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Bringing the Park Land Back to Parkland

Restoring the Morken Meadow

When I first moved to Parkland four years ago, I was excited by the prospect of living in a town called Parkland. The name conjured up images of sprawling parks and quiet arboretums. When I arrived, I was surprised to learn that, besides PLU, Parkland is mostly urban sprawl. Eventually, I learned that the name Parkland is more than 100 years ago. Before PLU was founded, before ranchers and farmers commandeered the land, much of this area was dominated by prairies.

The main goal of my fellowship was to create a prairie restoration plan for the Morken Meadow. In order to create this plan, I researched the history of prairies in the Pacific Northwest. In my research, I visited various prairies throughout the region and read many scientific articles about prairie restoration. I learned that prairie restoration is very difficult. Some of the biggest obstacles to restoration are invasive species, encroachment of development, loss of native diversity, and the lack of pristine reference prairies. Due to the many difficulties involved with prairie restoration, PLU has two options: we can create a comprehensive restoration plan and follow it diligently and unfalteringly, or we can choose not to attempt any restoration. If our commitment falls anywhere in-between, I suggest that PLU chooses the later. If we half-heartedly attempt prairie restoration, our efforts will fail. Yet, despite the difficulty of prairie restoration, I believe that it is possible. If PLU chooses to restore the Morken Meadow, a comprehensive plan will be necessary. After completing my research, I created such a plan by combining an adaptive management approach with a phased implementation strategy. This paper presents my recommended restoration plan.

This paper will consist of the following:

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Prairies in the Pacific Northwest

Twelve thousand years ago, the place where Pacific Lutheran University currently resides was buried under a mile of ice (5). In fact, if we could travel back in time, we would be able to walk from the top of the Olympic Mountains all the way across the Puget Sound to Mt. Rainier without decreasing in altitude. In this 4,000 year period, glaciers around the Pacific Northwest helped carve out the geographical region now known as the Willamette Valley-Puget Trough-Georgia Basin (WPG) ecoregion (5). Subsequently, in the dry period after the glacial retreat, an extensive prairie ecosystem formed and was prevalent until white settlement began in the mid-

1800's. With over 350 different plant species, these prairies were a spectacular rainbow display of seasonal wildflowers and blue-green bunchgrasses with only the occasional Garry Oak scattered amongst them (1). For example, when Fort Lewis was first being built, soldiers could ride their horses all the way from the Northern border of the base to Olympia without seeing a single tree (12).

Almost immediately after settlement began, the prairies started to deteriorate. Farmers, ranchers, and city dwellers pressured Native Americans to stop their periodic burns. This cessation of fire played a pivotal role in the deterioration of prairies in the Pacific Northwest. Large woody plants, such as Douglas fir, had previously been unable to colonize the prairies due to the periodic fires. With the fires gone, forest-dwelling plants quickly invaded the open spaces.

Example of an oak savannah in spring (Photo credit Rod Gilbert)

In the Pacific Northwest, the vegetation structure of prairies is very important. Unlike the tall-grass prairies of the Mid-west, prairies of this region are dominated by short bunchgrasses, such as Roemer's fescue (1,4). Because they are bunchgrasses instead of rhizomatous mat-forming grasses (commonly found in lawn species and tall-grass prairies), there is space between the different grass plants for native forbs to grow. When newly introduced species began to disrupt this structure, it became much more difficult for prairie plants to grow. Fire cessation was another detrimental factor. Over thousands of years of fire management by Native Americans, many forbs had developed ways to thrive in the presence of fire. Without this abiotic force, many plants could no longer spread their seeds effectively.

Of the 150,000 acres of prairies formerly present in the Puget Sound area, only 9% still remain, with only 2-3% still being dominated by native species (1,5) For effective restoration to occur, it is important for biologists to study high-quality remnant prairies (5). Sadly, those are very hard to find. Even the best prairies that we currently have are infested with hairy cat's ear (*Hypochaeris radicata*) and other common invasive species. Many key plants and animals (especially pollinators) are extinct or endangered (5). All of these issues leave us with a difficult situation: it is much harder to restore something when there is no model to base restoration goals upon. All we have are records of the prairies from 150 years ago and a few remnant prairies scattered around here and there. Due to the lack of evidence for scientists to follow, prairie restoration must be based on a certain amount of imagination and creativity. The only way to really guess what prairies originally looked like is through trial and error experimentation. With global climate change promising more extreme temperatures to come, we may soon learn that it is not possible to restore areas as they used to be. All we can do is try our best to support this endangered ecosystem, one of the most endangered in the country, before it disappears entirely.

Local Restoration Resources:

Even though the extent of prairie lands has decreased considerably, PLU is lucky to be close to some of the best remnant prairies in the WPG ecoregion. Only a few miles away from campus, Joint Base Lewis McChord (JBLM) is home to the largest remnant prairie in our region: the periphery of their artillery field. Although the middle of this enormous field more closely resembles the crater-pocked lunar surface than anything else, the periodic fires started by artillery shells have helped the edges of this area to remain in remarkable prairie condition. When the military eventually noticed the veritable treasure-trove of ecological wealth on their base, they hired a full time biologist to focus on maintaining prairie plant diversity (12).

Another nearby prairie location is in Littlerock, a small town ten minutes south of Olympia. Their two prairies, Glacial Heritage and Mima Mounds, are well maintained by the Center for Natural Land Management (CNLM) (13). One of the most significant resources present at this location is their native seeds: CNLM manages two seed collection facilities in the Littlerock area where native prairie plants are grown in raised beds for seed collection or in plastic plugs for transplanting into their prairies. The CNLM also collaborates with JBLM during the fire season to coordinate controlled burns at both sites.

Another local resource is the University of Washington Restoration Ecology Network (UW-REN). (26) This group works to restore various sites throughout the Puget Sound area, with the closest site being the Pierce College Oak Woodland. Less than 10 miles away, this restoration site is managed through collaboration between UW-REN, Pierce College, and the city of Tacoma. One of their main restoration goals is for the site to be integrated into academic activities at Pierce College, in classes such as botany, restoration ecology, and environmental science. I will advocate for a similar restoration goal at PLU later in this paper (27).

