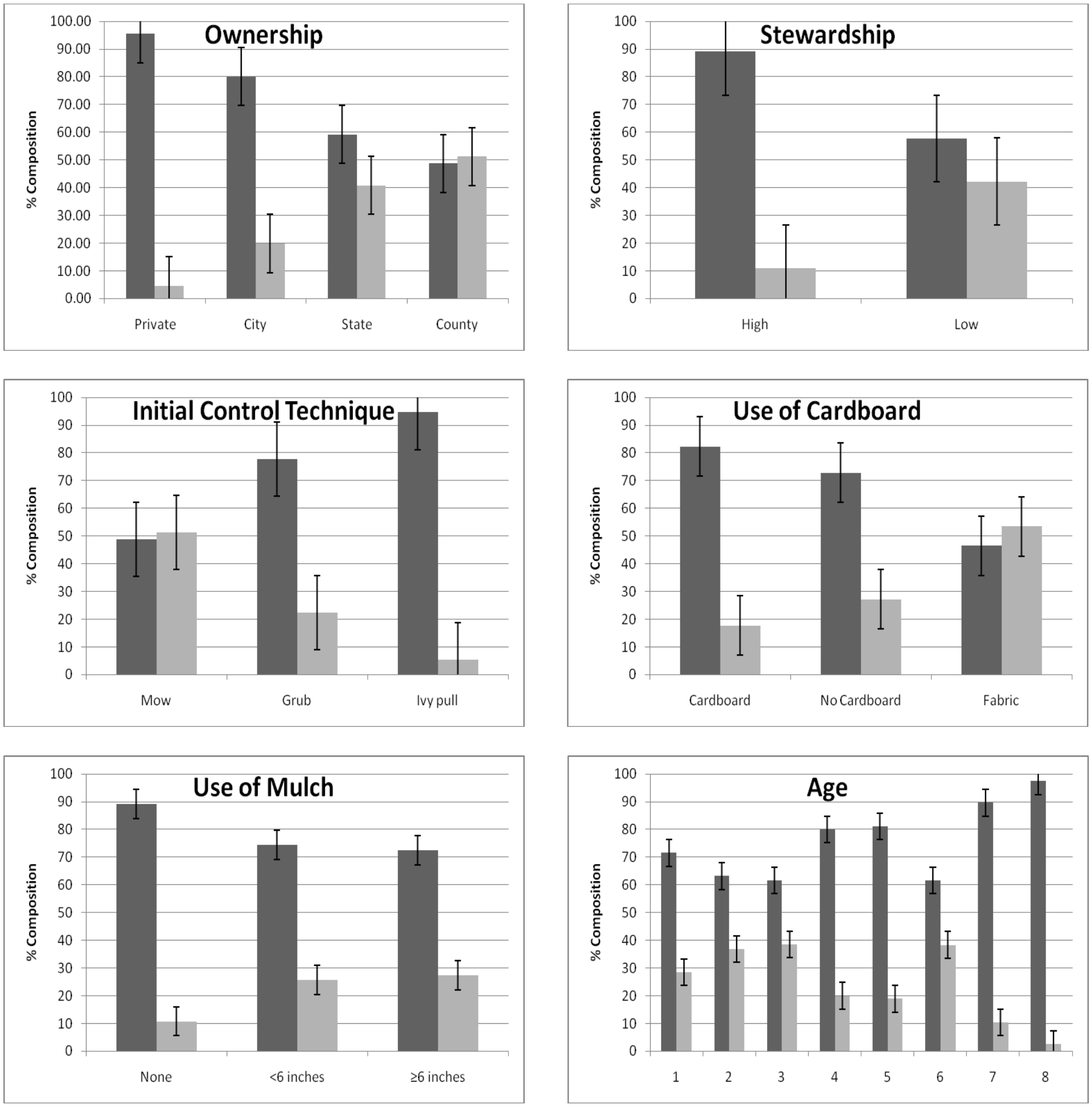

Figure 4: The mean and the standard deviation (±1) of native cover (dark) versus non-native cover (light) for the explanatory variables (site ownership, level of stewardship, invasive control technique, use of cardboard and wood chip mulch, and age of restoration).

Table 6: ANOVA and Tukey HSD multiple comparison results for factors ownership, stewardship, initial invasive plant control technique, use of cardboard, use of mulch, and age.

Dependent Variable	Factor	DF	MSE	F	*p*	Multiple Comparisons
Native Composition	Ownership	3	0.424	6.78	0.0016	Private>County, Private>State, City>State
	Stewardship	1	1.287	22.41	<0.001	High>Low
	Control	2	0.377	4.76	0.02	Grub>Mow, Ivy pull>Grub
	Cardboard	2	0.160	1.67	0.21	N.S.
	Mulch	2	0.090	0.89	0.42	N.S.
	Age	7	0.104	1.06	0.42	N.S.

In addition to the ANOVA and Tukey's HSD, multiple regression tree (MRT) analysis (Figure 5) was used to examine the relative significance of the explanatory variables on vegetative cover (De'ath 2002). MRT uses regression analysis to determine which factors have the greatest effect on species composition, followed by the next greatest, and so on. The different factors appear on a picture in the form of a regression tree with different "leaves" or nodes. The first node in the analysis explains 29% of the variation in species composition with an error of 0.485. The MRT resulted in three leaves, with ownership as the first partition, then stewardship, and finally the use of mulch. The use of cardboard and initial control technique were not significant enough to appear on the multiple regression tree.

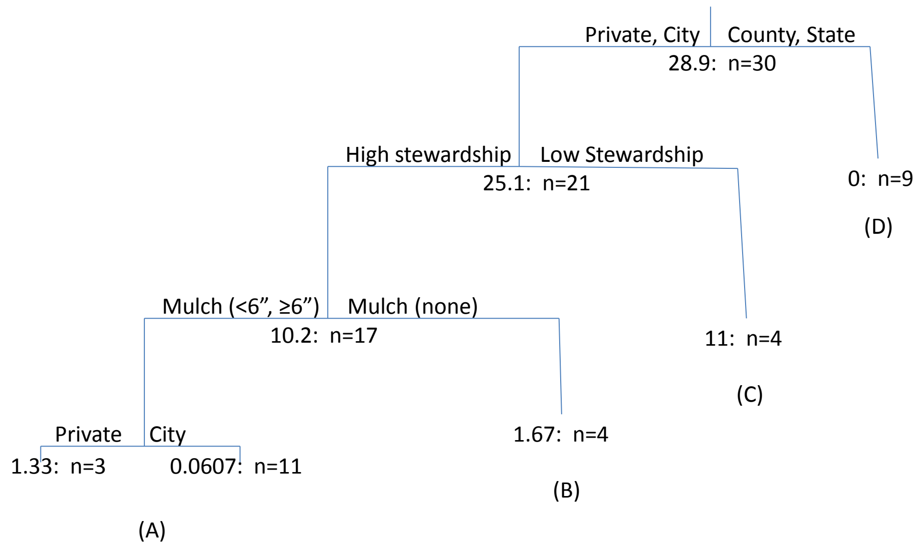

Figure 5: Multiple regression tree (MRT) analysis of species composition across the capstone restoration sites against the total native cover of the sites. The first node of the MRT explains 29% of the variation and the second node explains 25% of the remaining variation.

4.4 *Vegetative Cover at Various Layers*

Among the vegetative layers measured, Pearson's correlation shows that trees demonstrate a negative correlation with non-native species (r = -0.37, p = 0.04) (Figure 6). Tall shrubs are positively correlated with non-native species (r = 0.51, p = 0.004). Short shrubs and herbs are not correlated with proportional representation of non-native vegetation.

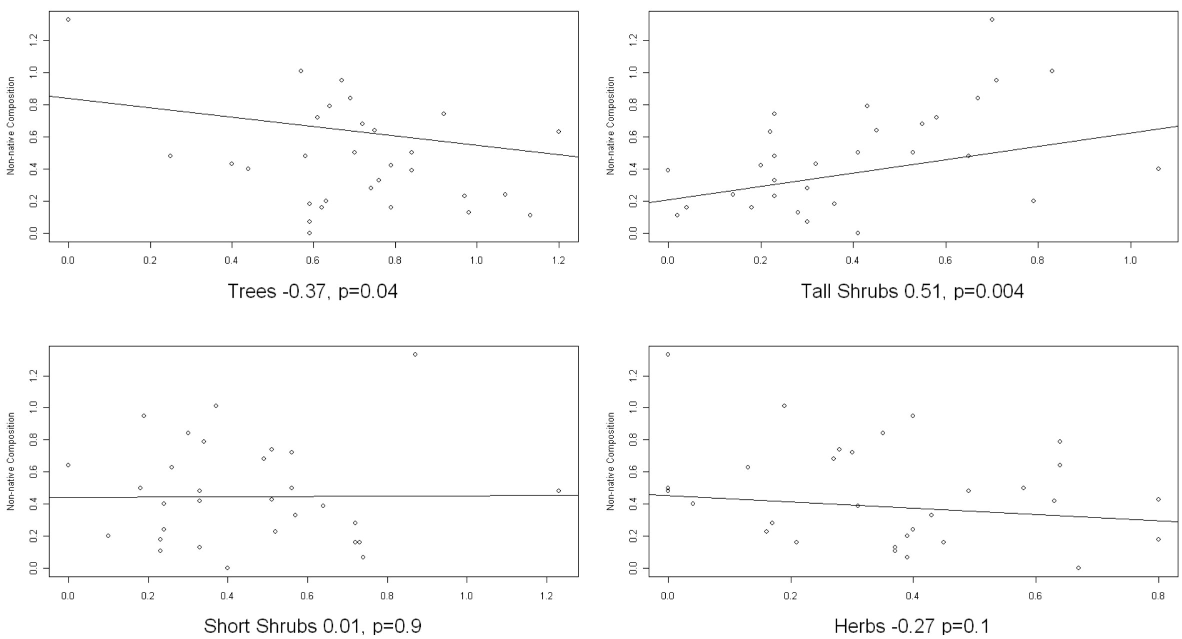

Figure 6: Correlations of total non-native cover across the sites with various vegetative layers (trees, tall shrubs, short shrubs, and herbs).

The various vegetative layers (trees, tall shrubs, short shrubs, and herb layers) were also examined and visualized using non-metric multidimensional scaling (NMDS) ordinations (Figures 7-10). NMDS was chosen because the tests can produce robust visualizations of data despite numerous zero-values and highly variable data with lack of normality (McCune and Grace 2002). NMDS ordinations of all species yielded a stress of 21 on two dimensions after 40 random starts. Although there is overlap of the standard deviation, sites that were maintained by stewards versus those that had little maintenance were separated in ordination space (Figure 7). Native species are positively correlated with stewarded sites, and non-native species are positively correlated with non-stewarded sites. Canopy cover is correlated with native species (Figure 6, r^2=0.18, p=0.05) (Figure 8), and sites that have greater evergreen cover (r^2=0.22, p=0.04) are more positively correlated with native species than deciduous covers (r^2=0.06, p=0.4) (Figure 9). Trees (r^2=0.06, p=0.42), short shrubs (r^2=0.22, p=0.03), and herbaceous (r^2=0.37, p=0.002) layers were positively correlated with native species, but tall shrubs were negatively correlated to native species (r^2=0.4 , p= 0.001)(Figure 10).

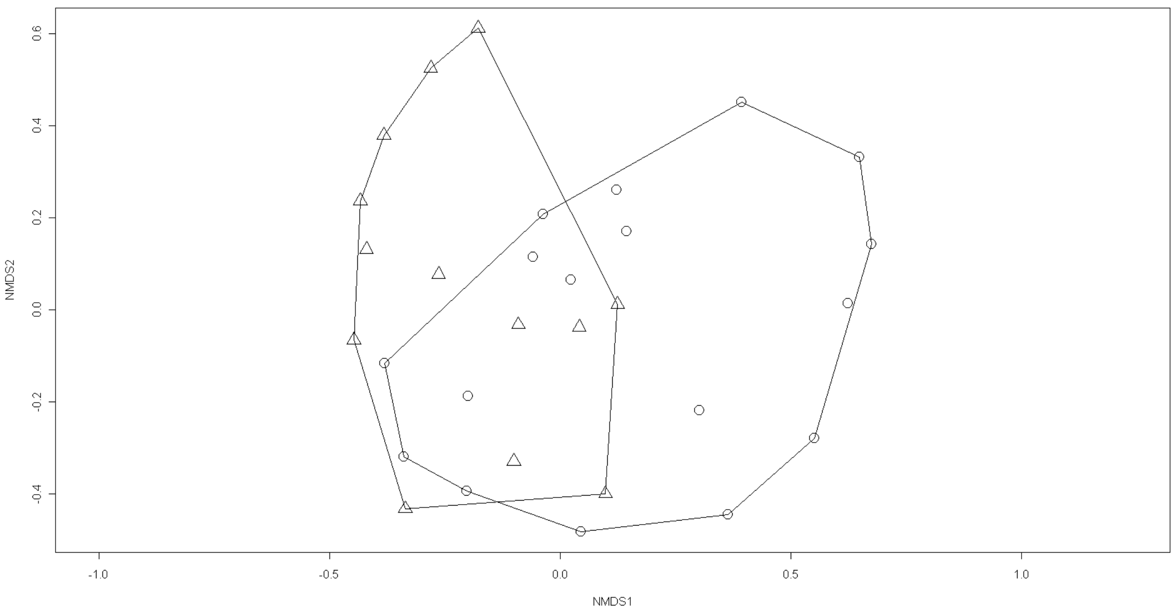

Figure 7: NMDS ordination demonstrating the separation in ordinal space between highly stewarded (circles) and low stewardship sites (triangles).

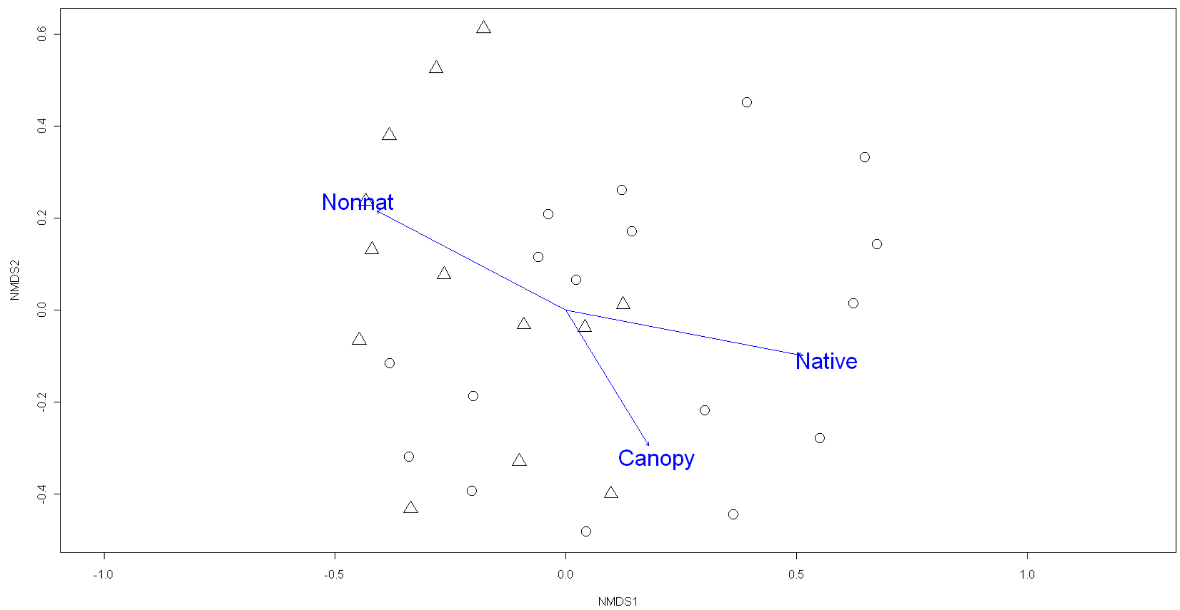

Figure 8: NMDS showing the negative correlation of native versus non-native species cover. Canopy cover is positively correlated with native species.

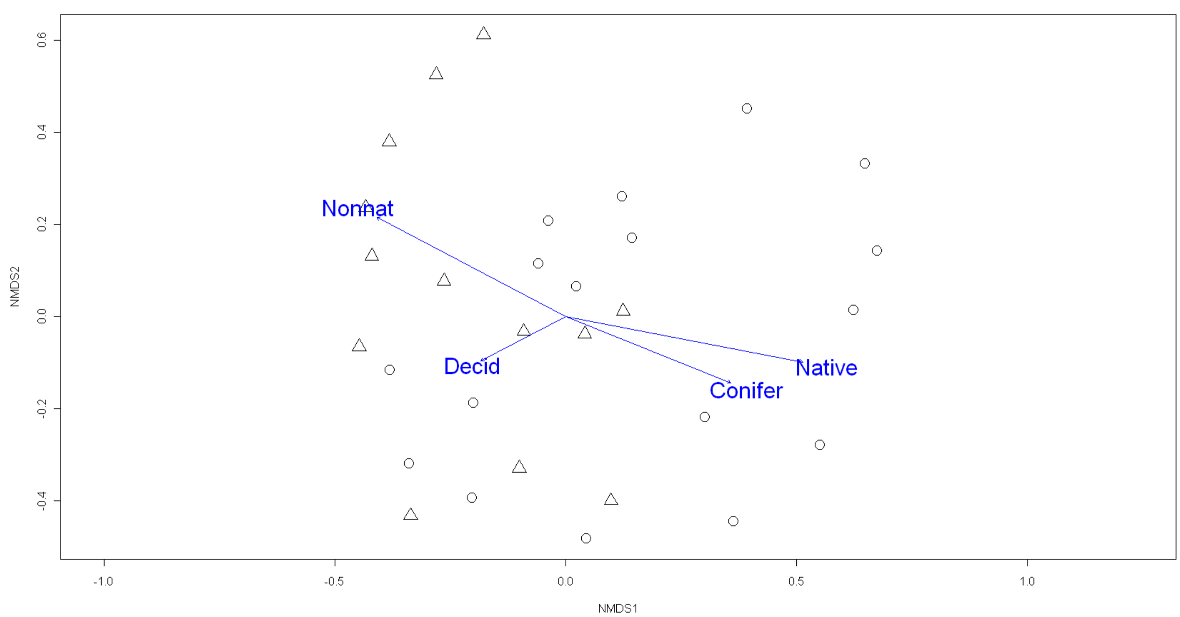

Figure 9: NMDS visualizing the significant positive correlation of coniferous cover on native species cover. Deciduous cover does not contribute significantly.

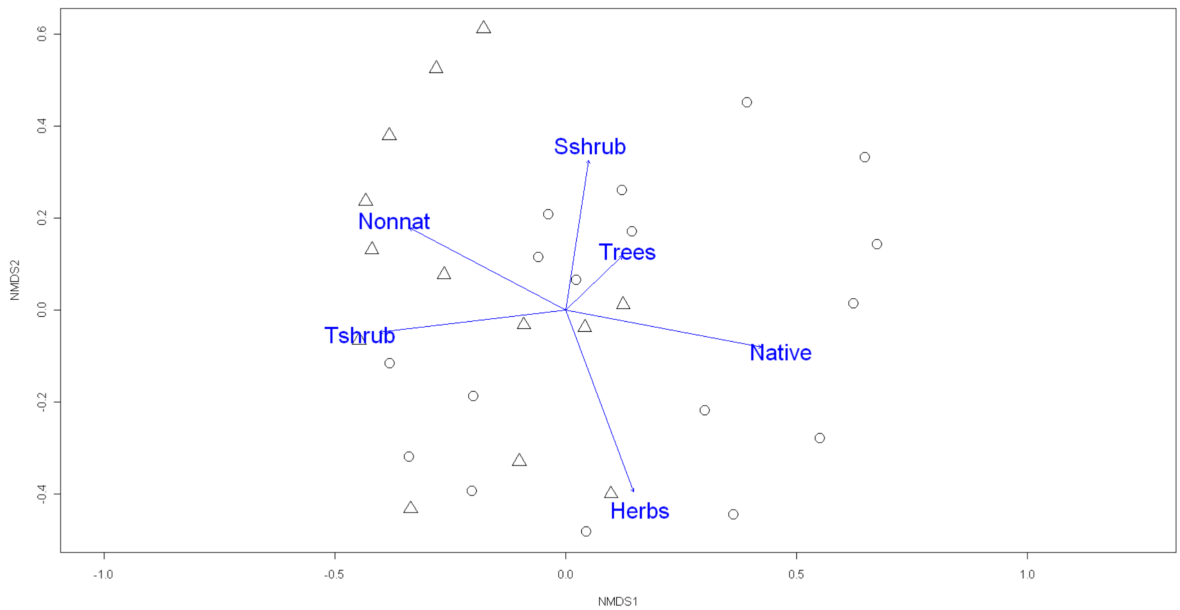

Figure 10: NMDS showing the various vegetative layers (trees, tall shrubs, short shrubs, and herbs) and their contribution to species composition. Trees, short shrubs, and herbs are positively correlated to native cover, but tall shrubs are correlated with non-native species cover.

4.5 *Species Diversity*

For evenness, the Shannon Index was selected for its moderate discriminant ability and ease of calculation of alpha diversity for each site (Magurran 1988). Shannon indices typically run on a scale of 1.5 to 3.5 (low diversity to higher diversity), but can reach a value as low as zero and as high as five (MacArthur and MacArthur 1961, Whittaker 1972). Twenty-eight of thirty sites resulted in a Shannon Index from 1.5 to 2.72. Mosher Creek (2008) and UBNA (2006) fell below these values at 1.33 and 1.01 respectively (Figure 9).

ANOVA was employed in order to compare values of diversity at the sites based on the explanatory variables of ownership, stewardship, initial invasive plant control technique, use of cardboard, use of mulch and age (Table 4). For native richness, ownership, stewardship, initial invasive plant control technique, and the use of cardboard were significant. Privately and city owned sites had greater native richness than state owned sites. It follows that sites that were stewarded exhibited greater native richness than sites that did not receive stewardship. Grubbing and ivy pulls work better as an initial invasive plant control technique than mowing, and the use of cardboard was important in the degree of native richness. Age of restoration was not significant in native richness.

The alpha Shannon diversity index yielded different results than the species richness measure (Table 7, Figure11). Ownership was still significant with privately and city owned sites exhibiting greater species diversity than state sites, and state sites having greater diversity than county sites. Stewardship was still significant for the Shannon index. Initial control technique was significant, again with grubbing contributing more to diversity than mowing. The use of wood chip mulch contributed to native diversity, with using less than six inches of mulch contributing more than using more than six inches of mulch. The use of cardboard and age of the restoration site did not have significant effects on the Shannon Index.

Table 7: ANOVA results for native species richness (top) and the Shannon Index (bottom) of diversity. Included are the degrees of freedom (DF), mean square error (MSE), F statistic, and p value of significance (α=0.05)

Dependent Variable	Factor	DF	MSE	F	*p*	Multiple Comparisons
Native Richness	Ownership	3	207.7	4.51	0.01	Private>State, City>State
	Stewardship	1	448.3	9.14	0.005	High>Low
	Control	2	311.2	4.76	0.02	Grub>Mow, Ivy pull>Mow
	Cardboard	2	388.6	3.66	0.04	Yes>No
	Mulch	2	68.05	1.09	0.35	N.S.
	Age	7	63.81	1.02	0.44	N.S.
Shannon Index	Ownership	3	0.431	5.78	0.004	Private>State, City>State State>County
	Stewardship	1	0.366	3.58	0.07	N.S.
	Control	2	0.615	8.30	0.002	Grub>Mow, Ivy pull>Mow
	Cardboard	2	0.076	0.66	0.5	N.S.
	Mulch	2	0.358	3.84	0.03	<6 inches > ≥6 inches
	Age	7	0.081	0.67	0.70	N.S.

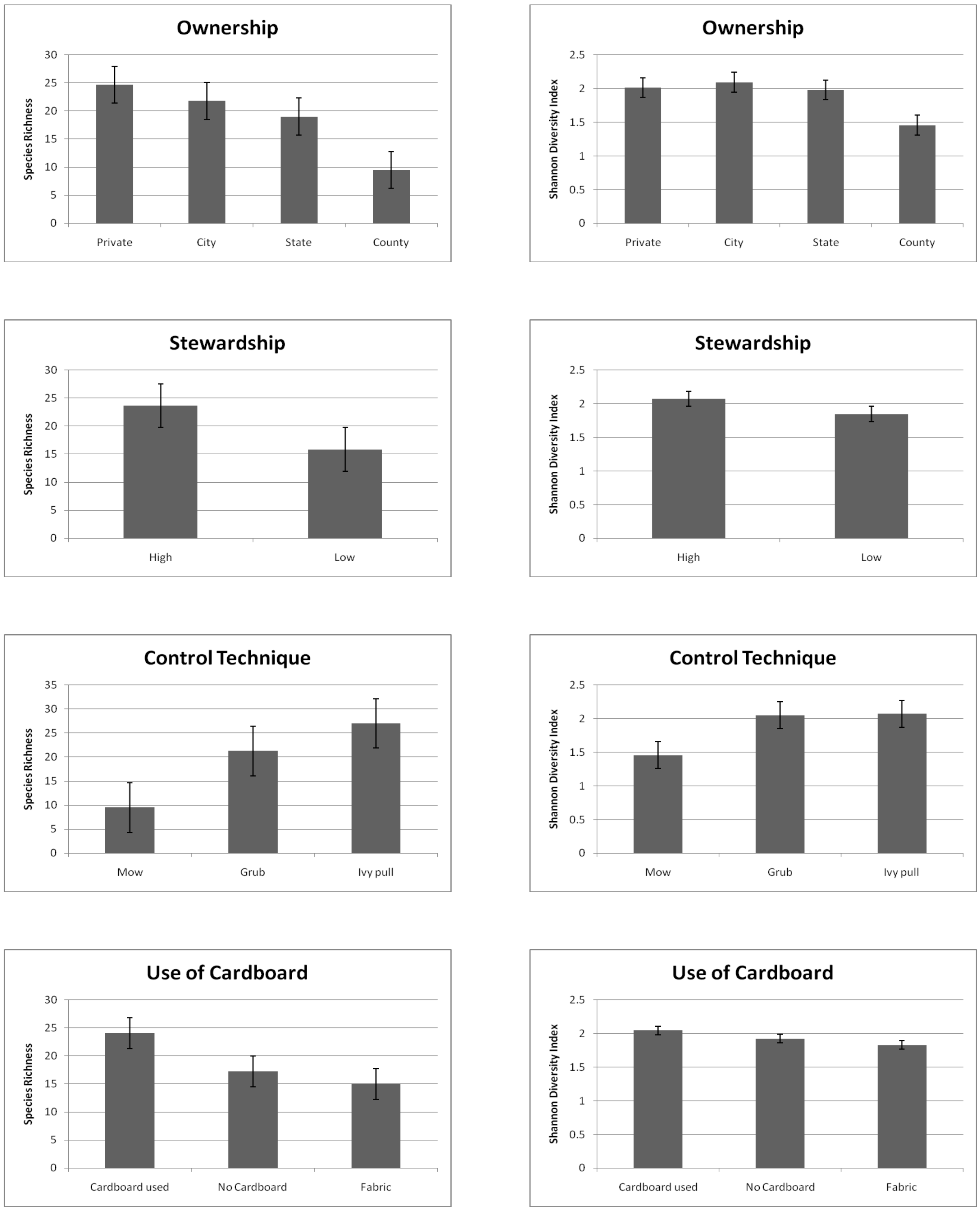

Figure 11: Graphical representation of native richness (left), and the Shannon diversity index (right) and the standard error across the significant factors of site ownership, stewardship, initial invasive plant control technique, use of cardboard, and use of mulch.

5.0 DISCUSSION

Restoration is the process of changing a degraded ecosystem to a state in which it becomes able to withstand periodic environmental stressors and to recover from disturbance (SER 2004, 2011, Clewell and Aronson 2007, and Walker et al. 2007). The UW-REN capstone students accomplished this through the enhancement of native species composition and ecosystem services, and through the promotion of succession. As urban development encroaches upon habitat, fragmentation and edge effects compromise the ecological integrity of the system. Human actions at local scales have regional effects, both positive and negative, and even small patches of native vegetation may prove useful in bringing about changes at the landscape scale (Jackson et al. 2001, Sullivan et al. 2009). Corridors in urban environments may enhance the ecological health of a severed landscape (Sullivan et al. 2009). Restoration may create habitat corridors, which connect and allow for the movement of organisms and energy to flow across the landscape (SER 2009).

5.1 *Project Goals*

Clear goals are important in determining the success of a restoration project (Clewell and Aronson 2007, del Moral et al. 2007, Hobbs 2007, Osenberg et al. 2006, SER 2008). A qualitative comparison was conducted on the client RFP's and the student as-built reports to ascertain whether the students were successful in interpreting the original plans for restoration outlined in the RFP documents. The capstone student project goals matched the goals found in the RFP documents. All the groups from the thirty different projects were successful in interpreting and following the major goals outlined in the RFP. Nearly half of the groups even enhanced the goals and added more goals and objectives for attaining a successful restoration project.

Facilitating succession presented as the most common path to successful restoration in the project documents. Students demonstrated that they understood the importance of site maintenance, and where there were continuous sites the groups made maintaining previous sites part of their work plan whether it was requested or not. Many students directly reached out to the community to ensure the future success of their restoration, and/or made signs for the site to educate passers-by of the importance of the restoration sites. The capstone groups were diligent in incorporating an educational context, community involvement, and public awareness for their projects, although not all projects resulted in consistent stewardship of the site. The return of ecosystem function, such as improving stream water quality, and the method of shading invasive species through native plantings, was also important to the student groups. In addition, some projects sought to limit or reduce erosion, or stabilize a slope once non-native species had been removed.

5.2 *Ecological Findings*

Restorers may look to historical knowledge to aid in determining the success of a project (Brewer and Menzel 2009). The capstone restoration sites that were evaluated are located in what is considered by Franklin and Dyrness (1988) as the *Tsuga heterophylla* zone in the Puget Sound trough. Historically, Western hemlock is considered the climax species, along with *Pseudotsuga menziesii* and *Thuja plicata* also contributing major components to species composition. *Alnus rubra* and *Acer macrophyllum* are the dominant deciduous trees, with *Populus balsamifera* ssp., *trichocarpa* and *Fraxinus latifolia* growing prominently along waterways. *Gaultheria shallon* is a dominant understory species in drier areas, while *Polystichum munitum* dominates the understory in wetter areas (Franklin and Dyrness 1988). Around 1900 the Puget Lowland area of western Washington was logged of its mainly coniferous overstory. Now deciduous species dominate (Collins and Montgomery 2002, Roberts and Bilby 2009).

Cover is often used to measure function at a site, because it is assumed that with the recovery of vegetation follows the reestablishment of habitat and ecological processes as succession is initiated (Halle and Marzio 2004, Ruiz-Jaen and Aide 2005). The cover data from this project indicate that these restoration sites are located generally in Puget Lowland areas that were severely disturbed by logging, where relatively short-lived, deciduous *Alnus rubra* and *Acer macrophyllum* dominate (Roberts and Bilby 2009). *Tsuga heterophylla, Pseudotsuga menziesii,* and *Thuja plicata* occur to a lesser degree, but do not comprise the majority of the canopy cover as found in non-disturbed or less-disturbed sites. While *Populus balsamifera* ssp. and *trichocarpa* can be found in relative abundance across the sites, *Fraxinus latifolia* abundance is lacking. Although *Gaultheria shallon* was historically a dominant understory species, it is found much lesser amounts today. *Polystichum munitum*, on the other hand, is relatively abundant.

Urbanization negatively affects forest regenerative properties, seriously altering the canopy structure (Roberts and Bilby 2009). As a means to promoting succession and sustainability, capstone students often endeavored to introduce conifer species that will eventually reach canopy height and provide dense, evergreen shade. The current outcome of this effort was measured by counting the number of regenerating trees found on the restoration sites. Trees that measured five inches or less in diameter at breast height were considered to be regenerating. *Thuja plicata* was the most common regenerating tree, found at 83 stems per acre across the sites. *Pseudotsuga menziesii* and *Tsuga heterophylla* were also commonly found to be regenerating, at 35 and 24 stems per acre respectively. It is especially important to promote regenerating evergreen conifers in riparian areas, as the present dominance by *Alnus rubra* is negatively impacting streams, and even Puget Sound. Changes from conifer to deciduous cover along urban streams, especially nitrogen-fixing *Alnus rubra*, increases nitrogen inputs and limits primary productivity, and may contribute to periods of low dissolved oxygen in Puget Sound according to a study by Roberts and Bilby (2009). Additionally, coniferous vegetative cover is important in shading the stream in order to maintain cooler water temperatures in the summer months, thus providing habitat amenable to various trophic levels (Roberts and Bilby 2009).

Reducing light availability from increased native coniferous canopy species can not only provide microhabitats for other native vegetation adapted to low light levels to establish, but it will shade out most invasive species that cannot tolerate low light levels (D'Antonio and Chambers 2006, Funk et al. 2008). Invasive species can change ecosystem function and halt succession by outcompeting native species either by competing for resources or altering nutrient cycling (Clewell and Aronson 2007, D'Antonio and Chambers 2006, Funk et al. 2008, Menninger and Palmer 2006, Prack et al. 2007, Walker and del Moral 2003). Clewell and Aronson (2007) point out that enhancements in native species composition among other things may result in a system that is sustainable and able to recover from environmental stressors and disturbance.

As with any restoration project, invasive species presented a challenge to the capstone students. *Rubus armeniacus*, *Phalaris arundinacea*, *Convolvulus arvensis*, *Ranunculus repens*, and *Hedera* spp. were the most commonly found non-native, invasive species at the capstone restoration sites. These invasive species, when not controlled, can form a monoculture or dominate communities to such a degree that native species abundance, and therefore ecosystem function, may decline. The initial removal of non-native species may show an immediate reduction in such species, but subsequent removal may be necessary, too (Prack et al. 2007). Successfully sustainable and resilient ecosystems with diverse native plant communities are largely resistant to invaders (D'Antonio and Chambers 2006).

Although enhancing species diversity is a goal in many restoration projects, sometimes the goal of restoring ecological function takes priority (del Moral et al. 2007, Palmer et al. 2007, Palmer 2009). Measurements of vegetation cover can reflect certain types of ecosystem function such as stormwater and pollutant amelioration, nutrient cycling, productivity, etc. (Clewell and Aronson 2007). In order to enhance desired ecosystem functions, restoration projects often install dominant native plant species to quickly return function to the system (del Moral et al. 2007). Most notable for facilitating improvements in ecosystem functioning in these capstone projects was the use of *Salix* species and *Physocarpus capitatus*, as they were expected to suppress non-native plant species. Kim et al. (2006) demonstrated that invasive species such as *Phalaris arundinacea* can be shaded out by densely planting willows in forested wetlands. Using species such as *Salix* spp. and *Physocarpus capitatus* is proving effective in reducing non-native plant cover on these restoration sites and should be examined further. Initially such sites may demonstrate low diversity (del Moral et al. 2007), such as at Mosher Creek and Thrasher's Corner, but the sites are functioning to inhibit the proliferation of invasive species, and creating a space where native later-successional species can thrive if introduced to the restoration area. Although some ecosystem functions may be improved with a single species, such as in the use of *Salix* spp. or *Physocarpus capitatus*, the site will not be as ecologically resilient nor will it exhibit the physical complexity of vegetation structure that provides for habitat diversity, than if several species contribute to a function (Naeem 2006).

As areas become filled and light penetration is altered at a site, it becomes evident that various vegetative layers play a role in the ratio of native to non-native cover for the thirty study sites. Trees, short shrubs, and herbs are negatively correlated with non-native plant cover. Tall shrubs are positively correlated with non-native plant cover. It has been demonstrated and observed that tall shrubs such as *Salix* spp. and *Physocarpus capitatum* are efficient at shading out non-native species when densely planted. This is what was observed at all of the sites that used this technique, where more tall shrubs were installed at sites that were particularly overgrown with invasive plants. Although they may be shading out such invasive plants at most of a site, some research plots included areas where the tall shrub shade did not reach.