In my research, I was lucky enough to be able to visit both of the prairies in Littlerock, one of their nurseries, and the large prairie on JBLM. One of the first things I learned from visiting these sites and talking to the people involved with prairie restoration was how difficult it really is. More than any other ecosystem in this area, prairies are the most difficult to maintain (5). Prairies are already an artificial ecosystem; by this, I mean to say that they were originally maintained and shaped by Native Americans. Therefore, a certain amount of work is already inherent in their maintenance. Now, with the addition of invasive species, burn bans, habitat fragmentation, approaching residential buildings, and a whole list of other factors, prairies are even harder to maintain. Fortunately, prairie research has grown considerably in the Pacific Northwest in the past few years, and scientists have been able to come up with a few creative strategies to aid in restoration efforts.

Restoration Strategies:

In many restoration projects, a common practice is to follow along with something called adaptive management (See side bar on page 4) (4). The main focus of this form of management is on control of invasive species. Some of the most common strategies used to control invasive species are application of herbicides, prescribed fire, mowing, solarization, hand weeding, and

Adaptive Management: (From (4))

1. Establish Management Goals and Objectives.
2. Determine which invasive species have the potential to prevent attaining those goals and objectives (prioritizing species is necessary: based on ecological threat and feasibility of management).
3. Identify methods for managing those invasive species.
4. Develop a management plan to move conditions toward management goals and objectives.
5. Monitor and assess the effectiveness of management actions.
6. Reevaluate, modify, and start the cycle again.

reverse fertilization. Depending on the situation, scientists choose to apply one or more of these strategies. Generally, the cases that show the greatest success are those that apply numerous strategies in tandem (4). In order for us to determine which strategies to implement, it is important for us to understand the costs and benefits involved with each strategy. These are outlined in Index 1 at the end of the paper.

Even though these various strategies have their pros and cons, it is impossible to know how each of them would affect invasive species at PLU. One very important thing I learned from the numerous papers discussing restoration strategies was the variability found in different sites. One strategy can have completely different outcomes in two different sites. Because of this variability, I propose an integrated approach deriving from Adaptive Management and the experimental approach known as a phased implementation plan (2).

Experimental Framework:

The initial step in the restoration process is to define restoration goals and objectives. Thus, the first question is: what *can* we do with this space? The restoration site is located directly south of the Morken Center for Learning and Technology (Figure 1). At around 1/9 of an acre (4,900 square feet), this small area is unofficially named "the Morken Meadow." Because of its relatively small size, our restoration goals must be to scale. The Morken Meadow will never be a spacious oak savannah, complete with Taylor's checkerspots (an endangered butterfly species) and streaked horned larks (an endangered bird species). Instead of full-scale prairie restoration, a more suitable goal for this area would be a prairie demonstration garden. A prairie demonstration garden shows all of the floral diversity of a full-sized prairie, just on a smaller, more compact scale. It is planted with a high diversity of forbs so as to demonstrate the multi-colored beauty of native prairies. Along with its aesthetic value, a demonstration garden would act as an educational tool. For example, for the biology and environmental studies departments, it could act as an outdoor classroom or a site for scientific research. It could also be used to educate the Parkland community. How many people in Parkland know that this area used to be covered with prairies? Imagine the faces of elementary school students when they come to see the Morken Meadow in May, a purple sea of camas flowers dotted with meadow buttercups and chocolate lilies.

Figure 1. Morken Meadow: The experimental area is around 4,930 square feet and is broken up into two sections. The entire field is sloped downwards, from the parking lot on the southern side down to Morken on the northern side. There is currently a buffer zone (around 20 feet wide) that is being mowed between the building and the experimental area. In this photo, the experimental area is outlined in red.

To summarize:

Main Objective: create a prairie demonstration garden to satisfy the following goals:

- Aesthetic beauty.
- Habitat restoration.
- Education.
- A sense of historical place.

These are the goals as I define them. Before restoration can begin, these goals must be discussed and refined by all of the stake-holders involved: Facilities, the Sustainability Department, any applicable academic departments, PLU administration, etc. For a restoration projects to be successfully created and maintained, a unified set of goals is necessary.