Tree cover also plays a significant role in the suppression of non-native species, although restoration can be successful under a variety of canopy types, if the site is actively maintained. This study has shown that coniferous cover is significantly correlated with native species composition, while deciduous cover is not. Therefore, greater conifer cover, which lowers light penetration to a site and the seasonality of light availability (Anderson et al. 1969), can affect the success of restoration in terms of native species composition.

5.3 *Management and Technique*

Diversity measures can be used to indicate the ecological integrity of a system (Magurran 1988), and although in an unstable environment diversity can be low, instability does not necessitate low diversity (Whittaker 1972). Clewell and Aronson (2007) point out that enhancements in native species composition may result in a system that is sustainable, has ecosystem function, and is able to recover from environmental stressors and disturbance. The explanatory variables of ownership, stewardship, invasive plant control technique, use of cardboard, and use of wood chip mulch play a role in predicting diversity at the restoration sites. Alpha diversity, or the diversity of individual sample units, needs two measurements to fully capture the complexity of a plant community (Whittaker 1972). Measurements of species richness and evenness are commonly used, and the Shannon index is the most widely used evenness and richness measure of diversity (Ricotta and Anand 2006). The Shannon index (H') uses species percent composition (Peet 1975), p_{sp}, and is given by the magnitude of the sum of $p_{sp}*\ln(p_{sp})$ for each species (McCune and Grace 2002, Whittaker 1972). For a given number of species, N_{sp}, the maximum value of the Shannon index is $\ln(N_{sp})$, at maximum evenness. Differences in the result can reflect a change in dominance of any given species. Shannon indices reflect the importance of species with moderate cover, but rare species' affects are somewhat dampened, as it measures the proportionate diversity in the community. The absolute value of the Shannon index by itself reveals little about a community, and it is almost always used to compare the diversity among sites and/or conditions (MacArthur and MacArthur 1961, McCune and Grace 2002, Whittaker 1972).

Sites can have similar richness, but greater evenness in the representation of the species present would result in greater diversity, as it is commonly defined in the ecological literature (Magurran 1988). In this study, ownership, stewardship, control, and use of cardboard were associated with native richness, while ownership, stewardship, control, and use of wood chip mulch were significantly associated with changes in the Shannon Index. The application of wood chip mulch was associated with higher diversity but not with greater species richness. Thus, it appears that the enhancement of diversity through wood chip mulch application resulted from greater evenness, not from an increase in the number of native species (which was largely controlled by the project design). A study by Miller and Seastedt (2009) in a thinned ponderosa pine forest showed that wood chip mulch decreased understory native species diversity for naturally regenerating plant species. But in areas such as the capstone sites, where much of the desirable native vegetation is installed, the insignificant richness contribution of mulch is counter intuitive at first glance. However, upon closer inspection, it is evident that mulch is contributing to greater evenness, which means that mulch is contributing to greater overall plant survival without regard to species (i.e. richness). On the other hand, cardboard is significant to richness at the capstone sites. This interesting result could be attributed to the use of cardboard contributing to richness as a result of the density of planting that occurs on sites where cardboard was used compared to sites where cardboard was not used. Perhaps at sites with cardboard, plants are inherently more densely installed. This can be determined in future studies by examining and comparing the planting plans from the As-Built documents.

Significant differences in native cover composition were examined in relation to the explanatory variables of ownership, degree of stewardship, initial invasive plant control technique, use of cardboard, use of mulch, and age of restoration. Ownership, stewardship, and initial control technique were significant factors in affecting native species composition. According to these results, the use of wood chip mulch and cardboard did not significantly influence the proportion of plant cover associated with native species. Privately owned sites have greater native species composition than county and state owned sites, and city sites are more likely to have greater native species composition than state owned sites. High levels of stewardship result in greater native species composition than low stewardship, and mowing does not work as well as grubbing for initial invasive plant control technique in the outcome of native species composition.

MRT was also used to examine significant factors. The multiple regression tree resulted in four leaves, with ownership as the first partition, accounting for 29% of the variance. The second partition was high versus low stewardship, accounting for 25% of the variance, and the third partition showed the use of mulch. Finally, the fourth partition showed that under high stewardship and the use of mulch (10% of the variance), privately owned and city owned sites are separated (3% of the variance). Ownership and stewardship account for most of the variance in this particular analysis. Where stewardship is high, mulch is important in determining native species composition, but control technique and the use of cardboard were not significant enough to be included in any of the leaves. A study executed by Cahill et al. (2005) indicates that mulching an entire restoration site is more effective than simply placing a ring of wood chip mulch around plantings. MRT and ANOVA results show that the role of mulch in the success of these restoration projects is unclear. However, whether students mulched or not- and the measurement of such mulch applications- could only be determined from the student documentation of each restoration project. Although students may have had the intention of mulching at least six inches, or more than six inches, the actual depth was not quantified. Therefore, mulch was examined again using ANOVA, separating sites that used wood chip mulch and those that did not use wood chip mulch. The results were interesting in that using wood chip mulch was not significant in native composition, richness, or diversity. However, there are good theoretical bases to support the use of wood chip mulch in restoration plantings (Cahill et al. 2005). Mulch helps retain soil moisture, controls weeds, keeps soil temperatures cooler in summer and warmer in winter, and provides organic matter to the plants and soil, especially for sites that may not receive regular maintenance or stewardship (Cahill et al. 2005). While MRT is usually complementary to ANOVA (De'ath and Fabricius 2000), these analysis techniques do have differences. Variables at the top of the tree better explain variation and are more important than variables at the bottom of the tree (McCune and Grace 2002). In the end, while stewardship is of the utmost importance in successful restoration, initial control technique and the use of mulch should also be considered important in determining the resulting native species composition. The use of cardboard should be considered carefully, weighing the benefits of deploying the resources to acquire the cardboard against the only slight benefit it seems to offer the outcome of native species composition.

Although the results of this study are specific to the UW-REN capstone program, some lessons learned for stewardship and technique may be applied to small scale restoration projects elsewhere. As described above, this study has established that stewardship is one of the most important factors in determining the successful outcome of restoration. Without periodic maintenance and the manipulation of species composition, restoration rarely succeeds, especially in systems that require ameliorating human impacts such as in urban areas (Clewell and Aronson 2007, Hobbs 2007, Walker and del Moral 2003). Capstone students have already proven that they are capable of performing maintenance on a previous year's site while implementing a new restoration in the vicinity. Although there is a lot of continuity in the UW-REN sites and some sites build on each other, making cohesion a priority will enhance the success and quality of restoration.   If this were the usual protocol of the capstone program, then there would be greater chance of successful restoration. However, resources may not be available to implement this suggestion. Restoration, especially in urban environments, can take a long time and demands a sound commitment of years (Sullivan et al. 2009, Walker et al. 2007). It is not always easy to enlist volunteers to steward the maintenance and monitoring of restoration projects, but, as previously stated, engaging citizens in restoration instills a sense of ownership, place and community, and produces results that improve local ecosystem functioning (Clewell and Aronson 2007, Vivek and Messer 2008). Establishing stewardship was one of the most challenging tasks facing the UW-REN capstone students. Sites were maintained and thrived, and therefore resulted in greater native species composition, where stewardship programs were already in place before implementation of capstone restoration projects. Regular maintenance was severely lacking on sites implemented without pre-existing stewards. In these situations, although usually unsuccessful, through effective communication (Gold et al. 2006) and persistence the capstone students made every effort to gain public interest in their projects, and to promote the importance of stewardship. Eight months in the UW-REN capstone program may not be long enough to establish these public bonds. It can take years to convey an ecological message in such a way that people take an active interest. In the case of UBNA

(2006), which had the most non-native cover of all the sites, although every effort was made, it took years before a successful stewardship program was created. It would be informative to perform monitoring on this site again in the future, in order to quantify the ecological improvements already evident from the newly-established stewardship of this site by concerned citizens.

5.4 *Monitoring and Recommendations*

Monitoring of restoration projects is critical as it can provide information as to whether action must be taken in order to keep the site on a successional and sustainable trajectory (Walker and del Moral 2003). Monitoring ecological restoration puts it in a scientific setting that provides an opportunity to test ecological and restoration theories, and to consider the community context, contributing to adaptive management and maintenance protocols (Hobbs et al. 2007, Palmer et al. 2006, Palmer 2007, Prack et al. 2007). Most restoration projects are not monitored (Palmer et al. 2006), and thus, the importance of this study becomes clear. It is possible to track actual trajectories of change if evaluations determine species composition, invasive vegetation potential, presence of functional groups, ecological processes occurring at a restoration area, diversity, and the role of the site in the landscape (Clewell and Aronson 2007, Suding and Gross 2006). There are many measurements that may be included in any monitoring program, but often such assessments do not include data describing the site before restoration was implemented. In future UW-REN restoration projects, it is recommended that a thorough evaluation of the site occur before the implementation of the restoration project so that site attributes and important changes may be detected in future years. A discussion of specific pragmatic elements that should be considered in future capstone projects to facilitate long-term monitoring is presented in Appendix A.

Ideal monitoring should include the evaluation of trophic levels other than vegetation (Voigt and Perner 2004), especially invertebrates and soil microbial communities, since they are essential to sustainable ecosystems and good indicators of ecosystem function (Halle and Marzio 2004, Menninger and Palmer 2006). However, such endeavors are time-consuming and costly, so inferences must usually be made from simpler site factors such as plant cover. Chronological photographs of restoration projects are especially useful in communicating restoration techniques and adding further to adaptive management of sites (Clewell and Aronson 2007). Another important consideration in monitoring is that a site can be on a successful trajectory even if it does not meet immediate goals (Walker and del Moral 2003). Some indicators of ecosystem processes take a long time to recover, and may not be determined in the first few years of monitoring (Ruiz-Jaen and Aide 2005). Instead, success may be indicated by achieving multiple goals over time, including the establishment of native species richness, ecological function, and the involvement of the community. The evaluation in this study was conducted for a single growing season on restoration sites of various ages. More substantial results could be gained by monitoring over a longer period of time. If possible, maintenance, community involvement, evaluation, and monitoring of the UW-REN capstone projects should continue if the sites are to reach a state of being self-sustaining ecosystems.

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APPENDIX A: Applications and Lessons Learned

This study was conducted on specific restoration sites that were implemented in an educational context with a community partner in the UW-REN capstone program. Although the results are specific for these study sites, some results may be applied to small-scale restoration projects that are conducted in a similar fashion, with similar goals, objectives, and challenges. However, in this appendix I reflect upon some lessons that I learned from the field work and data analysis that could be applied to improve the outcomes and future long-term monitoring of UW-REN capstone projects in particular.

Through the implementation of their restoration project, the capstone student teams are required to produce maps, documentation, and a monitoring plan that are meant to facilitate monitoring to assess success and to guide adaptive management of the site. However, there are improvements in the details of what is required that could facilitate the usefulness of these assignments (Table 8). It should be noted that some of these suggestions are already being incorporated in recent revisions of capstone assignments (W. Gold, personal communication).

Table 8: Recommendations for future monitoring and evaluation of capstone projects.

Initial monitoring	Before project implementation, record the baseline cover values of vegetation at the site
Implementation monitoring	Upon implementation of the project, again record the cover values of vegetation at the site
Maps	Use GPS coordinates to outline polygons, landmarks to delineate a site, note interesting and permanent site features, and map to scale
Map text	Use text to supplement the map with site description
Plant lists and plans	Report density of plant installation
Photo points	Establish permanent photo points
Stewardship	Implement projects considering potential stewardship
Goals	Monitor for goals achieved

Improved frequency and uniformity of vegetation monitoring should be implemented in future capstone projects. Vegetation cover should be assessed at the project's outset (before invasive species are removed) and immediately following completion of the project. Common permanent plots and/or transects should be used before and after project implementation so data is directly comparable. In addition, permanent photo points should be established and photographs taken both before and after the project. Each of these monitoring features should be clearly marked in a permanent fashion so they can be found even when dense vegetation develops over a number of years. I would suggest utilizing labeled rebar and GPS coordinates. In addition, GPS coordinates may be used to outline the various polygons at a site, so that they, too, may be found in future years. Good maps are extremely important. As many details as possible should be included in any map derived from the restoration project. Noting landmarks, interesting and permanent site features, a brief yet detailed description of the site, and an accurate map scale will aid future monitoring. A record of planting densities, in addition to a detailed planting map would aid in comparisons of the site through time. These monitoring protocols should be implemented considering the potential support of stewards, and the time and effort that they will be able to invest in a monitoring protocol. Finally, a good monitoring protocol will evaluate the goals achieved at the site over time.

APPENDIX B: Site Summaries

Table 9: Site summaries with stewardship level (high or low), percent composition, and diversity values.

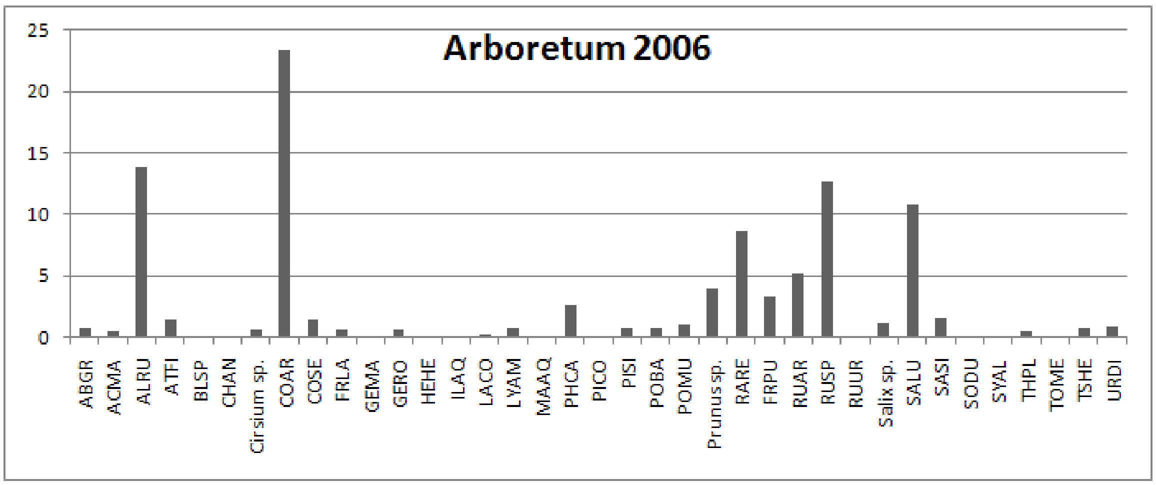
Site	Steward-ship	% Native Composition	% Non-native Composition	Native Rich-ness	Shannon Diversity Index
Arboretum 2006	Low	61	39	30	2.44
Arboretum 2007	Low	50	50	16	1.90
Earth Sanctuary 2004	High	82	18	31	2.32
Earth Sanctuary 2005	High	99.5	0.5	27	1.98
Earth Sanctuary 2006	High	97	3	30	1.97
Earth Sanctuary 2008	High	99	1	15	1.86
Evergreen 2001	High	95	5	20	1.77
Fern Hollow 2001	High	100	0	25	2.19
Frink Park 2002	High	98	2	40	2.10
Grass Lawn Park 2003	High	44	56	13	2.19
Lawton Park 2002	High	97	3	29	2.23
Licton Springs 2002	High	79	21	21	2.52
Licton Springs 2004	High	96	4	22	1.91
Licton Springs 2005	High	77	23	21	2.26
Mosher Creek 2008	Low	28	72	10	1.79
Rotary Park/ Little Bear Creek 2004	Low	64	36	13	2.18
Swamp Creek 2005	Low	92	8	19	1.70
Swamp Creek 2006	Low	54	46	22	2.08
Swamp Creek 2007	Low	56	44	24	2.45
Thrasher's Corner 2002	Low	85	15	14	1.78
UBNA 2006	Low	6	94	7	1.14
UBNA 2001, 2003	Low	79	21	10	1.10
UBNA 2002, 2004	Low	77	23	12	1.68
UBNA 2004, 2005	Low	33	67	9	1.91
W. Duwamish Greenbelt 2004	High	86	14	16	1.92
W. Duwamish Greenbelt 2005	High	98	2	14	1.63
W. Duwamish Greenbelt 2006	High	89	11	26	2.30

White Center 2008	Low	65	35	20	1.87
Yesler Creek 2007	High	84	16	30	2.17
Yesler Creek 2008	High	94	6	22	1.88

Arboretum 2006

Project goals: To assess and maintain previous plantings in an adjacent graduate student plot, demonstrate diversity of flora found in lowland riparian areas of the Pacific Northwest, enhance stream water quality, stabilize stream bank.

Species composition (%):

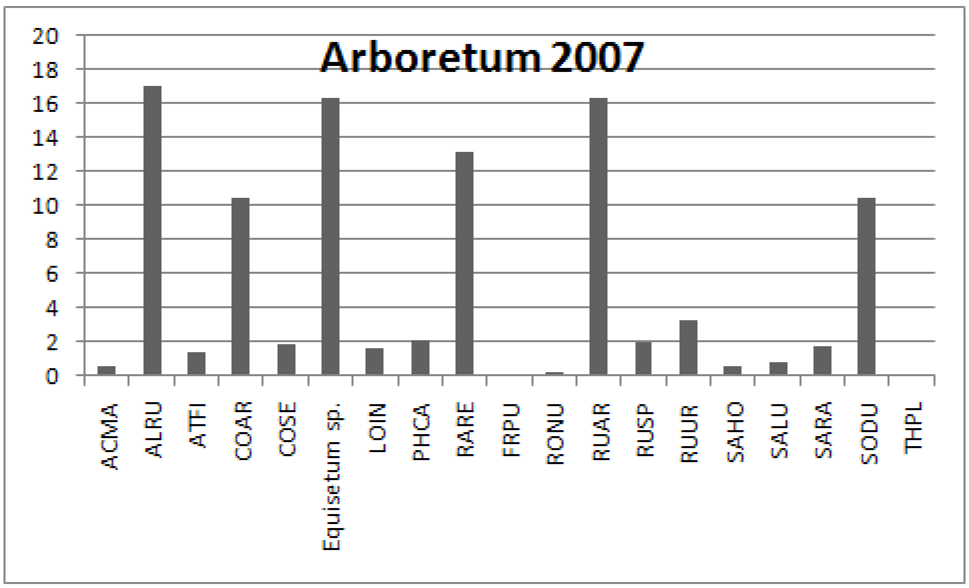


Notes and conclusions: There are several invasive species near the site that pose a potential threat to the native species integrity of Arboretum 2006. *Convolvulus arvensis*, *Geranium robertianum*, and *Rubus armeniacus* reside nearby. *Ranunculus repens* dominates an open area on this site. Although this evaluation does not monitor the stream water quality, it was noted that the stream bank appears to be stabilized with the native plantings in place. Regenerating conifer species include *Thuja plicata*, *Tsuga heterophylla*, *Picea sitchensis*, and *Abies grandis*.

Arboretum 2007

Project goals: To promote the re-establishment of a Pacific Northwest lowland riparian community, demonstrate diversity of flora found in lowland riparian areas of the Pacific Northwest, establish and maintain view corridors as delineated by the University of Washington Botanical Gardens (UWBG), and maintain past and current restoration sties.

Species composition (%):

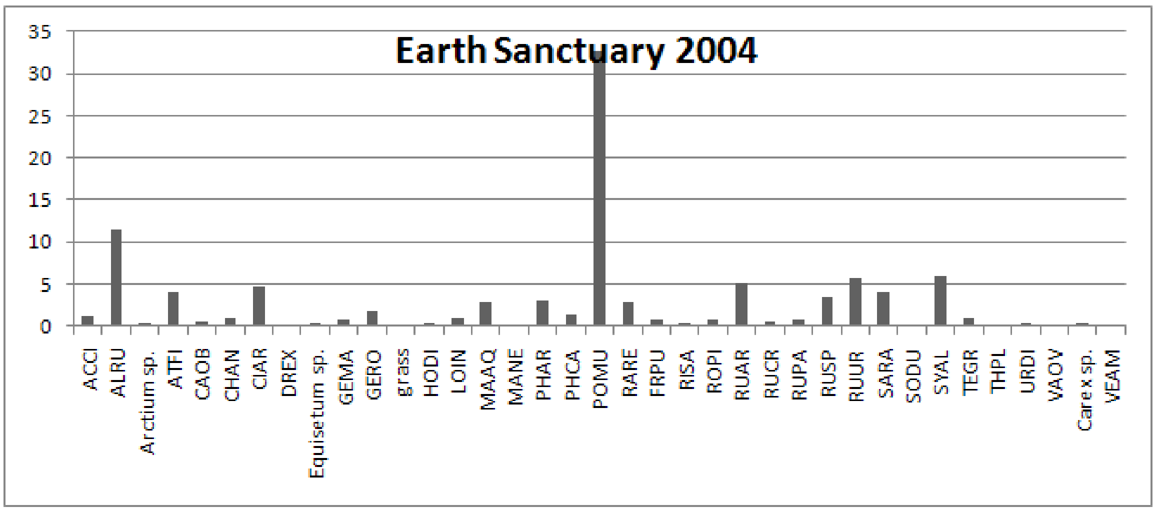


Notes and conclusions: Although this site presented as overgrown with invasive plants (mainly *Convolvulus arvensis*), there were no invasive plants noted growing in the shade of the densely planted *Physocarpus capitatum*. Nearby invasive plant species that are a potential threat to the site include *Convolvulus arvensis*, *Solanum dulcamara*, and *Rubus armeniacus*. An effort to maintain view corridors is evident as a path was left established to the water's edge. There were no regenerating conifer species located at this site.

Earth Sanctuary 2004

Project goals: To provide habitat for birds and wildlife by providing diverse native plant species and spatial structure. Create a visual, auditory and ecological barrier that controls input of water, propagules, garbage, and other materials from the road to the fen while providing selected views to the fen. Improve aesthetics of roadside. Provide educational material to client.

Species composition (%):

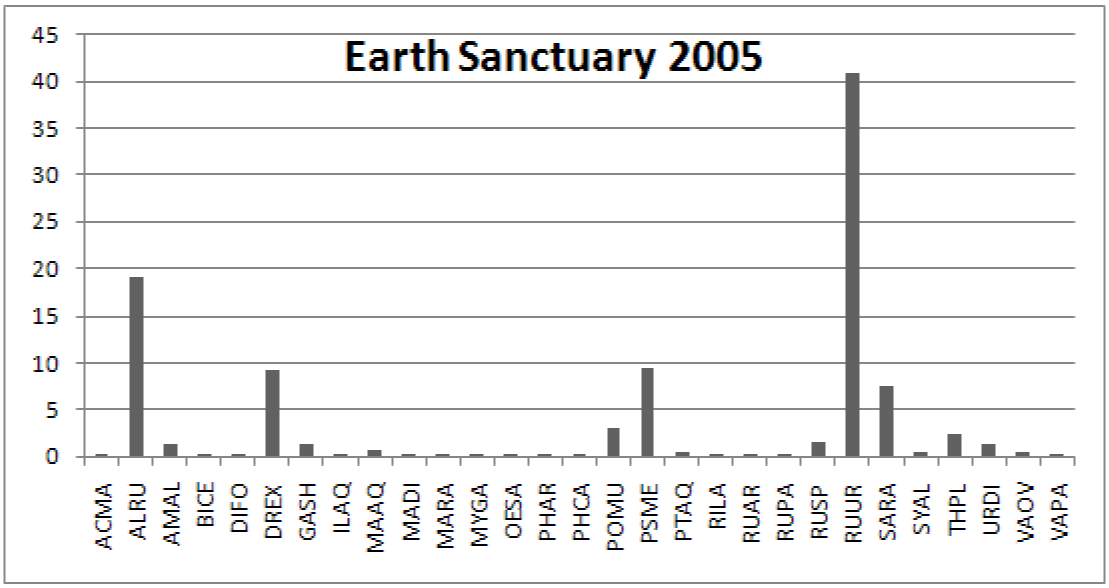


Notes and conclusions: This site is very well maintained and has few invasive species on the site or nearby. However, some *Phalaris arundinacea*, *Rubus armeniacus*, *Geranium robertianum*, and a trace of *Solanum dulcamara* were located. Although this site does provide structure for wildlife and a barrier from the road to the fen, few regenerating conifers were recorded. Fortunately, the site is surrounded by mature *Pseudotsuga menziesii*.

Earth Sanctuary 2005

Project goals: To create continuity between the 2004 and 2005 restoration projects. Increase habitat for birds and wildlife by providing diverse native plant species and spatial structure. Promote succession. Create a barrier along the road to limit input to the fen of water, invasive propagules, garbage, and other materials while providing selected views into Earth Sanctuary. Improve aesthetics of the roadside.

Species composition (%):



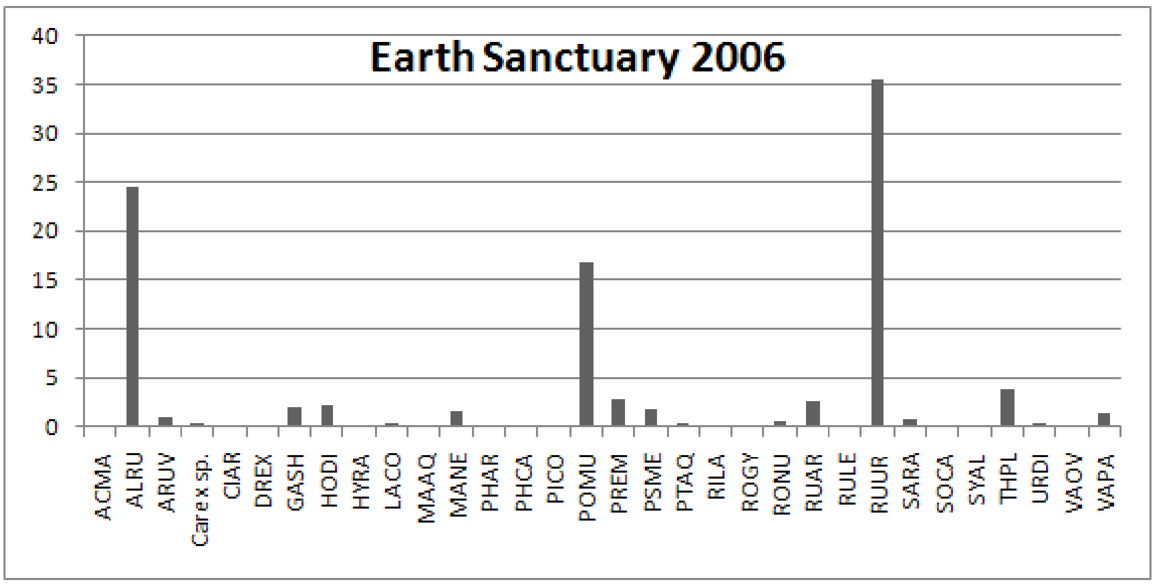
Notes and conclusions: This project indeed adds to the restoration conducted in 2004 by directly extending from that site. Again, this is a very well maintained site and few invasive species were found, except for a patch of *Rubus armeniacus* and a trace of *Phalaris arundinacea*. Nearby potential invaders include *Ilex aquifolium* and more *Phalaris arundinacea*. This site is useful to wildlife as there was evidence of beaver activity and a woodpecker visited during the monitoring. The promotion of succession is underway with regenerating conifer species such as *Thuja plicata*, *Pseudotsuga menziesii*, and *Pinus contorta*.

Figure 12: The Earth Sanctuary project before implementation (above) and in summer 2010 (below). Note the sparsity of plants in 2005, and the now present regenerating conifers and dense native composition.

Earth Sanctuary 2006

Project goals: Create a connection between 2004, 2005, and 2006 restoration projects. Augment habitat for birds and wildlife by installing native plant species in a random spatial structure. Promote native canopy succession. Limit the amount of erosion on the roadside embankment and reduce the amount of pollutants that reach the fen. Develop roadside aesthetics to enhance long term community involvement in Earth Sanctuary and restoration.

Species composition (%):

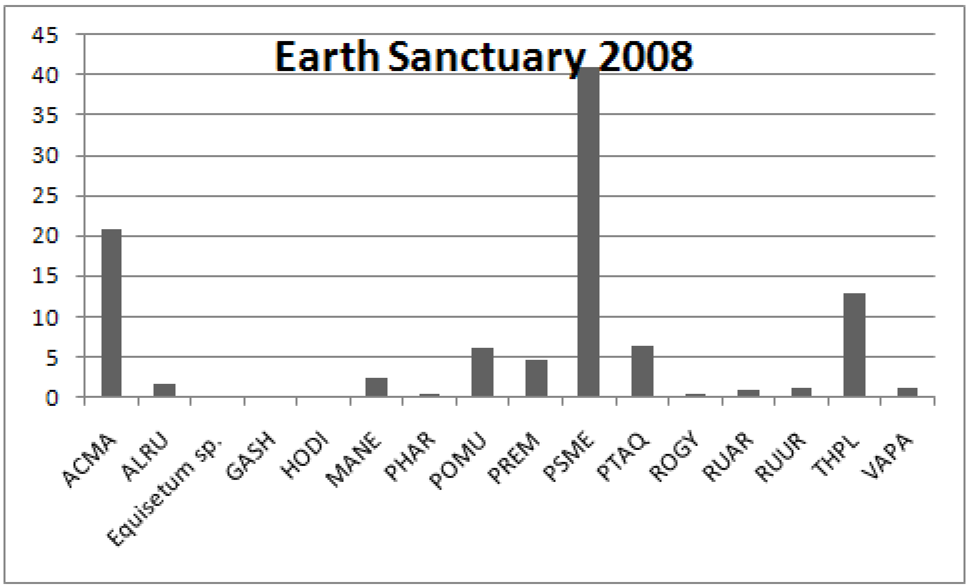


Notes and conclusions: This restoration project extends from the 2004 and 2005 sites. Again, it is very well maintained and few invasive species were found, but there was some *Rubus armeniacus* and *Phalaris arundinacea*. *Rubus armeniacus* is also found nearby. Soil stability was noted as stable, therefore the efforts to stabilize the slope next to the road are working. This site has ample canopy cover as it contains several mature and maturing *Pseudotsuga menziesii* and *Thuja plicata*. Succession is being promoted by the many thriving *Thuja plicata* that were planted by the capstone group.

<u>Earth Sanctuary 2008</u>

Project goals: Assist in the transformation of the site to a native plant dominated, functional buffer between the fen and the road. Present the site as both a model for successful roadside restoration in the Pacific Northwest and as a feature that will promote interest in the Earth Sanctuary.

Species composition (%):

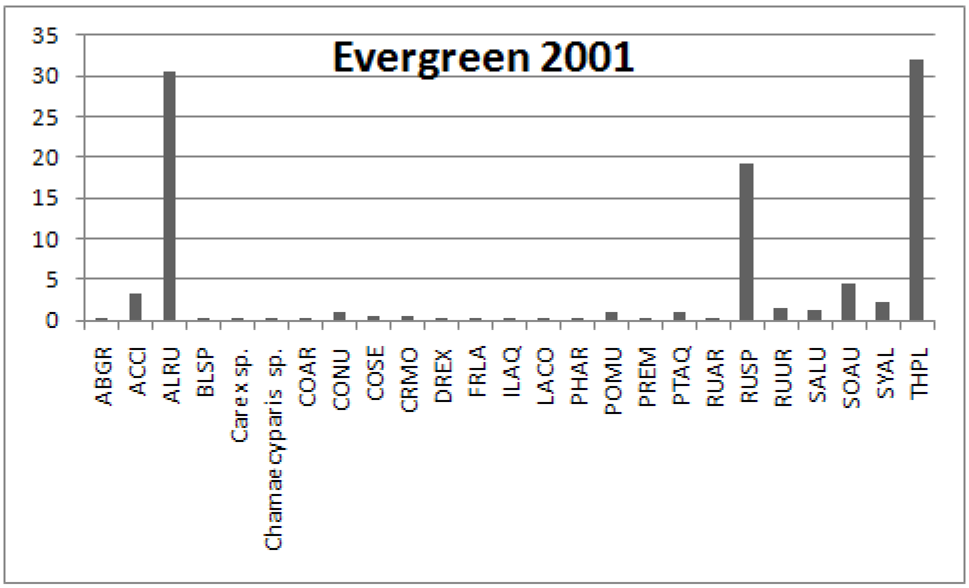


Notes and conclusions: This is a very well maintained site, but does contain some *Rubus armeniacus* and *Phalaris arundinacea*. There is an excellent sign describing the Earth Sanctuary and its restoration efforts. There is a strong presence of mature and maturing *Pseudotsuga menziesii* and *Thuja plicata*, and there are a few regenerating *Thuja plicata* as well.

Evergreen 2001

Project goals: To restore a forested wetland and the filtration function of the detention pond. To restore the function of the biofiltration swale and to protect it from future erosion and compaction. To improve the function of the drainage stream and to stabilize the banks from further erosion. To create a "Trail of Discovery" for the Evergreen School community that showcases the installed native Northwest plant communities as well as educates the community on the function and importance of the multifaceted biofiltration systems located on the site.

Species composition (%):



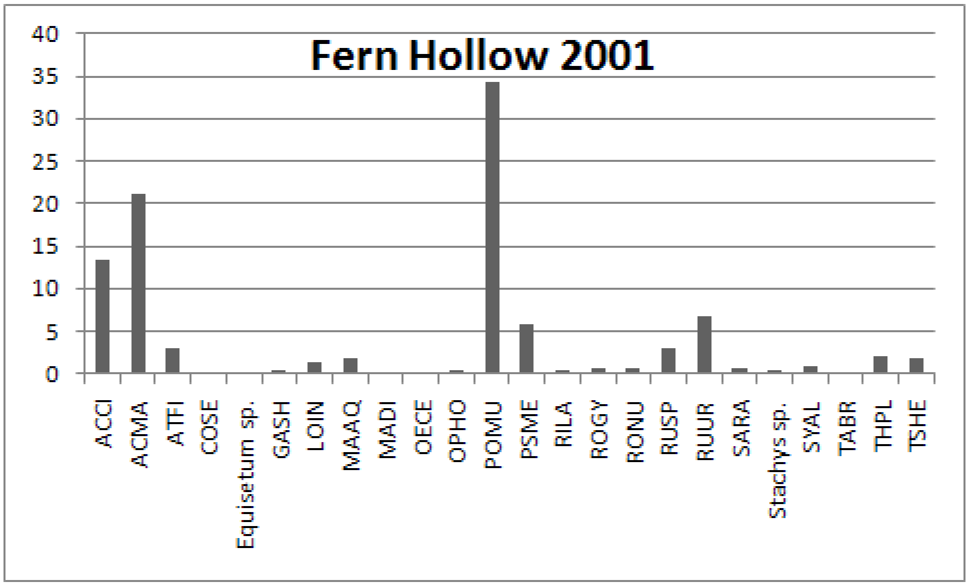
Notes and conclusions: This site is unique in that it is a forested wetland restored with the intention of bringing function back to a bioswale on the site. Although determining the functionality of the detention pond was outside the scope of this study, it was noted that the depressional area was bare and wet, indicating that the invasive species that once dominated were diminished, and that the bioswale was performing some function. However, in other parts of the restoration site there are some invasive species of concern such as *Solanum dulcamara, Crataegus monogyna*, *Ilex aquifolium,* and a trace of *Phalaris arundinacea*. There is a mature *Thuja plicata* encompassing much of the site, and regenerating conifers in the area include

Pseudotsuga menziesii and *Tsuga heterophylla*. There is a trail through the restoration site, and its use was witnessed during the monitoring.

Fern Hollow 2001

Project goals: To control erosion and stabilize the stream bank. Restore the riparian ecosystem vegetation and enhance animal habitat.