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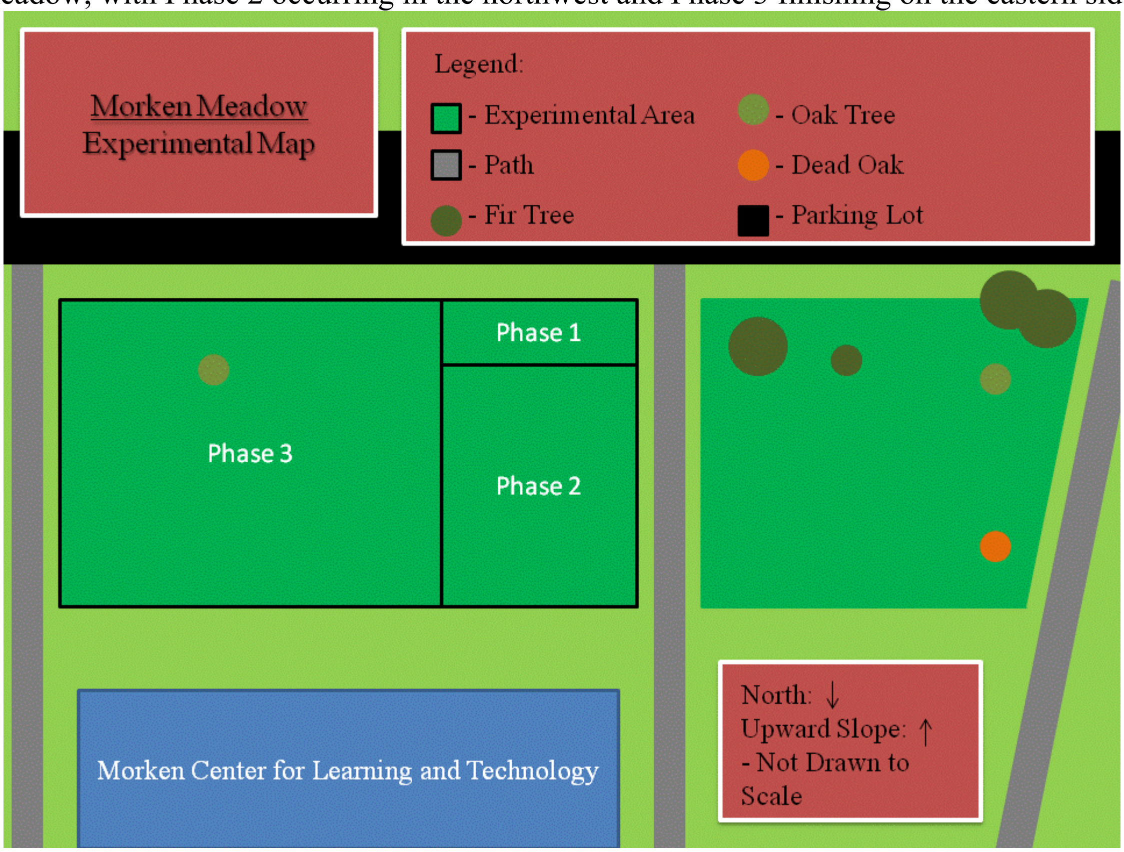
Once the goals have been agreed upon, the next step in the process is to determine the current state of the restoration site. What is the distribution of native and invasive species? Right now, the meadow is dominated by invasive species (see species list in Index 2). In my observations of the area, I was only able to identify three native prairie species: camas, yarrow, and Garry oak. The lack of native species is unfortunate because it means that we will have to obtain native seeds to plant. On the other hand, it is good in terms of invasive species removal. Instead of having to tip-toe around a large number of fragile native species, we can use easier, more time-efficient invasive species removal mechanisms. According to my sources, camas is one of the hardiest native plants (12). Capable of surviving most common restoration practices, there is little need for us to worry about harming this bulb-forming perennial. Although yarrow may not be quite as tough, it is a very common plant and will be easy to replant. As for the Garry Oaks, only two of the previously planted specimens appear to be alive at this point. As long as we leave an adequate buffer zone around them, they should continue to grow well all by themselves.

When a restoration area is dominated by invasive species, one common restoration technique is to kill all of the plants in the area using herbicides and fire. After a few years of this, when the seed bank is diminished and the ground is bare, the area is ready for native plants. This technique can be practiced all at once, or in increments using something called a phased implementation plan (2). I recommend that we use the second strategy. A phased implementation plan is made up of distinct phases in which different portions of the area are used. In the first phase, a small portion of the total restoration area is prepared for restoration (all of the plants in this area are killed). The area is then split into a number of experimental plots. These experimental plots are treated differently depending on a set of experimental variables. At the end of this period, the most effective treatment is determined, and the second phase may begin. In this phase, the actions of the first phase are repeated, but on a larger scale. At the end of the second phase, the most effective treatment is again determined. In phase three, the rest of the Morken Meadow is subjected to this final treatment (Figure 2). The fourth phase is the long-term management phase. This phase is focused on upkeep and monitoring.

Figure 2. Phased Implementation Plan: Phase 1 begins in the southwestern portion of the meadow, with Phase 2 occurring in the northwest and Phase 3 finishing on the eastern side.



Experimental Design:

Phase 1:

Following along with the adaptive management plan, the next step in the process is to determine which invasive species could pose the greatest threat to restoration efforts. Of the invasive species currently dominating the Morken Meadow (Index 2), the most threatening to this project is invasive grass. This threat is mainly based on prairie structure. The dominant grass in South Sound prairies is Roemer's Fescue, a native bunchgrass. Unlike common invasive grasses, such as velvet and bent, which form dense mats of vegetation through lateral stolon growth, bunchgrasses grow in bunches, leaving surrounding areas open for forb growth. Thus, invasive grasses are threatening because they crowd out native plants by changing the prairie structure.

The next step is to identify methods for managing these grasses. Because of their invasiveness, they must be completely removed. If we leave any of them in the meadow, they will quickly re-colonize the space. According to the phased implementation plan, invasive removal will occur in an experimental context focused on three different variables: chemical, mechanical and mixed removal (Figure 3). The chemical removal scheme will use two different herbicides: glyphosate and sethoxydim. Sethoxydim is a grass-specific herbicide that will be sprayed in the spring (April-May) (25). Glyphosate is a broad-spectrum herbicide that will be applied on a sunny day in the late winter/early spring (March-April). The mechanical removal scheme will utilize tilling, either with a rototiller or a tractor. Tilling is common strategy used by organic farmers to reduce weed cover. Tilling will occur in the spring (April-May) (24). While tilling will kill many weeds and reduce thatch cover, it will release many more dormant weeds from the soil seed bank in the process. Thus, after two weeks, these newly emergent weeds will be killed using hoes or a propane torch. Finally, mixed removal combines mechanical and chemical means of invasive species removal. In the spring, these plots will be tilled. Then, instead of using hoes or a propane torch, the emergent weeds will be killed with glyphosate. Each of these treatments will continue for two years. In the off-seasons (whenever treatments are not occurring), mowing will occur in the experimental areas as well as in the areas outside the experimental areas. This mowing will occur at regular intervals in order to keep the invasive plants from going to seed and adding to the seed bank.

Figure 3. Invasive Species Removal Methods: Treatments include sethoxydim (S), glyphosate (G), tilling (Ti), hoeing or torching (H/T) and mowing (M).

		Treatments			
Year	Season	Chemical	Mechanical	Mixed	Control
1	Spring	G and S	Ti and H/T	Ti and G	
	Fall	M	M	M	M
2	Spring	G and S	Ti and H/T	Ti and G	
	Fall	M	M	M	M

Each of these three experiments will be replicated four times in a grid of twelve 10 ft^2 subplots. This grid can be oriented in two ways (Figure 4). The first, a straight line of twelve subplots along the top (the south side) of the hill, would be the best in terms of giving the best results. With this orientation, we would be able to randomly mix the three different treatment regimens. The second orientation, two rows of six subplots, would be easier to prepare but perhaps it would not give as good of results. For this option, we would have to put the subplots in blocks of four (two across by two tall) delineated by treatment. If we arranged the areas randomly, intermingling of results could occur. For example, if a chemical treatment was above a mechanical treatment, the herbicides could pour down the hill into the mechanical treatment area, altering the final results.