Species composition (%):

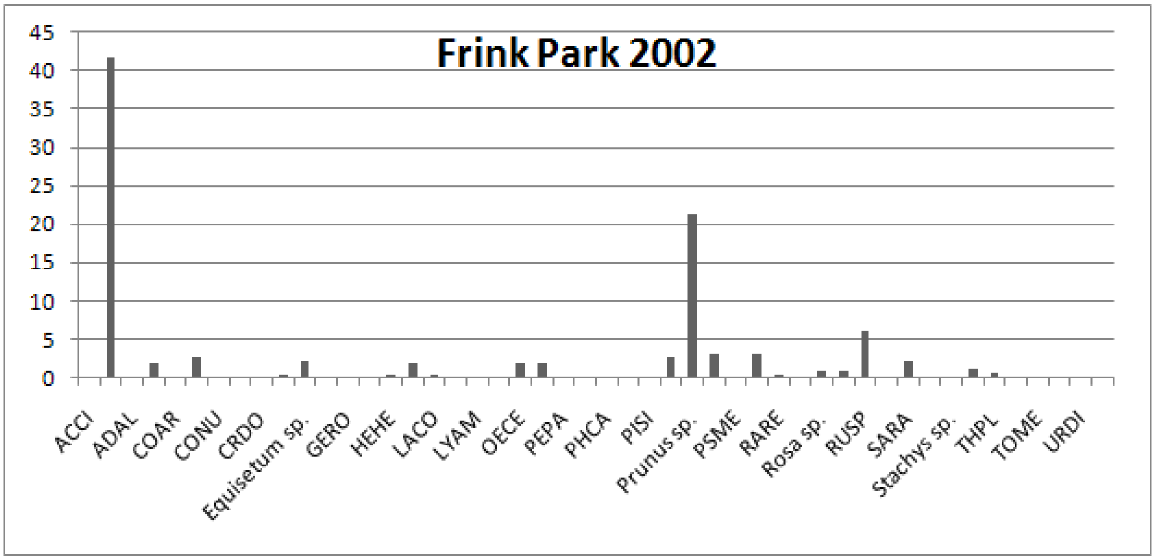


Notes and conclusions: This is a very well maintained site, and no invasive species were recorded. The stream bank and slope appear to be stabilized by the native vegetation installed by the capstone group. There are several mature *Pseudotsuga menziesii* on the site. There were many regenerating conifers, including *Tsuga heterophylla*, *Thuja plicata*, and *Pseudotsuga menziesii*.

<u>Frink Park 2002</u>

Project goals: To stabilize the slope with woody debris, just netting, native plantings, and a drainage pipe outlet (Jacob's ladder).

Species composition (%):



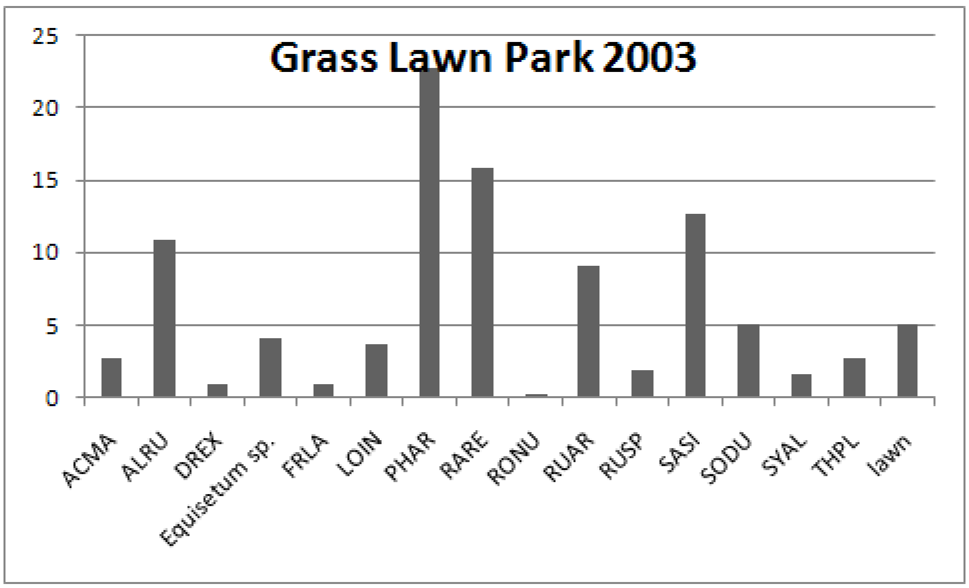
Notes and conclusions: A challenge to the implementation of this site was that the client changed from TREEmendous Seattle to the Friends of Frink Park during the program, but many goals were achieved including slope stabilization with woody debris and jute netting, native plantings, and the construction of a drainage bioswale pipe outlet (nicknamed Jacob's ladder). This is a very well maintained site by the Friends of Frink Park group, and has few invasive plants including *Rubus armeniacus*, and traces of *Phalaris arundinacea* and *Solanum dulcamara*. Although the canopy consists mainly of *Acer macrophyllum*, there are plenty of regenerating *Thuja plicata*.

Figure 2: Frink Park 2002 project at the completion of implementation (above) and the project site in the summer of 2010 (below). This site resulted in a very diverse community of native vegetation.

Grass Lawn Park 2003

Project goals: To restore a native plant buffer that ties in with adjacent native plant communities, accommodates the seasonal standing water, and increases habitat diversity. Manage standing water to support proposed vegetation and prevent off-site flooding. Provide educational opportunities for park visitors about restoration and invasive species control methods.

Species composition (%):



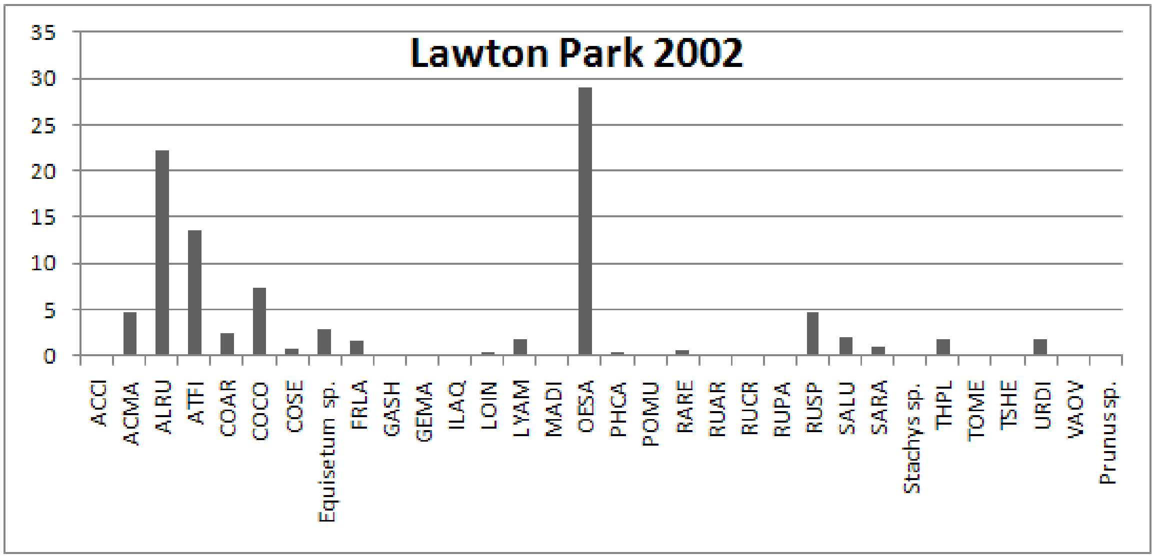
Notes and conclusions: Although this site is maintained, there are several invasive species found on and near the site including *Phalaris arundinacea*, *Rubus armeniacus*, *Ranunculus repens*, *Ilex aquifolium*, *Hedera* sp., and *Solanum dulcamara*. The Salix sp. that were installed are thriving, but little else in the plantings survived. This assessment cannot determine the accommodation of standing water on the site. There is no signage indicating the act of restoration, but the students documented having discussed their restoration project with users of the park.

Figure 14: The Grass Lawn Park 2003 project before implementation (above), and in the summer of 2010 (below). This site was planted with many understory species, but is lacking in tree regeneration.

Lawton Park 2002

Project goals: To return the forested wetland, which is currently full of invasive plants and mature deciduous trees, to native Pacific Northwest character. To provide a document for the current project and recommendations for future restoration efforts.

Species composition (%):

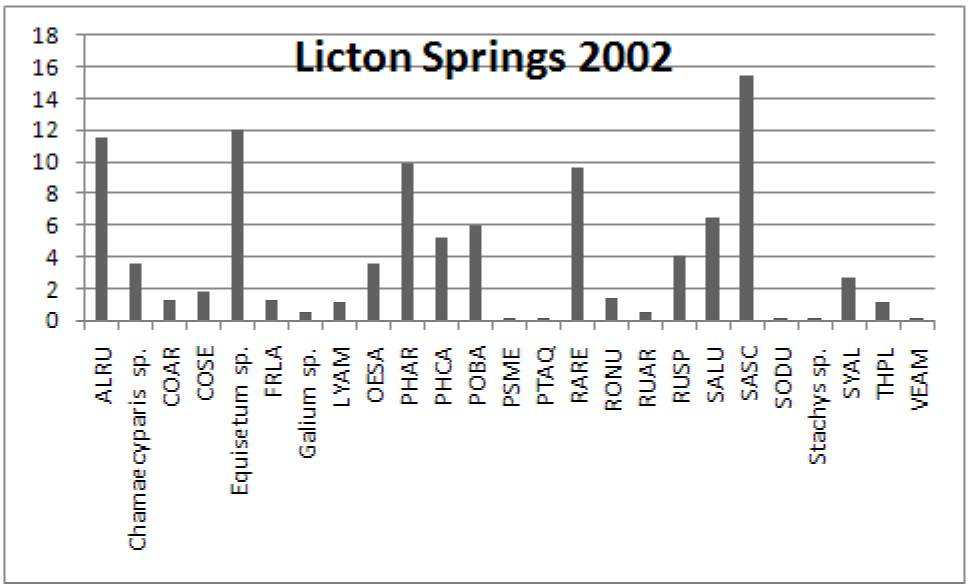


Notes and conclusions: This is a well-maintained site with few invasive plant species including *Convolvulus arvensis* , *Ranunculus repens*, and a trace of *Prunus laurocerasus* and *Rubus armeniacus*. *Thuja plicata* is the only regenerating conifer species.

__**Licton Springs 2002**__

Project goals: To enhance the site by visually defining the mineral spring, and improving interpretive signage. To define the physical outline/boundary using rocks or other landscaping techniques. To provide educational signage (natural history, natural science, human/cultural history and significance). To restore native plant landscape, remove invasive plants, and suppress future growth (cut, cardboard, mulch technique). To implement a planting plan, emphasizing plants that tolerate flooding, and will shade out reed canary grass.

Species composition (%):

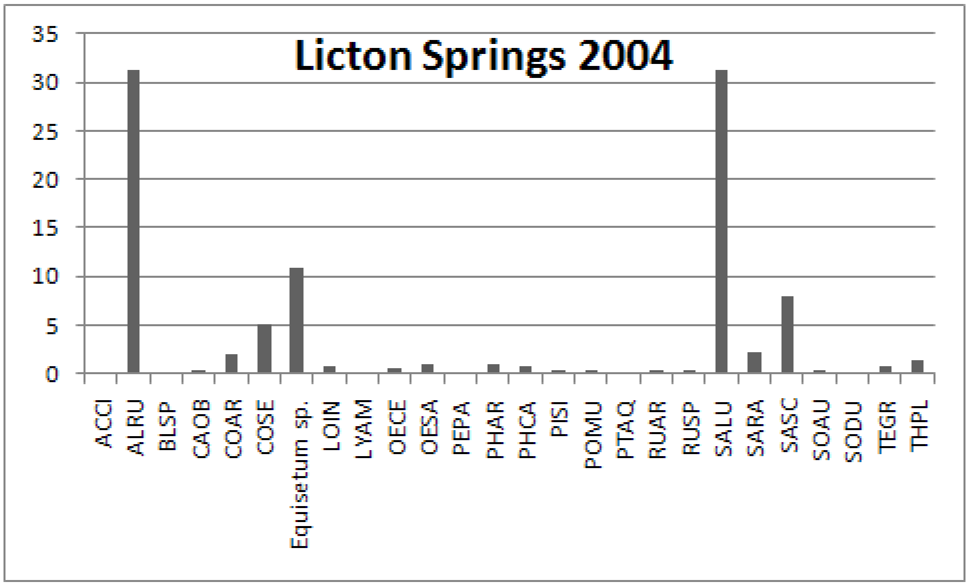


Notes and conclusions: This is a well maintained site, but does contain *Phalaris arundinacea*, *Rubus armeniacus*, *Solanum dulcamara*, and *Ranunculus repens*. The mineral spring has been well defined and there is an educational sign at the site. The presence of some invasive species indicates that they were not all shaded out or suppressed with other methods. There are few regenerating conifers (*Thuja plicata* and *Pseudotsuga menziesii*).

Licton Springs 2004

Project goals: To restore a forested wetland community by ecologically linking previously restored sites. To educate the public about ongoing ecological restoration on the site. Prevent erosion that could result from invasive vegetation removal.

Species composition (%):

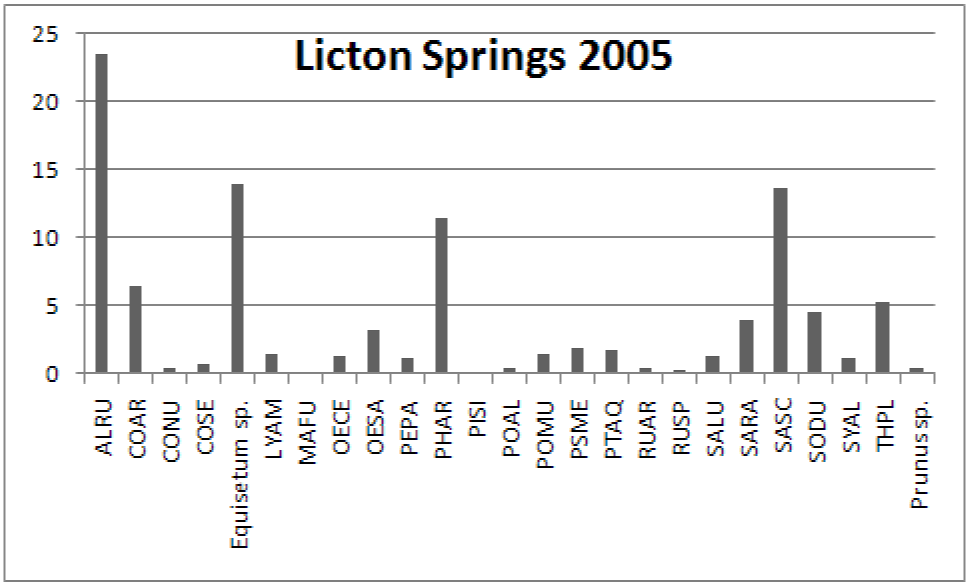


Notes and conclusions: This is a well-maintained site and has few invasive species including *Solanum dulcamara*, *Phalaris arundinacea*, *Rubus armeniacus*, and *Convolvulus arvensis* . The soil was noted as dry and stable, with no erosion. The students had several opportunities to educate the public as the clients, Friends of Licton Springs held monthly work parties. There were no regenerating trees found on this site.

Licton Springs 2005

Project goals: To restore a forested wetland community, the establishment of an "upland forest" for the newly excavated "habitat ponds", and to connect two previously restored sites. Re-introduction of Pacific chorus frog habitat.

Species composition (%):

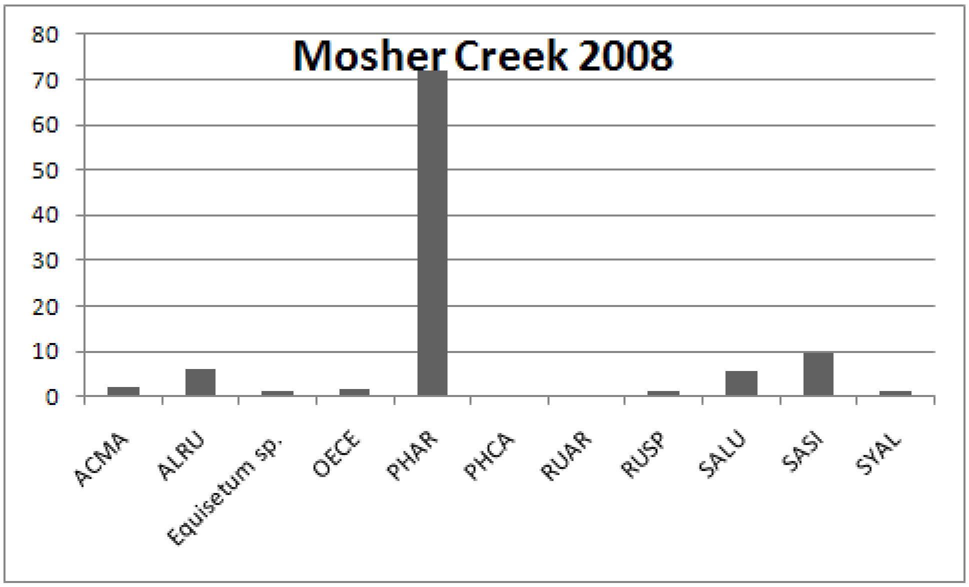


Notes and conclusions: Although the reintroduction of the Pacific chorus frog was not implemented during the capstone, this site has other successes. This is a well maintained site. The few invasive species include *Prunus laurocerasus*, *Rubus armeniacus*, and *Solanum dulcamara*. The upland forest is well underway with many regenerating *Thuja plicata*.

<u>Mosher Creek 2008</u>

Project goals: To suppress the dominancy of invasive *Phalaris arundinacea*. To enhance salmonid habitat in Mosher Creek. To re-establish a native vegetative community that is typical of riparian corridors in the Puget Sound lowlands. To foster ecological citizenship in the community to ensure ongoing success of current and future restoration projects. To increase the understanding of effective shading techniques to suppress *P. arundinacea* for future projects along Mosher Creek and other riparian corridors in the Puget Sound lowlands.

Species composition (%):

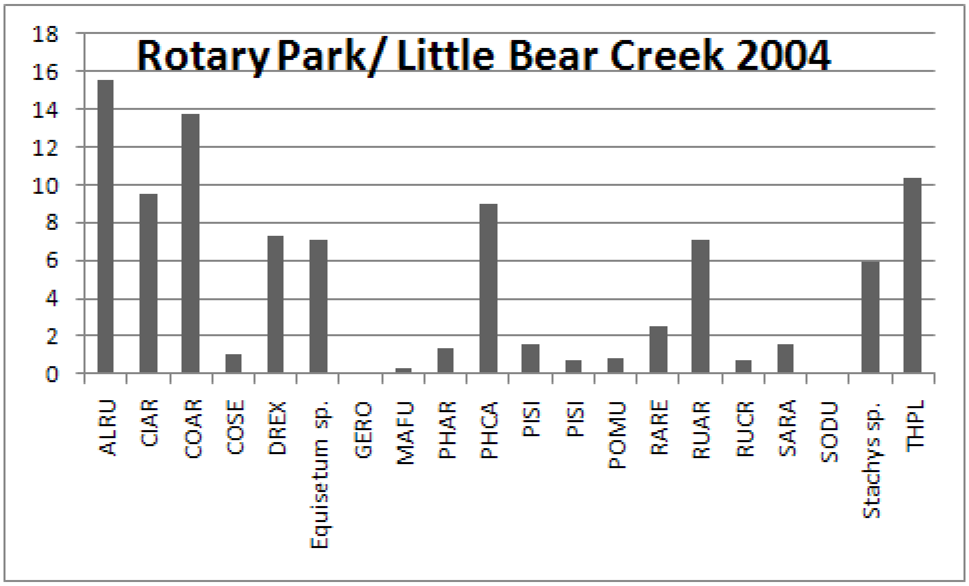


Notes and conclusions: This site was densely planted with willows, and where present they seem to be suppressing the growth of *Phalaris arundinacea*, although it is still quite dominant on the site.

<u>Rotary Park 2004</u>

Project goals: To complete initial invasive species inventory of Rotary Club Park. To protect existing native plant species. To salvage existing native species. To create sustainable native plant communities that will enhance habitat for wildlife. Provide education and public awareness.

Species composition (%):

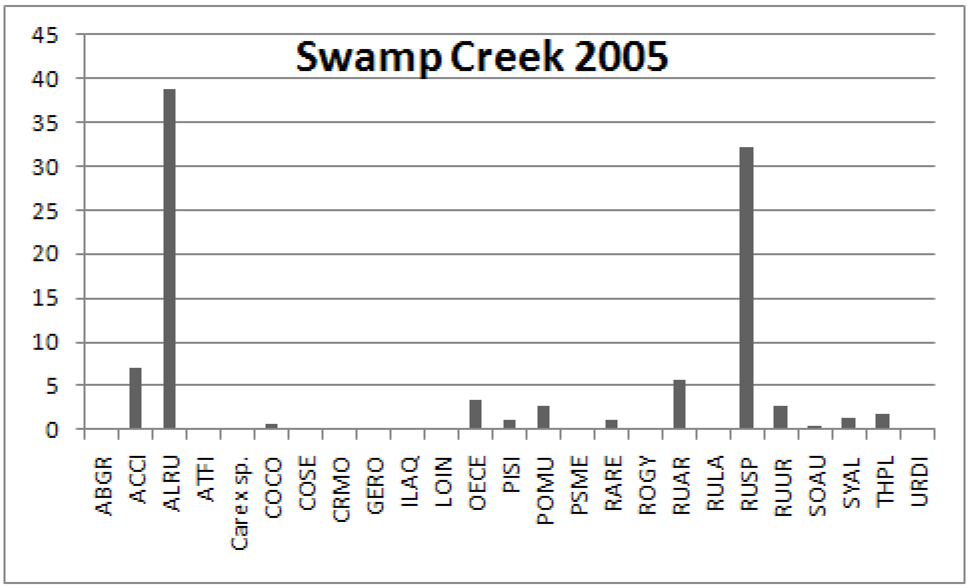


Notes and conclusions: Native species are thriving at this site, but invasive plants include *Convolvulus arvensis*, *Geranium robertianum*, and *Ranunculus repens*. *Thuja plicata* and *Picea sitchensis* represent the few regenerating trees.

Swamp Creek 2005

Project goals: To establish new and enhance existing native plant communities, reduce the likelihood that invasive, non-native plant communities will reestablish, enhance water quality, and increase species and structural diversity. To reduce the erosive power of the onsite stream and encourage flooding in lower elevation zone of the site, meanwhile planting species that will be conducive for future beaver activity.

Species composition (%):

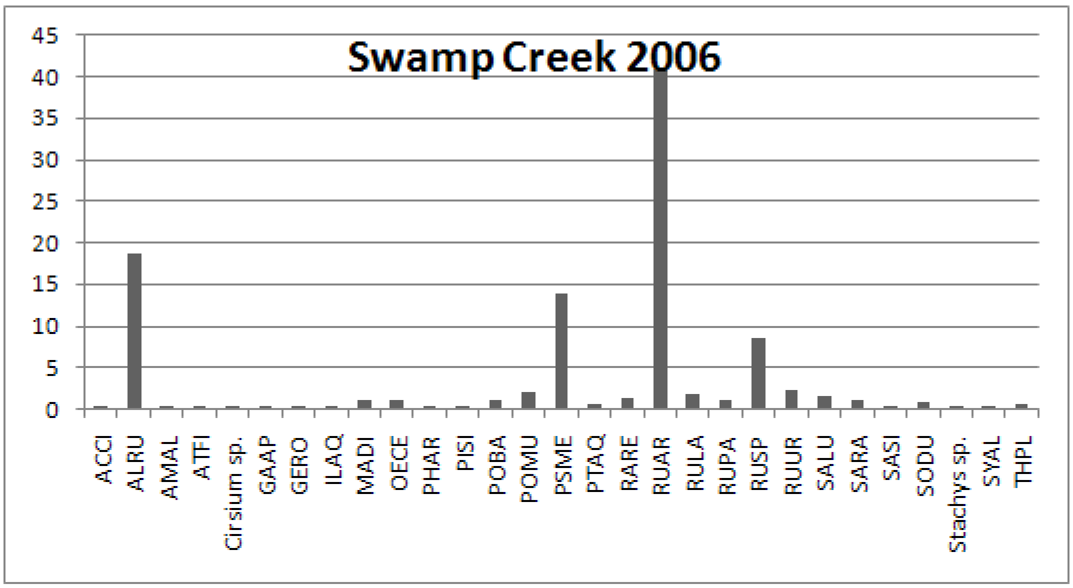


Notes and conclusions: This evaluation cannot testify to the hydrology of the site, however the soil stability was noted as stable in the area. Native plants are thriving here, but some invasive plants of concern include *Solanum Dulcamara*, *Ilex aquifolium*, *Rubus armeniacus*, *Geranium robertianum*, and *Ranunculus repens*. This site also had a dense deciduous canopy, mainly of *Alnus rubra*. *Thuja plicata* and *Tsuga heterophylla* were the few regenerating trees.

Swamp Creek 2006

Project goals: To establish a baseline for future monitoring of new site. Minimize invasive species while enhancing new and existing native plant communities through structural and species diversity. To reduce erosive power of the creek and subsequently enhancing water quality, through encouraged flooding of the low-lying area at the bottom of the 'Upland Grass Area'. Directly involve community in the restoration of the Community "Highlight" Area.

Species composition (%):



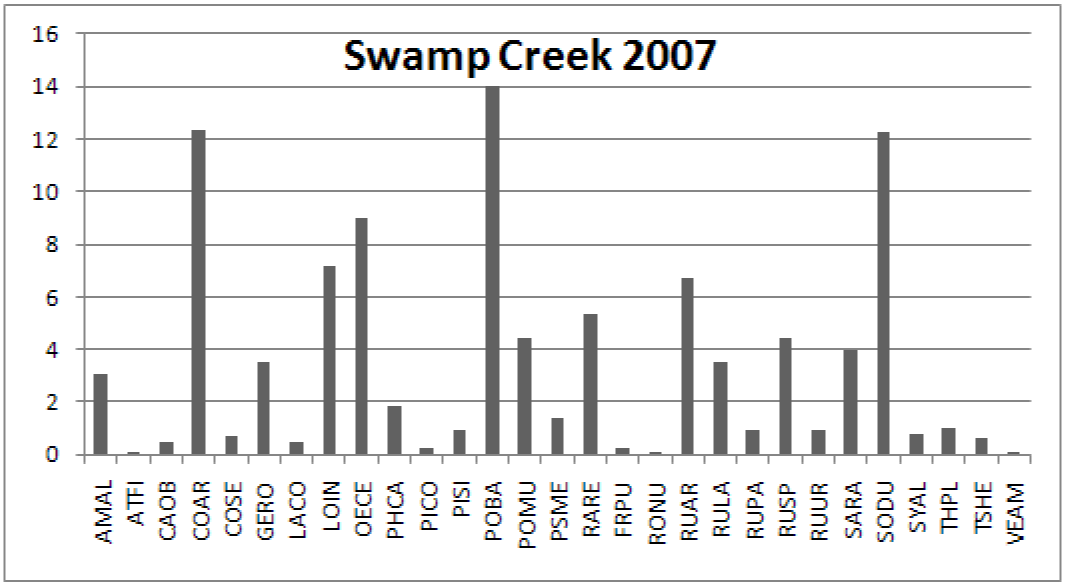
Notes and conclusions: Despite maturing *Pseudotsuga menziesii* in the vicinity, this site contains much *Rubus armeniacus,* covering over 70% of the site. *Picea sitchensis* and *Pseudotsuga menziesii* are the regenerating trees.

Figure 15: Swamp Creek 2006 upon implementation (above) and again in the summer of 2010 (below). This site continues to have abundant cover of invasive *Rubus armeniacus*.

<u>Swamp Creek 2007</u>

Project goals: To improve the water quality of the stream to enhance salmon habitat. To actively manage succession to promote an ecosystem consistent with Puget Sound lowland riparian areas. Increase biodiversity. Monitor and maintain previous adjacent sites.

Species composition (%):



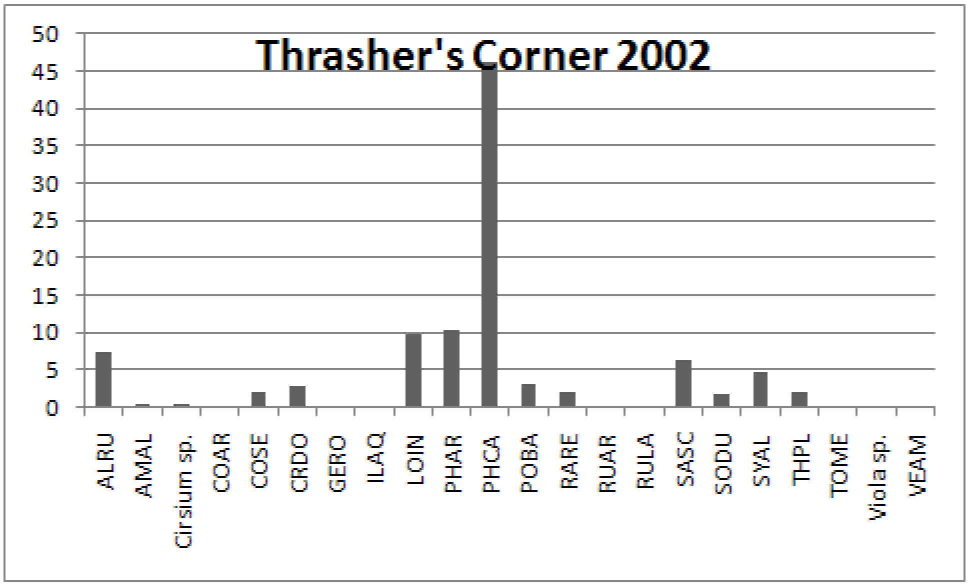
Notes and conclusions: This site has the most native cover of the three Swamp Creek sites. It also has the most regenerating trees, including *Thuja plicata*, *Tsuga heterophylla*, *Pinus contorta*, *Pseudotsuga menziesii*, *Picea sitchensis*, and *Abies grandis*.

Figure 16: Swamp Creek 2007 upon restoration implementation (above) and again in the summer of 2010 (below). It is evident from these photographs that the capstone plantings are thriving.

Thrasher's Corner 2002

Project goals: To remove and control invasive exotic species. To restore a native plant community. To conduct test plots near our site to determine methods for deterring growth of *Phalaris arundinacea*. Provide enjoyment and education for the public.

Species composition (%):

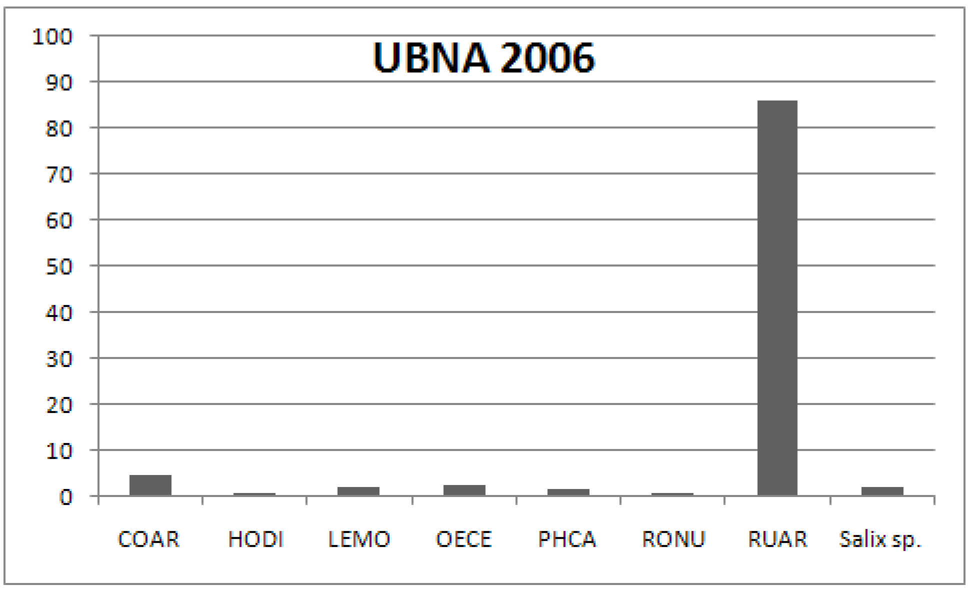


Notes and conclusions: *Physocarpus capitatum* was densely planted at this site, and it was noted that it is shading out the *Phalaris arundinacea*. Other invasive plants are present, but in small amounts. Although there is a deciduous canopy, there are no regenerating trees.

UBNA 2006

Project goals: Meet the client's request to assess, maintain, and enhance last year's site. Remove and suppress *Rubus armeniacus* and other invasive plants at the current site, NE 41st Street and Surber Drive, as requested by client in RFP. Mitigate for losses of wildlife habitat resulting from blackberry removal. Address clients' concerns over community sensitivity to ongoing UBNA activities by providing a functional and attractive demonstration of what restoration can do to a neglected area. Communicate project details and rationale with client and surrounding community to encourage involvement and stewardship.

Species composition (%):

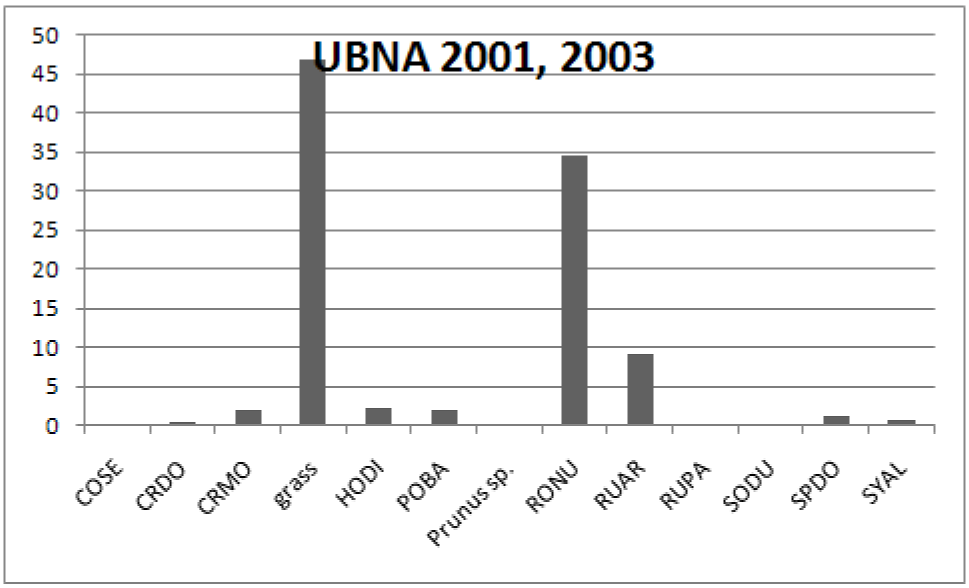


Notes and conclusions: This site is overrun by *Rubus armeniacus*, has little diversity, and no regenerating trees. Unfortunately efforts by this capstone group and all others at UBNA were unsuccessful in attaining stewardship. However, most recently Friends of Yesler Swamp was formed, and UBNA RA Jake Milofsky's efforts are paying off as the site is now reaching a more restored state.

UBNA 2001, 2003

Project goals: From 2003: To promote a structurally and species diverse native plant community, thereby restoring the ecological health of a disturbed wetland buffer. To assess, record, and evaluate past restoration work. To continue to nurture the surrounding Laurelhurst community's involvement and accessibility to the wetland. 2001 changed projects during the capstone to start restoration at UBNA: Restore native biodiversity and improve wildlife habitat in a disturbed wetland buffer located on the west bank of the East Basin of the UBNA. Develop an experimental/educational approach.