Figure 4: Comparing the two different orientation strategies. Control measurments can be taken anywhere outside of the experimental area.

For phase one, the initial results will be based on how well each of the three strategies prepares the soil for native species. This will be measured in terms of percentage of bare soil in each plot. This measurement will be taken in fall of the second year after all treatments are finished.

In an experiment by Stanley *et al.*, seeding was most successful in the immediate aftermath of a burn (2). This was due to the fact that controlled burns open up soil for native seeds to thrive. Unfortunately, we will not be able to use controlled burns on the Morken Meadow. This is why I have recommended the use of tilling. I hypothesize that one of the two strategies utilizing tilling (mechanical and mixed) will clear up the most ground. The chemical method might do a good job of killing off the invasive species, but if a thick layer of thatch remains, it may prove difficult for native seeds to establish themselves.

Native Seeding:

Native seeding can occur in two different ways: broadcast seeding or plugging. For broadcast seeding, a specific mass of seeds is taken and is distributed evenly around an area of bare soil. The soil is then raked lightly in order to increase the contact between soil and seeds. Plugging is synonymous with transplanting. Plugs are grown in cylindrical holes in plastic racks. They are generally planted a year or two before being transplanted into the restoration area. They are called plugs because little holes are made in the dirt first, then the plugs are used to plug up the holes.

In the Stanley *et al.* experiment, they used broadcast seeding for all of their seeds (2). However, in their study, they mentioned that Roemer's Fescue was slow to establish when grown from seed. So, for phase one, we will plug fescue and broadcast seed the other species. All in all, we will use nine different native species in this experiment (Index 3, Sidebar).

At the end of the first year of phase one, we will plant Roemer's Fescue in plastic trays for plugging. The next fall, at the end of the second year of phase one, we will transplant the fescue and broadcast the other seeds into the experimental area. Each subplot will be planted with the same diversity of seeds (Index 3). This will start the second round of phase one. The following May and June, the following variables will be measured: number of native and non-native species present in each plot, percentage of native grass cover compared to native forb cover, and percentage of native plant cover to nonnative plant cover. These variables will be measured by looking at 1–m^2 sampling quadrats in each of the areas.

After data is collected, phase two will begin with the next experimental area. Based on the results found in stage one (invasive species removal) and stage two (native establishment) of phase one, the phase two experimental area will be treated with the most effective invasive species removal regimens.

Phase 2:

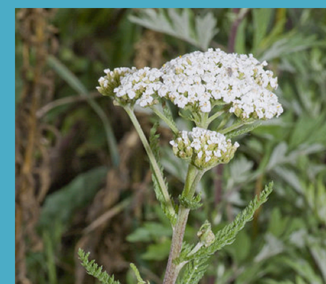
Whichever strategy was the most efficient at removing invasive species in phase one will be used to remove invasive species across the entire phase two experimental area. This time, instead of testing invasive species removal strategies, phase two will focus on the most efficient form of native plant seeding. The three test variables in this phase will be (1) broadcast seeding, (2) partially plugging fescue, and (3) completely plugging fescue.

1. Broadcast seeding: for this variable, all of the plants will be sown from seed (including Roemer's Fescue).
2. Partially plugging fescue: half of the Roemer's Fescue seeds will be grown as plugs for these plots. The other half of the grass seeds will be broadcast seeded along with the other plant varieties.
3. Completely plugging fescue: All of the Roemer's Fescue will be grown as plugs. The other plants will be broadcast seeded.

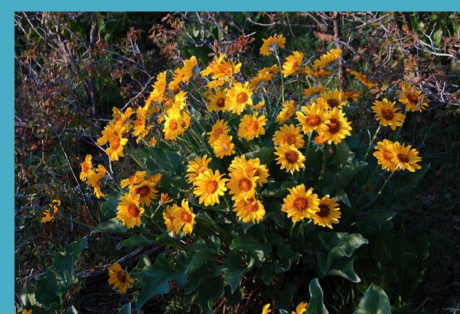
This experiment is focusing on the following question: does it make a noticeable difference when prairie grasses are broadcast seeded versus when they are transplanted as plugs? If phase two

Native Species Used in This Experiment:

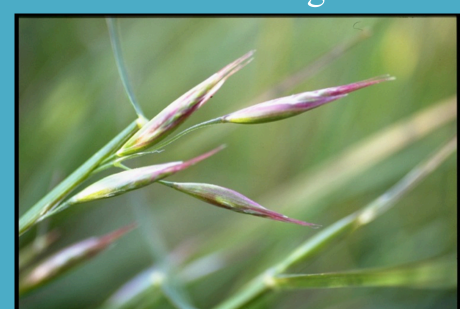
Common Yarrow



Arrowleaf Balsamroot

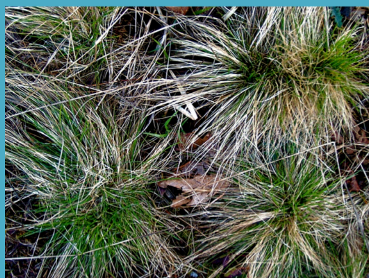


California Oatgrass

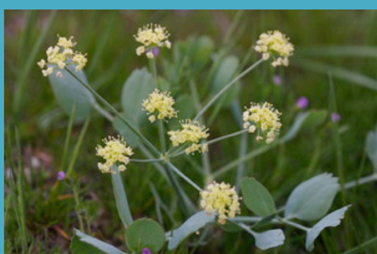


Oregon Sunshine

Roemer's Fescue



Barestem Biscuitroot



Common Lomatium

Seablush

Western Buttercup

shows that there is not a difference, this will make phase three much easier. If, however, plugging makes a difference, it would be beneficial in the long run for us to plant plugs of grasses throughout the entire Morken Meadow area.