Species composition (%):

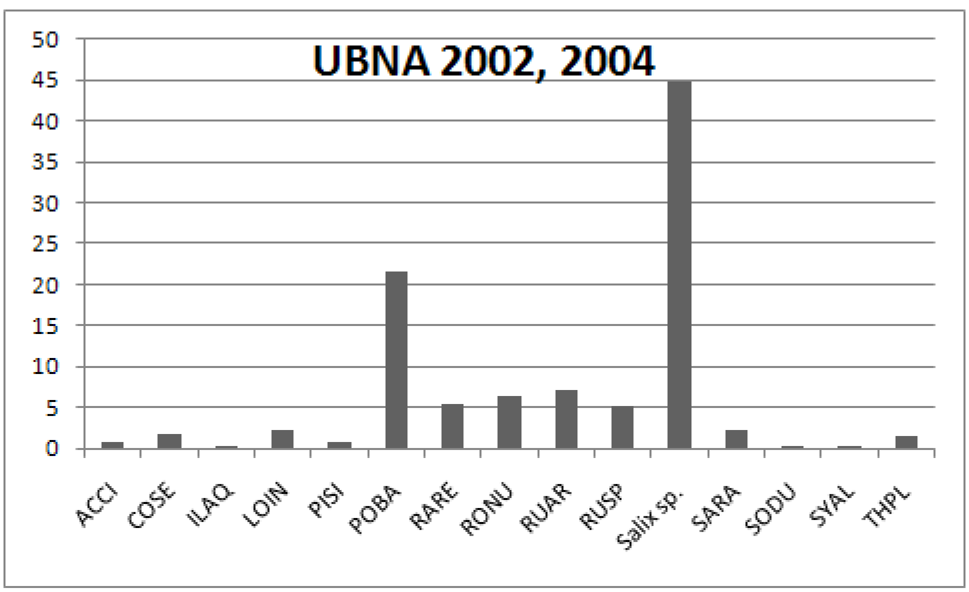


Notes and conclusions: This site was planted mainly with shrubs and deciduous regenerating trees. There are no regenerating conifers.

UBNA 2002, 2004

Project goals: From 2004 (read again): To restore a diverse plant community to the East Basin site. To control invasive species. To complete a loop trail. To create and restore shoreline focal area. To design educational materials for the public. From 2002: To increase native plant species and structural diversity and improve wildlife habitat in a disturbed wetland buffer located on the west bank of the east basin of the Union Bay Natural Area. To systematically monitor previous restoration efforts in the east basin in order to determine the most effective site preparation methods and most effective native species selected for various site conditions. To continue to nurture community understanding, accessibility, and participation, regarding the restoration work in the east basin, while also controlling human impacts in order to protect newly planted areas and sensitive shoreline habitat. ("Community" refers to Laurelhurst residents, University of Washington, and any other visitors to the site).

Species composition (%):

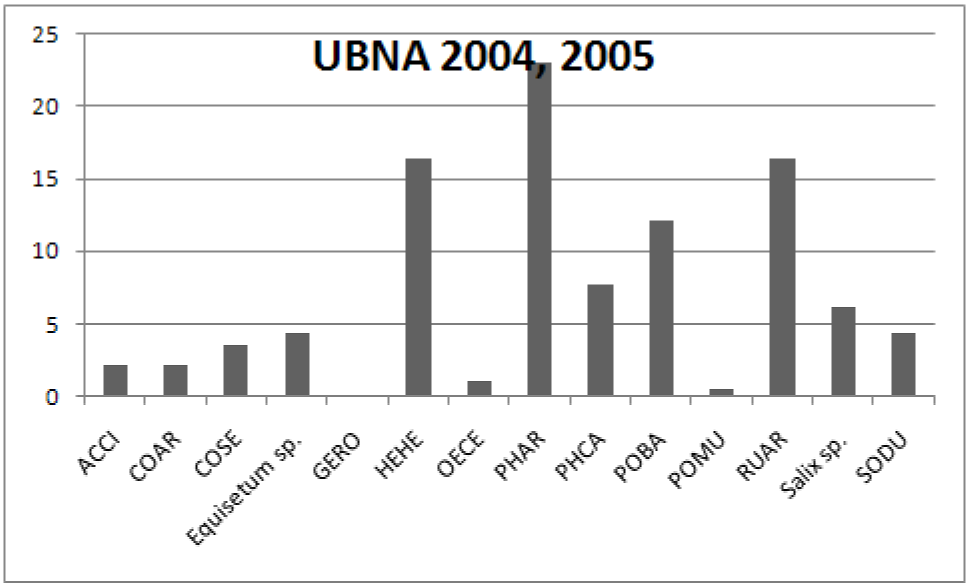


Notes and conclusions: This site once again demonstrates the usefulness in densely planting tall shrubs to shade out invasive plants. Although there is a small amount of *Rubus armeniacus, Ranunculus repens,* and *Ilex aquifolium,* native species abound here. There are many regenerating conifers including *Thuja plicata*, *Pseudotsuga menziesii*, and *Tsuga heterophylla*.

UBNA 2004, 2005

Project goals: 2004: To restore a diverse plant community to the East Basin site. To control invasive species. To complete a loop trail. To create and restore shoreline focal area. To design educational materials for the public.

Species composition (%):

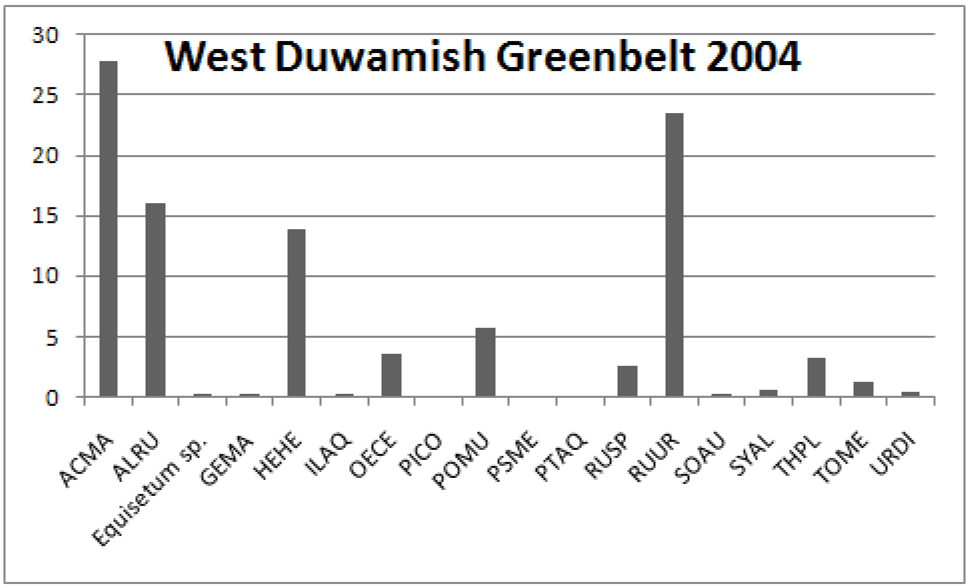


Notes and conclusions: Invasive plants such as *Rubus armeniacus*, *Phalaris arundinacea*, and *Hedera* sp. pose a threat to the integrity of this site. Other invasive plants are present in small amounts. There are no regenerating conifers.

West Duwamish Greenbelt 2004

Project goals: To support the establishment and growth of native vegetation by controlling the extent and cover of invasive vegetation. Preserve the quality of a natural drainage system and enhance the stability of the stream bank. Reintroduce the native plant community. Restore amphibian and near-stream habitat.

Species composition (%):

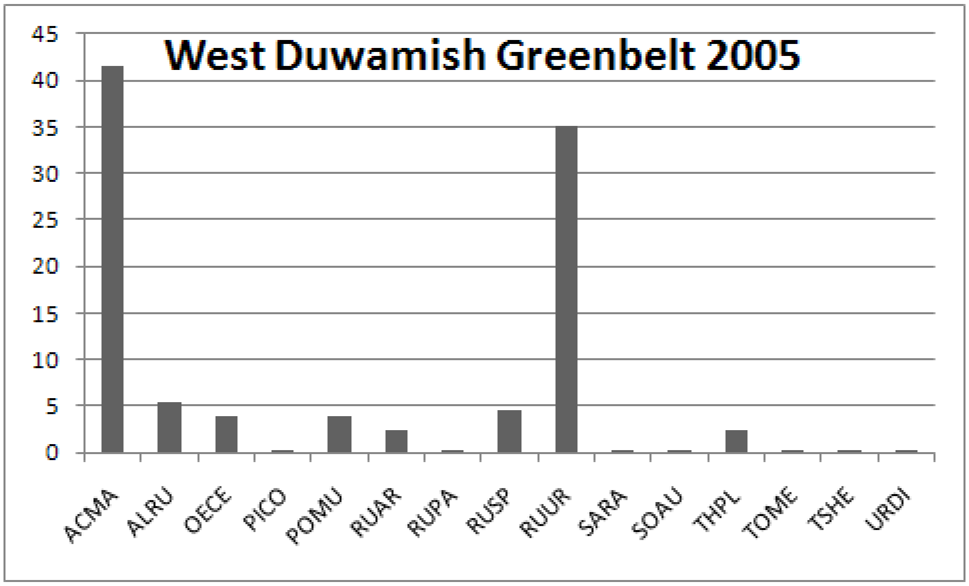


Notes and conclusions: Although this site has a *Hedera* sp. problem, it still has greater native species cover. Regenerating trees include *Pinus contorta*, *Thuja plicata*, *Pseudotsuga menziesii*, and *Tsuga heterophylla*.

West Duwamish Greenbelt 2005

Project goals: Control invasive species on the site to allow for native revegetation. Restore native vegetation to encourage species diversity and discourage invasive species in the power line corridor and adjacent forest. Stabilize the slope to reduce erosion. Incorporate an artistic element into the restoration site.

Species composition (%):

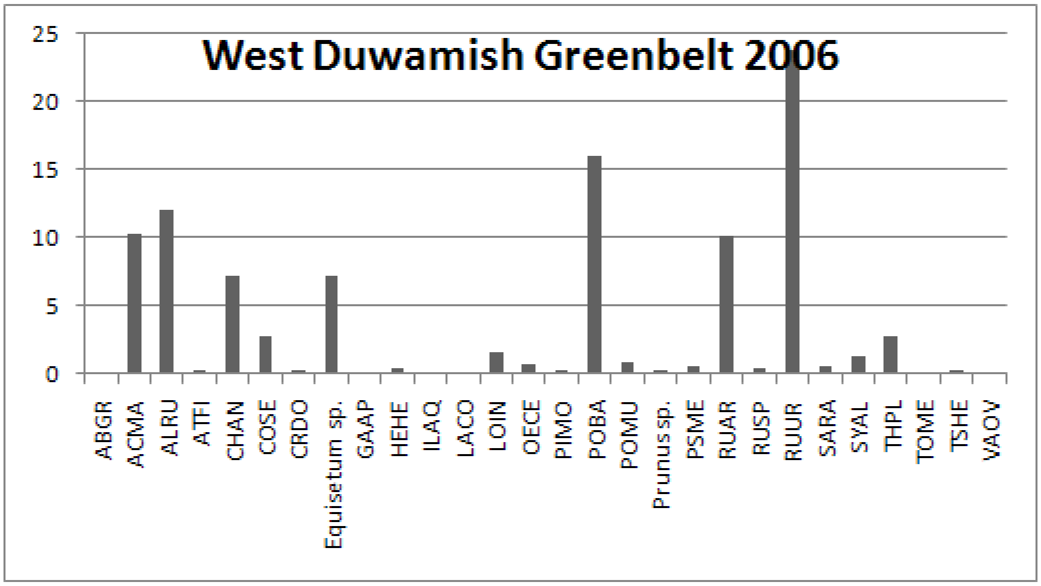


Notes and conclusions: This site presents with few invasive species (only *Rubus armeniacus*), and many regenerating *Thuja plicata*.

West Duwamish Greenbelt 2006

Project goals: Increase native plant diversity within the Duwamish Greenbelt. Decrease the extent of non-native, invasive species. Enhance habitat for wildlife. Decrease risk of erosion. Increase public awareness of the West Duwamish Greenbelt restoration project.

Species composition (%):



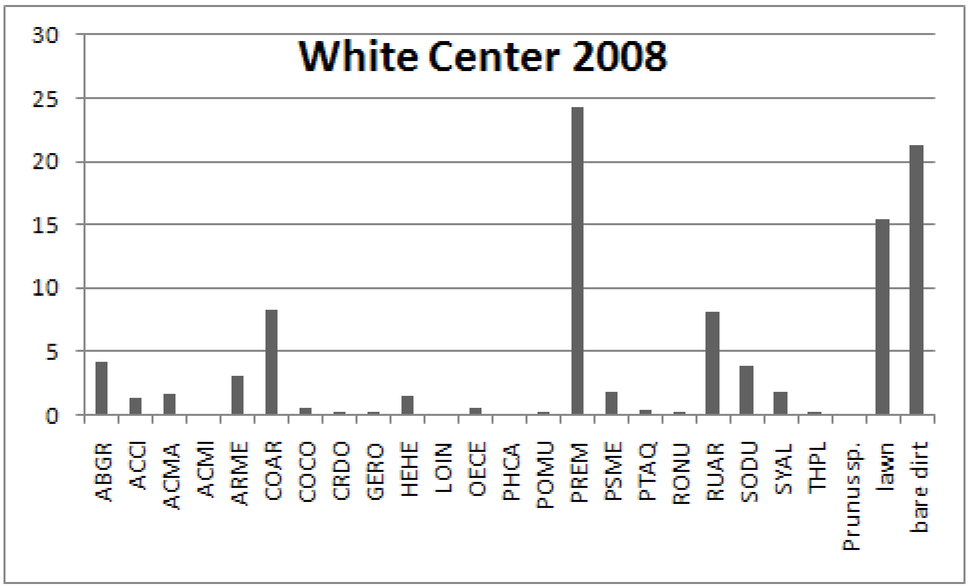
Notes and conclusions: This well maintained site has a high population of native species. *Rubus armeniacus* is present on the site, and *Hedera* sp. threatens from nearby. There are many regenerating conifers, including *Thuja plicata*, *Pseudotsuga menziesii*, *Picea sitchensis*, and *Abies grandis*.

Figure 17: The West Duwamish Greenbelt 2006 before project implementation (above), and again in the summer of 2010 (below). Through effective control techniques and high stewardship, this site has undergone a transformation from the sea of *Rubus armeniacus* shown in the top picture to a site rather rich in native diversity and composition.

White Center 2008

Project goals: Improve the ecological functioning of the upland riparian/wetland edge habitat. Improve access and sightlines into the southern parcel of the park for the public and for future restoration work. Design and create environmental education materials that emphasize the existing habitat and ongoing restoration work. Foster community stewardship of the park.

Species composition (%):

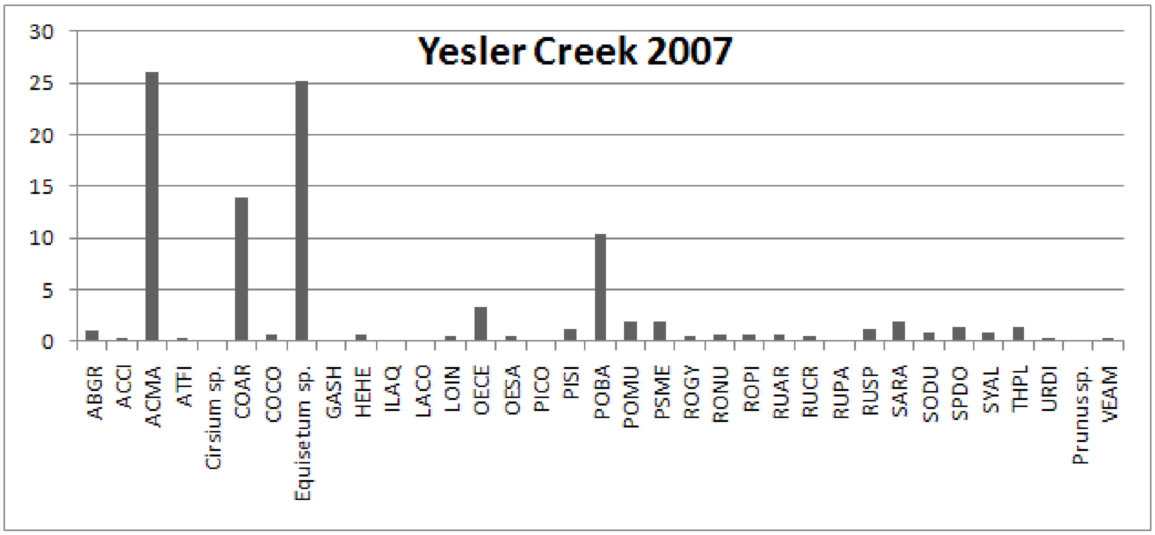


Notes and conclusions: Restoration should be continuing at this site, which currently has landscape cloth on most of it to control invasive plants. The invasive plants present on the site include *Convolvulus arvensis* , *Rubus armeniacus*, *Solanum dulcamara*, and *Hedera* sp.. Although most of the regenerating trees are *Corylus cornuta* (beaked hazelnut), there are *Thuja plicata* and *Pseudotsuga menziesii* as well.

Yesler Creek 2007

Project goals: Promote the establishment of a multi-layered native lowland Puget Sound riparian plant and wildlife community. Create a sense of community ownership and foster greater park stewardship to ensure ongoing success of past, current, and future restoration efforts. Generate deliverable (printed material and/or slide presentation) describing Yesler Creek and its relative location and importance within the greater watershed.

Species composition (%):

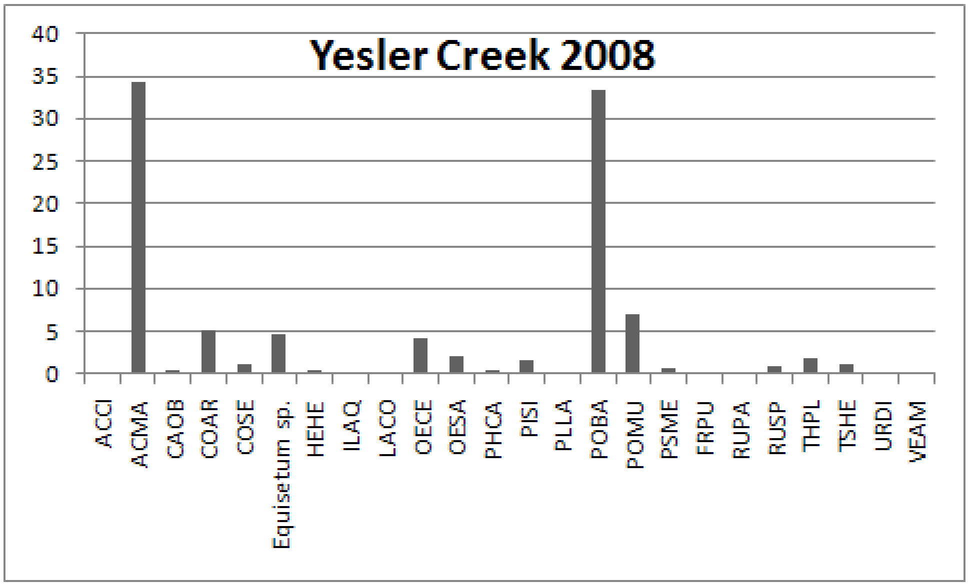


Notes and conclusions: This site is well maintained and has a regular stewardship group (Friends of Yesler Creek). Restoration is on-going at this site and in adjacent areas. There are few invasive species, but those of concern include *Rubus armeniacus*, *Hedera* sp., *Ilex aquifolium*, *Prunus laurocerasus*, and *Convolvulus arvensis* . There are many regenerating conifers including *Pseudotsuga menziesii*, *Pinus contorta*, *Thuja plicata*, *Picea sitchensis*, and *Taxus brevifolia*. The group was unable to find the historical information requested by the client.

Yesler Creek 2008

Project goals: Enhance the native Puget Sound riparian lowland plant community along Yesler Creek appropriate to site conditions. Enhance wildlife presence along Yesler Creek. Promote the continued success of restoration efforts surrounding Yesler Creek through the development of community stewardship. Research and summarize the historical changes in the hydrology of Yesler Creek.

Species composition (%):



Notes and conclusions: This site is well maintained by the Friends of Yesler Creek group, and has very few invasive species including *Rubus armeniacus*, *Hedera* sp., and *Convolvulus arvensis* . There are many regenerating conifers including *Picea sitchensis*, *Tsuga heterophylla*, *Thuja plicata*, and *Pseudotsuga menziesii*. The group was able to find some historical information. Restoration at this site and adjacent areas is on-going.

APPENDIX C: Monitoring Protocol (SUN, 2009)

Guidelines for SUN/GSP Vegetation Monitoring Protocols for Restoration Projects in Seattle Parks

Equipment List

- Field Forms
- Pencil
- Camera
- Compass
- Diameter tape
- Clinometer
- 50 foot (or meter) measuring tape
- Wooden stakes
- Two different colors of pin flags or flagging
- Pojar or other plant reference book

Establishing Sampling Plots

1. Determine the location of the 1/10ac plot in an area that is representative of area to be restored (use best team judgment based on site assessment and common perception of the location for the restoration project area). **It is very important to minimize the trampling of the area to be sampled. Do not pull invasive plants on the site (at least until after the monitoring is completed). Assign one person to do the plot layout.**

2. In your field notebook record a detailed narrative description of the location of the center of the sampling plot using visible permanent land features, pacing and compass directions or GPS locations. Use sufficient detail so that someone not familiar with the site and plot can locate the exact same hub in future monitoring.

3. Place a 1”x2” x 48” wooden stake at the hub of the circular plot; an orange capped 1’ rebar flush with the ground at the base of the wooden stake is a good back up to find the hub in the future.

4. Using a compass, face <u>true</u> north (declination of 17.2˚ easterly) and direct one monitor, pacing or pulling a measuring tape in the northerly direction, placing a marker (flags) at 37’ (11.3m). Repeat the process for each of the other three points of the compass (E, S, W). This completes the establishment of the sampling plots and area to be monitored. It is also helpful to place flags between the cardinal directions (e.g. NE, NW, SE, SW) along the boundary of the plot to help see the plot boundary clearly.

5. Site description information such as aspect, physical features, soil sampling, etc. should be done after monitoring to minimize trampling.

Photo Documentation

Standing at the hub of the sampling plot, facing N, take a photograph of the vegetation along the N line. Repeat the process for each of the other three points of the compass (E, S, W).

Monitoring Priorities

There is an order of monitoring that should be observed: monitor percent cover first, then do the installed species enumeration, growth and vigor before doing the tree density, DBH and height estimates. This order is necessary to maintain the monitoring site in the best condition to obtain the best observations and data.

A. Estimating Percent Cover in Circular Plots

1. Estimating cover will involve focused attention and teamwork. The first step is to develop a plant list. This can be done as the observer "pulls the line" to establish the compass points and looking out from the hub. The list can be augmented if additional species are located during monitoring. The list should contain the scientific and/or common names of native and invasive trees, shrubs, herbaceous plants and vines. Species codes are then assigned using the first two letters of the genus and the first two letters of the species name. Use the **cover data form** to record all estimates.

2. Once the species list is established, position monitors at each point of a quarter sector of the plot (e.g. one person at the hub, one halfway up the boundary line and one person at the 37' (11.3m) boundary). The person at the hub will be the recorder. If there is a fourth person on the team, that person can be the recorder but should be stationed on the outside perimeter of the sampling plot to minimize trampling.

3. Vegetation in each quarter should be estimated out of 100% total for each layer. Each layer is evaluated independently and therefore the total for the plot can add up to greater than 100%. For example, it is possible to have 50% ivy on the ground, 80% snowberry in a low shrub layer and 40% beaked hazelnut in a high shrub layer.

4. Once positioned, cover estimates are made systematically one species at a time. The recorder calls a species and each observer makes a visual estimate of what he or she estimates the area of the species covers in the sector and makes an estimate of the percent that species covers in the sector sampled. Only parts of the plant species that are within or overhanging the sector are included; deductions for gaps between leaves and stems are not made. **Think bird's eye view. Draw an imaginary line around the canopy of individual or groups of the target species, visualize the amount of foliage loosely pushed together in a mass within the sector and make an estimate of the <u>percent of the sector that foliage covers</u>. For large amounts of foliage, think in units of 10-25%; for smaller amounts of foliage, think in units of 1-5%. If there is only one small plant, use a**

minimum of 0.1% so the species is recognized as a trace. Once each observer makes an estimate for the first species, the recorder will ask each observer to give their estimate and the group will decide which is the best estimate to record for the species. Repeat this process for each species in the sector. As a point of reference, 0.3m x 0.3m = 0.1%; 0.7m x 0.7m = 0.5%; 1m x 1m = 1%; 1m x 2m = 2%, 2m x 2m=4%.

5. Repeat this process for the other sectors. Once all sectors are monitored, the estimates for each species will be combined into a total cover estimate for the entire sampling plot. Calculations should be done later and not in the field. Remember, a 40 percent estimate of snowberry cover in one sector represents only a 10 percent contribution to the total plot.

6. A word about plant identification. If you do not know the species or are not confident in your identification, take a picture or draw and describe the dominant features of the plant in your field notebook. Use an alias name (unknown composite #1, etc.) to record all occurrences of the same species until the plant can be identified. Remember the 1 in 20 rule: do not pick plant specimens unless you see at least 20 other similar plants in the immediate area. Also, do not pull any Class A noxious weeds or other designated weeds of concern as the Park staff or Noxious Weed Program staff may want to confirm the presence of the species.

B. Estimating Tree Density and Measuring DBH, Height and Canopy Cover

1. **Tree density** is determined by identifying and recording the number of all native and non-native trees occurring within the 1/10th acre plot including non-native tree-like species such as cherry laurel, English holly, and European mountain ash (*Sorbus aucuparia*). In order for a tree to be included in the sampling plot, more than half of its trunk must occur inside the plot.

2. Measure and record the **diameter at breast height** (dbh breast height is defined as 4.5 feet from the ground surface) for each tree using a diameter tape or calipers. For trees smaller

than 4.5 feet in height, measure and record the average stem diameter 4” (fist width) above the ground to the nearest ½ inch.

3. **Tree height** is measured to the nearest foot using a clinometer. To determine the height of a tree, you will need to measure the distance from the tree to be measured, the percent angle from your eye to the top of the tree and the distance from your eye to the ground. The best height estimates are made at percent angles less than 80%. Percent angles are given on the right hand scale of the clinometer. Standing 40-60’ from the tree usually will give percent angles of about 80% or less. Record the distance from the tree, percent angle from the clinometer and the distance from your eye to the ground on the monitoring form or field notebook. Electronic clinometers such as the Hagloff do not have a separate scale for percent angles and calculate this angle based on user input.

3. **Colonization by English ivy** is assessed and recorded for each tree, if present.

4. **Snags** are recorded in the same way as live trees, with “snag” as the species code. A snag is any dead tree greater than 5 feet in height and greater than 5 inches in diameter. DBH and height are recorded for each snag. In addition, a decay class of I, II or III is assigned for each snag. Decay class I is a tree that has recently died and has intact bark, branches and hard wood. Decay class III characterizes wood in an advanced state of decay with little or no bark or branches left intact. Decay class II is an intermediate state between these two extremes.

5. **Coarse Woody Debris (CWD)** refers to any downed wood or standing wood shorter than 5 feet in height in the case of stumps. CWD must be larger than 5 inches in diameter to be recorded. If a piece of CWD has a portion that is larger than 5 inches in diameter but then decreases in size, record the length of the portion that is inside the plot and larger than 5 inches. Only record the lengths of wood that lie within the plot boundaries. The length of the CWD piece should be measured to the nearest foot or half meter and entered in the height column. Measure the diameter at a point halfway along the log to get an average diameter.

C. Estimating Site Structure and Productivity

1. The **slope position** of the entire site is categorized into one of the following categories:

- **Bottom;**
- **Lower;**
- **Mid-slope;**
- **Plain;**
- **Ridgetop;**
- **Riparian Terrace**

Select the category that most closely matches the above selections and circle that category on the data sheet.

2. The **aspect** of the site refers to the direction the topography is sloping on the site. Imagine that a bucket of water is emptied in the center of the plot and determine what direction the water would flow. One of the following options should be selected on the data sheet:
N; NE; NW; S; SE; SW; E; W; Flat

3. **Soil moisture** can be determined by removing and examining a small amount of soil. One of the following categories should be selected on the data sheet:
Damp soil; Dry soil; Saturated soil; Standing water

4. To assess **soil texture**, a small amount needs to be removed with either your hands or a sharp object such as a spade. ***Clay soils*** are composed of very fine clay and sand particles that are very sticky. To determine whether you have a clay soil, take a small amount into your hand and try to roll it into a ball. If it forms a ball easily and does not fall apart, you most likely have a clay soil. ***Sandy soils*** on the other hand are made up of larger sand particles and do not clump easily. If the soil feels gritty and is made up of sand grains that do not adhere to each other, you most likely have a sandy soil. ***Silt*** is made up of soil particles that are larger than clay but smaller than sand. These soils are usually found in floodplains and riparian areas. They are dark in appearance and sticky unlike sand, but will crumble if made into a ball and will not hold together. Silt particles often feel like flour. ***Gravel*** has the

largest particles and is usually fairly easy to distinguish from the other soil types as it appears to be made up of a lot of small stones.

5. The **seral stage** of the site is the level of its structural development into a forested community. Look at the entire site and choose one of the following options:

- **Shrub pioneer** (<10% canopy cover)
- **Sapling** (trees are 1”-5” DBH)
- **Early mature** (trees are 30-60 years old on average)
- **Mid-mature** (trees are 60-120 years old on average)
- **Late mature** (trees are 120-180 years old on average)
- **Old growth** (trees are >180 years old)

6. Assess the proportion of **bare ground** on the site in the same way that you would use for the percent cover estimates, but extrapolate for the entire plot. Bare ground refers to areas that do not contain vegetation either growing out of them or overhanging them directly less than a foot from the ground. If an area is covered in litter but does not have any vegetation present it is considered to be bare ground. Record the amount of bare ground present in one of the following categories:

0-20%; 21-40%; 41-60%; 61-80%; 81-100%

7. The amount of **soil compaction** present on the site should be noted such as the presence of heavy equipment, trails, trampling, etc. Mark one of the following categories:

None, Moderate or Heavy

If evidence of compaction is present, make notes describing it in the “compaction evidence” box.

8. Assess the soil stability of the site visually and select one of the following categories:

Stable soil; Erosion; Slumping; Slides

9. Assess the average litter depth of the site by determining the depth of the litter layer above the soil in a representative area in each of the vegetation quadrats. Visually estimate the average depth of the litter layer in one of the following categories:

0; .1-.5 inches; .5-1 inch; >1 inch

10. Note any **special features** present on the site such as trails, streams, wetlands, mountain beaver use, homeless encampments, garbage dumping, etc.

11. Estimate the **CWD cover** on the site in the same way that you would use for the percent cover estimates, but extrapolate for the entire plot. To qualify as CWD the wood must be greater than 5 inches in diameter. Record the amount of CWD present in one of the following categories:

0-5%; 6-10%; 11-25%; 26-50%; 51-100%

12. **Overstory canopy cover** is estimated visually using the circular sketch provided on the Plot Information sheet. Sketch each overstory tree present in the plot using the tapes as guides to estimate how much of the area is covered by canopy. For example, if a tree canopy extends over a third of the plot, draw in the canopy accordingly. If a tree's canopy extends beyond the sample plot boundary, record only the portion within the quadrat. Once all of the trees or areas of contiguous canopy cover have been sketched, use the drawing in conjunction with observations from the center of the plot to estimate the approximate percent canopy cover directly overhanging the plot.

APPENDIX D: Species codes

Species code	**Scientific name**
ABGR.t	*Abies grandis*
ACCI.ts	*Acer circinatum*
ACMA.t	*Acer macrophyllum*
ACMI.h	*Achillea millefolium*
ADAL.h	*Adiantum aleuticum*
ALRU.t	*Alnus rubra*
AMAL.ts	*Amelanchier alnifolia*
Arctiumsp.h	*Arctium* sp.
ARME.t	*Arbutus menziesii*
ARUV.ss	*Arctostaphylos uva-ursi*
ATFI.h	*Athyrium filix-femina*
bare dirt	bare dirt
BICE.h	*Bidens cernua*
BLSP.h	*Blechnum spicant*
CAOB.g	*Carex obnupta*
Carexsp.g	Carex sp.
Chamaecyparissp.t	*Chamaecyparis* sp.
CHAN.h	*Chamerion angustifolium*
CIAR.nn	*Cirsium arvense*
Cirsiumsp.nn	*Cirsium* sp
COAR.nn	*Convolvus arvensis*
COCO.ts	*Corylus cornuta*
CONU.t	*Cornus nuttallii*
COSE.ts	*Cornus sericea*
CRDO.t	*Crataegus douglasii*
CRMO.nn	*Crataegus monogyna*
CYSC.nn	*Cytisus scoparius*
DIFO.h	*Dicentra formosa*
DREX.h	*Dryopteris expansa*
Equisetumsp.h	*Equisetum sp.*
FRCH.h	*Fragaria chiloensis*
FRLA.t	*Fraxinus latifolia*
FRPU.t	*Frangula purshiana*
GAAP.h	*Galium aparine*
Galiumsp.h	Galium sp.
GASH.ss	*Gaultheria shallon*
GEMA.h	*Geum macrophyllum*
GERO.nn	*Geranium robertianum*
grass.g	grass
HEHE.nn	*Hedera helix*
HODI.ts	*Holodiscus discolor*
HYRA.h	*Hypochaeris radicata*
ILAQ.nn	*Ilex aquifolium*
LACO.h	*Lapsana communis*
lawn.g	lawn
LEMO.g	*Leymus mollis*
LOIN.ts	*Lonicera involucrata*
Lupinussp.h	Lupinus sp.
LYAM.h	*Lysichiton americanum*
MAAQ.ss	*Mahonia aquifolium*
MADI.h	*Maianthemum dilatatum*
MAFU.t	*Malus fusca*
MANE.ss	*Mahonia nervosa*
MARA.h	*Maianthemum racemosum*
moss.o	moss
MYGA.ss	*Myrica gale*
OECE.ss	*Oemleria cerasiformis*
OESA.h	*Oenanthe sarmentosa*
OPHO.h	*Oplopanax horridus*
OXOR.h	*Oxalis oregana*
PEPA.h	*Petasites frigidus*
PHAR.nn	*Phalaris arundinacea*
PHCA.ts	*Physocarpus capitatus*

PHLE.ss	*Philadelphus lewisii*	RUUR.ss	*Rubus ursinus*
PICO.t	*Pinus contorta*	SAHO.ts	*Salix hookeriana*
PIMO.t	*Pinus monticola*	Salixsp.ts	*Salix* sp.
PISI.t	*Picea sitchensis*	SALU.ts	*Salix lucida*
PLLA.h	*Plantago lanceolata*	SARA.ts	*Sambucus racemosa*
POAL.t	*Populus alba*	SASC.ts	*Salix scouleriana*
POBA.t	*Populus balsamifera*	SASI.ts	*Salix sitchensis*
POMU.h	*Polystichum munitum*	SOAU.t	*Sorbus aucuparia*
PREM.t	*Prunus emarginata*	SOCA.h	*Solidago canadensis*
Prunussp.t	*Prunus* sp.	SODU.nn	*Solanum dulcamara*
PSME.t	*Pseudotsuga menziesii*	SPDO.ss	*Spiraea douglasii*
PTAQ.h	*Pteridium aquilinum*	Stachyssp.h	*Stachys* sp.
RARE.h	*Ranunculus repens*	SYAL.ss	*Symphoricarpos albus*
RILA.ss	*Ribes lacustre*	TABR.t	*Taxus brevifolia*
RISA.ss	*Ribes sanguineum*	TEGR.h	*Tellima grandiflora*
ROGY.ss	*Rosa gymnocarpa*	THPL.t	*Thuja plicata*
RONU.ss	*Rosa nutkana*	TITR.h	*Tiarealla Trifoliata*
ROPI.ss	*Rosa pisocarpa*	TOME.h	*Tolmiea menziesii*
Rosasp.ss	*Rosa* sp.	TSHE.t	*Tsuga heterophylla*
RUAR.nn	*Rubus armeniacus*	URDI.h	*Urtica dioica*
RUCR.h	*Rumex crispus*	VAOV.ss	*Vaccinium ovatum*
RULA.nn	*Rubus laciniatus*	VAPA.ss	*Vaccinium parvifolium*
RULE.ss	*Rubus leucodermis*	VEAM.h	*Veronica americana*
RUPA.ss	*Rubus parviflorus*	Violasp.h	*Viola* sp.
RUSP.ss	*Rubus spectabilis*		