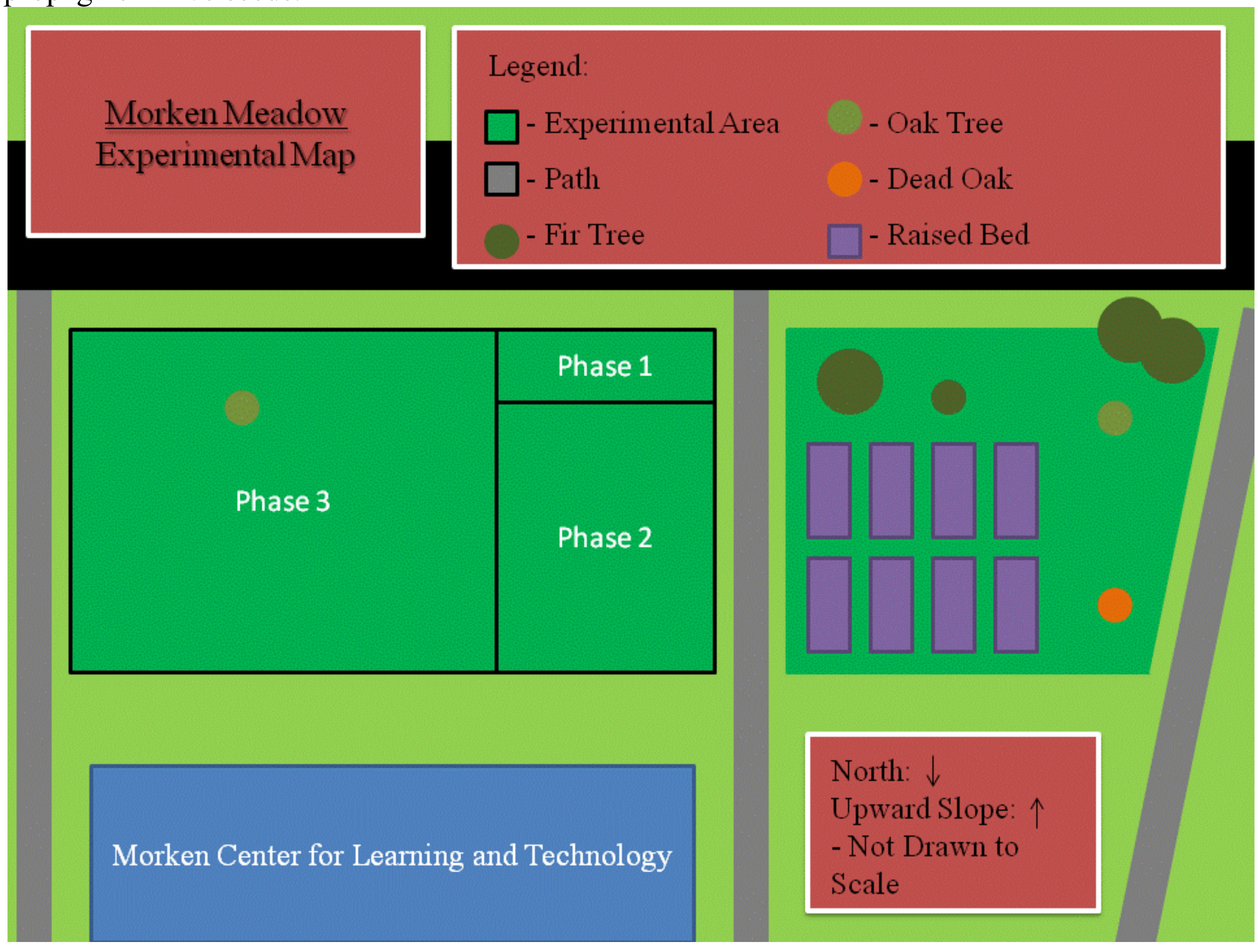
Phase two will also be split up into 12 areas, with each area being 15 ft^2. Instead of waiting one year to measure plant growth, like in phase one, in this phase we will wait for two years in order to give the plants enough time to establish themselves. Thus, plantings will occur during both years (Index 3). The success of each experimental variable will be determined using the same criteria as was used in phase one: number of native and non-native species present in each plot, percentage of native grass cover to native forb cover, and percentage of native plant cover to nonnative plant cover. Each of these variables will be measured by taking a 1–m^2 sampling quadrat measurement in a random part of each subplot.

Phase 3:

In this phase, the rest of the field will be restored. Depending on the results from the first two phases, this final restoration could occur in any number of different ways. I do not need to go into great detail about the methods of restoration in this area because they will be based on those used in phase one and two.

One specific note about this section is the prevalence of camas flowers. The distribution of camas flowers in this field is mostly in the phase three area (with a few in the phase two area and none in the phase one area). If the most successful invasive species removal strategy involves tilling the soil, this will not be good for the camas flowers. In this case, it might be beneficial to move the camas bulbs into another area, then transplant them back in along with the other native plants once invasive species have been removed. For this, I suggest that we make some raised beds in the smaller area adjacent to the main restoration site (southwest of Morken) (Figure 5). Raised beds would be beneficial for a number of different reasons. First, they would provide an area for native seed propagation. This is important for the Morken Meadow as well as for restoration on the golf course. Also, raised beds are much easier to weed than the ground where the camas flowers currently reside.

Figure 5. Raised Beds: Located adjacent to the Morken Meadow, raised beds could be used to propagate native seeds.



<u>Phase 4:</u>

Phase four is the long-term management phase. This phase begins for each experimental area at different times. For the phase 1 experimental area, this phase begins as soon as the experimental period is over. The same goes for the phase 2 and phase 3 areas. For the phase one area, this long-term management phase will start off with one more year of native plantings (Index 3). After that, the main job will be to maintain the native species abundance and make sure that invasive species do not take over. Because of the different invasive species removal strategies originally used in phase one, there may be some variation in invasive species cover in this area. Most of these invasives can be removed through hand-weeding, but if things start to get out of hand, a few measures can be taken. If invasive grasses start to come back, the best option is to use a grass specific herbicide (Sethoxydim). If invasive forbs are prevalent, spot weeding (with vinegar) or spot flaming (with a flame-weeder) can be used to remove them.

In the long-term, the successful creation of a prairie demonstration garden will depend on a few important factors: diligent removal of invasive species, addition of more native species, involving the community, and expanding educational components. All of these factors are essential for this to be a successful project. I will discuss each of these areas in detail, but first, I wish to raise another important argument. For a restoration project such as this to be successful, I believe that the deciding factor is not money, but time. Who will coordinate all of this? I believe that a full-time campus restoration ecology position could solve this problem. If there was a full-time restoration ecologist working at PLU, they could work with the sustainability department and with grounds to coordinate the various restoration projects on campus. The hillside and Fred Tobiason areas are a huge restoration undertaking as it is. When you start considering the Morken Meadow and the golf course, a full-time position begins to seem like a necessity. I do not know how this person will be hired or where the money will come from. Perhaps they could be a part time professor, teaching a restoration ecology class for biology and environmental studies students? Or, they could be a full-time restoration specialist. I am not sure about the bureaucratic matters related with creating a new campus job, but I have a good idea of what this person could do:

- Remove Invasive Species: In order to remove invasive species, the first step is to understand which species are invasive and which are native. Volunteers can be taught this, but they need a teacher. A restoration ecologist would be able to teach volunteers which plants to pull and which to leave. Also, they would be able to monitor the prairie and keep track of invasive species outbreaks. Thus, instead of waiting for invasive species to be prevalent before taking removal measures, invading plants could be removed before they are well-established. Because of the dynamic nature of prairie restoration, invasive species populations vary greatly from year to year. If a certain invasive plant became abundant one year, a restoration ecologist would be able to take more drastic measures (such as herbicide application). In this way, the presence of a restoration ecologist would help achieve the main goal of phase four: maintaining the long-term health of the prairie. According to the adaptive management strategy, continued monitoring and reevaluation of restoration measures is essential for long-term restoration success. A full-time position would help foster flexibility in response to environmental fluctuations.
- Propagate Native Species: When I visited the South Sound Prairies by Olympia (managed by the CNLM), I was amazed at the scale of their operations. Not only do they manage two very large prairies, but they also run two native-seed nurseries. At their nurseries, they have a full-time manager along with multiple full-time workers, interns, and help from weekly volunteer groups. Because of the degraded nature of most prairies in the WPG ecoregion, native seed propagation is an important facet of successful restoration. While we will be able to acquire seeds from local seed propagators (such as the CNLM), it would be beneficial in the long-term for PLU to set up its own seed propagation program for the following reasons: costs, genetics and diversity. First, buying all of our seeds would be expensive. Second, if we buy seeds from different parts of the WPG ecoregion, we will not be buying "native" seeds. They will be seeds from native plants, but due to regional differences in plant genetics, their genetic material will be slightly different in comparison to native plants in Pierce County. The best option for us would be to gather our own native seeds (on JBLM or other local prairies), propagate them in raised beds or green houses, then use the resulting seeds to repopulate our restoration sites. This would help with the third reason listed above: diversity. In this experiment, I followed along with the recommendations of Stanley *et al.* in planting nine different

commonly-available prairie plants (2). However, native prairies have a much higher diversity than. In the long run, our goal should be to increase the diversity of the demonstration garden. This is, of course, the dream scenario. Just like the previous category (invasive species removal), it is contingent upon having the necessary people power. Money is also an important consideration: would it cost more for us to acquire native seeds from local sources and plant them, or would it be cheaper to grow our own? If we were to grow our own seeds, we might require another full-time position to focus on native seed propagation. This factor would also impact the cost-benefit analysis. Nonetheless, whether a separate plant-propagation position is necessary or not, at least one full-time restoration ecologist position would be very helpful in terms of native seed acquisition and planting.

- Community Involvement: Volunteers are essential in successful restoration efforts. A full-time position could work to organize members of the Parkland community in restoration work-parties. This would be helpful both for invasive species removal as well as for plant propagation.
- Expanding Education: Signage is one way to educate people about prairies. A prospective student could walk up to the Morken Meadow some day and read a sign about the restoration project. The sign could help them to identify the camas or the Oregon sunshine growing in front of them. But, signs can only go so far. On the other hand, a full-time position could interact with visitors and lead tours of the prairie demonstration garden. They could invite students from local elementary schools to come learn about native prairies. They could work with PLU classes as well. The educational opportunities are numerous.

Current Strategies:

Because of the ambitious nature of this proposal, it will likely be some time before it can be fully-implemented. In the meantime, the main thing that we can do is to make sure that the invasive seed bank does not increase in size. The best way to do this is to mow the Morken Meadow before invasive plants go to seed. Thus, there are two main options. First, we could mow the Morken Meadow frequently, just like every other field on campus. In this way, the non-native plants would not go to seed. The other option would be to mow the meadow in the summer, fall and winter, but not in the spring. With this option, the camas flowers would be given time to grow and bloom.

Conclusion:

One of the first things that Rod Gilbert (the restoration ecologist for JBLM) said to me when we first met was, “You’re a brave one. Prairie restoration is about the hardest kind of restoration there is.” After all of my research, I have to agree with him. In order to be successful, we cannot underestimate the difficulty of prairie restoration. That being said, it is not impossible. If we wish to restore the Morken Meadow, we can do it. In order to do this, PLU will probably have to create a full-time restoration position, start a seed propagation program, and commit to a lengthy restoration process. Thus, this process will be costly in terms of time and money.

One may be inclined to ask the question: why does this matter? What is so important about prairie ecosystems? To answer this question, I turn to Aldo Leopold:

> The outstanding scientific discovery of the twentieth century is not television, or radio, but rather the complexity of the land organism. Only those who know the most about it can appreciate how little we know about it. The last word in ignorance is the man who says of an animal or plant: 'What good is it?' If the land mechanism as a whole is good, then every part is good, whether we understand it or not. If the biota, in the course of aeons, has built something we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first precaution of intelligent tinkering (29).

Even though Leopold wrote these words more than fifty years ago, his argument still rings true. Sustainability is not only about carbon dioxide or economics, but also about biodiversity. Biodiversity is the basis of ecosystem health, and ecosystem health is inextricably connected with life as we know it (30). If PLU truly wishes to become a sustainable institution, we must recognize and emphasize the important role that biodiversity plays in the world. Restoration of the Morken Meadow is a step in this direction.

<u>Index 1:</u> Invasive Species Removal Strategies

Herbicides: Out of all of the strategies listed above, use of herbicides has proven to be one of the most beneficial in removal of invasive species. The two most commonly used herbicides are glyphosate and sethoxydim (1,2). Glyphosate, the active ingredient in Roundup, is a broad spectrum
herbicide and one of the most commonly applied herbicides in the world (1,2,14).
Because of its ability to kill a wide range of
Because of its ability to kill a wide range of plants, it is often used in the initial phases of a restoration project to rid the area of invasive species. It has also shown positive results when applied after field burns (2). Many of the first plants to spring up after field burns are invasive (*Hypochaeris radicata*, *Leucanthemum vulgare*); therefore, an application of glyphosate closely following a field burn generally does more damage to invasive forbs than to native ones (2).

In terms of invasive grass removal, sethoxydim (the active ingredient in Poast) acts as a more selective, grass-specific herbicide (1,2). Fortunately for restoration practitioners, Poast does not affect the most common native grass (Roemer's fescue) and sedge (*Carex inops*) found in local prairies. Because of the resistance of these two species to Poast, many scientists have found it to be the most effective means of invasive grass removal, working more effectively than both glyphosate and controlled burns (7).

In weed removal, both herbicides excel. However, in the realm of toxicity their benefits begin to seem questionable. Many studies related to glyphosate state that it is relatively harmless to humans, with no lasting carcinogenic affects (14,15,19). Yet, even though glyphosate has been lauded as a non-toxic herbicide by Monsanto and the EPA, a growing pool of contrary evidence begs to differ. Many government tests focus specifically on glyphosate without including its common co-ingredients. For example, in Roundup, the most toxic ingredient appears not to be glyphosate, but to be its surfactant: polyoxyethylene amine (POEA) (16). When sprayed in or around water, this surfactant can have long-lasting harmful effects on aquatic flora and fauna, especially in the realm of microalgae and crustacean life (16). Some other recent studies have found increased rates of birth defects in people living close to agricultural fields sprayed with Roundup in Argentina (23). Because of the paucity of studies related to the inert ingredients in these herbicides, the full array of their negative health effects remains unknown.

Due to the uncertainties involved with these herbicides, many people have turned to more natural solutions. Although organic herbicides have not been used in prairie restoration, they are very common in organic agriculture. One common herbicide used by organic farmers is vinegar. Unlike household vinegar, farmers use 200-grain or 300-grain vinegar, which have much higher concentrations of acetic acid than the domestic variety (9). In an experiment where yucca extract was added as an adjuvant (at a concentration of 0.1% of the total liquid), vinegar was found to be effective against small weeds and ineffective against grasses (9).

Another example of an organic herbicide is Avenger Weed Killer. This substance is made from a citrus oil base, with the active ingredient being d-Limonene (10,11). This herbicide works by melting the waxy cuticle off the leaves of plants and dehydrating them (10). Like vinegar, this herbicide works best on younger plants. However, unlike vinegar, Avenger can work in cool temperatures (as low as 40^{o}F); vinegar needs the temperature to be at least 60^{o}F (10,11). Many other organic weed killers are currently available as well. One of the largest advantages of these herbicides is that they are made in organic ways. The main disadvantage is that they are new and have yet to receive much scientific testing beyond the necessary tests for their EPA certification.

Prescribed Fire: Unlike herbicides, fires were traditionally used by Native Americans to manage the prairies of the WPG ecoregion. The original usage of fire by natives served multiple objectives: clearing of land for hunting, burning of Douglas fir and big shrubs to maintain habitat for agricultural and medicinal prairie species (camas, bracken fern, chocolate lily, yarrow, etc.), clearing of underbrush to aid in acorn gathering in oak savannahs, and many more objectives (1). In modern prairies, prescribed fire is used mostly for its ability to remove invasive species and help with the propagation of native plants (1). In many restoration sites, thatch-forming grasses have taken over. Along with mosses and lichens, these plants form a dense mat of vegetation over the ground that imposes difficulties for the growth of native forbs. Fire can be used to remove thick thatch layers and clear up space for planting native species (1). In restoration, planting of native species is essential. It is easiest to plant plugs or seeds of native plants when the ground is clear, so understandably, fire can be very beneficial in this process (1).

Prescribed fire has shown some success when used in conjunction with herbicide application. In one test, the most effective form of invasive species removal was a regimen of biennial fire closely followed by glyphosate application (2). Another effective treatment added in an application of sethoxydim in the spring for the first two years of restoration (2). In this same study, fire was shown to have a negative effect on non-native forbs (particularly *Hypochaeris radicata* and Oxeye daisy), but a neutral effect on non-native grasses (2).

An important thing to consider is the time of application and the ecological goals involved. In the Pacific Northwest, the best time for controlled burns has proven to be in the late summer and early fall (from early August to mid-October) (1,8). Depending on the slope, direction of wind, moisture, weather, and fuel type, fires can have a variety of environmental effects (8). For example, when forcing a fire to go against the wind, called backing the fire, the rate of spread is very slow and the severity of the fire is high. This means that a large portion of the vegetation burns down to the ground. On the other hand, a head fire, one moving with the wind, will move much faster and will not decrease the vegetation with as much severity (8). All of these factors must be considered before adding fire into a restoration plan.

Mowing: Overall, the only way in which mowing was used as an effective conservation tool was in its control of large woody invasive plants, specifically Scotch Broom and Himalayan Blackberries (1). In terms of non-native grasses and forbs, both were found to increase under a mowing regimen (2). In some effective strategies, mowing was used as an initial treatment for restoration sites, but in long-term regimens, repeated mowing has been found to cause more problems than solutions.

Solarization: Solarization is the covering of a restoration site with clear plastic. This allows the heat of the sun to enter the plastic and become trapped like a greenhouse, heating up the ground enough to kill plants and diminish the viable seed bank (1). The solarization process is initiated by tilling the area and then inundating the soil in water (1,21,22). Water causes some of the seeds to germinate. Then, the water assists in killing those seedlings: in a previous experiment, researchers found that seedlings that are normally killed in dry soil at 70^{o}C were killed in wet soil at 50^{o}C (21). Once the restoration area is flooded, the plastic is spread out and the edges are buried under 20cm of soil (21).

One of the biggest issues with solarization historically has been its lack of related data and research. Due to the large size of many restoration sites, it is not economically or temporally feasible to apply enormous pieces of plastic over entire sites (20). That being said, it cannot be ruled out as an option for small restoration sites or places where use of herbicides is not allowed. In the experiments that have been completed, solarization has shown promising results. In one, solarization was more effective at creating bare ground than tilling, flaming, and herbicides, but unfortunately, the benefits only lasted for one year (19). In tests where the first year experimental plots were reduced (34% invasive cover) compared to controls (60%), by the second year, the percentage of invasive cover in experimental plots had returned to former levels (22). Another issue with solarization is the issue of plastic disposal. In very large restoration efforts, plastic eventually ends up in a garbage dump. One possible solution to this wastefulness is the use of biodegradable plastic covering, but this solution is not yet available in large enough quantities to be used for restoration purposes.

Mulching: With the word "mulching", I mean to group together black plastic mulching and sheet mulching in one category. While both of these strategies have rarely been applied in prairie restoration, I believe that they could be very helpful. Both are used to cover invasive species, smother those that are alive, and form a barrier to germination for those present in the seed bank. The first variety, using black plastic, is rather self explanatory. The plants in the field are either flattened or mowed, then plastic is put down, then wood chips are placed on top. The other variety is similar, but instead of black plastic, cardboard is used instead. For both of these strategies, overlapping the covering material is imperative (12). If there are any spaces in between, weeds will have an avenue of growth through the mulch.

Another thing to consider is clean-up. According to one of my acquaintances, black plastic is effective at killing weeds, but very hard to remove (12). After sitting for a year under wood chips, the plastic often deteriorates and falls apart. Trying to remove all of the plastic can prove to be an extremely difficult and ultimately impossible process. Because of the difficulties involved with black plastic, sheet mulching appears to be a superior option. Sheet mulching does not have to be removed because it is completely biodegradable.

Flame Weeder: Flame weeders come in a variety of shapes, sizes, and varieties with some using fire and others relying on infrared heat, steam, or turbulent air (20). These various weeders range from producing temperatures of 540^{o}C all the way up to 1090^{o}C in order to rupture plant cell walls. This form of fire is beneficial because it can be used in specific locations; if native species are particularly fragile one year, a flame weeder could be used instead of a prescribed burn to keep the weeds at bay. In organic agriculture, many farmers have turned to these weeders as a viable alternative to herbicides. Instead of applying herbicide following tilling, farmers can use these weeders to control any emerging weeds.

On the negative side, studies have shown that flame weeders are not as effective against large weeds, requiring numerous heat applications to finish the job (20). They have also been found to kill dicots more easily than grasses. Another study suggested that *Hypochaeris radictata* populations increase after flaming. Despite these drawbacks, flame weeding appears to be an effective, safe, and economical solution to weed control, especially when considered as a substitute to herbicides.

Reverse Fertilization: Due to the presence of many leguminous invasive species in the prairies of the Pacific Northwest, the historical carbon to nitrogen ratio has been disturbed. Prairie soils of the WPG ecoregion are historically rocky and nutrient poor, with low levels of nitrogen. Due to this current change in soil chemistry, some scientists hypothesized that a return to previous nitrogen levels could help native plants compete with invasives. Hence, reverse fertilization was tested (3,6,20). In this process, one must first choose an appropriate carbon source, then add it to the restoration site. Two of the most common carbon sources are wood shavings and sugar.

Scientists believe that addition of these materials helps feed the microbial community, which then pulls nitrogen out of the soil, depriving plants of an important nutrient source (3,6). Although this procedure has seen some success in the first years of research, any benefits accrued generally deteriorate in the following years, with some experiments showing marked increases in invasive species. These resurgences are thought to be associated with a collapse of the microbial community, returning both the nitrogen and the added carbon back into the soil.

Tilling: Tilling is a strategy often used by organic farmers to kill weeds and invasive plants. Tilling can be done with a tractor or a rototiller. This strategy kills the existing weeds while exposing other seeds for germination. One common strategy is to till repeatedly until weeds no longer sprout. Another strategy is to till once in the spring, and then every time that weeds come up after that, use herbicides to kill them off. The number of tills or frequency of herbicide applications will depend on the number of seeds in the seed bank (24,28).

Index 2: Current Species Diversity

In 2007, the Morken Center for Learning and Technology won an Honorable Mention award through the Education Design Showcase. On the Education Design Showcase website, Morken's "Sustainable Site" was described as thus: "A landscape of primarily native species allowed a significant portion of the site to be restored to the pre-existing oak savannah landscape. The native planted areas further the connection between this green building and its site, adjacent to one of the university's natural areas" (23). This sounds very nice, but where is the oak savannah? Where are the native plants? The area immediately adjacent to Morken is planted with natives plants (salal, Saskatoon, strawberry) but most of these plants are representative of local forests, not local prairies. In fact, if you look at the Morken Meadow, only a handful of the plant species are native. Here is a list of the species I have identified thus far:

Species List*:

Forbs:
- Ribwort/English Plantain (*Plantago lanceolata*)
- Yarrow (*Achillea millefolium*)
- Curly Dock (*Rumex crispus*)
- Common Tansy (*Tanacetum vulgare*)
- Sheep Sorrel (*Rumex acetosella*)
- Oxeye Daisy (*Leucanthemum vulgare*)
- White Clover (*Trifolium repens*)
- Curled Dock (*Rumex crisups*)
- Hairy Cat's-Ear (*Hypochaeris radicata*)
- Smooth Hawksbeard (*Crepis capillaries*)
- Some species of buttercup (meadow, western, creeping?)
- Common Camas (*Camassia quamash*)
- Black Medic (*Medicago lupulina*)

Grasses:
- Colonial Bentgrass (*Agrostis capillaris*)
- Common Velvet-grass (*Holcus lanatus*)
- Western Fescue or Barren Fescue
- Soft Brome (*Bromus hordeaceus*)
- Columbia Brome (*Bromus vulgaris*)
- Orchard Grass (*Dactylis glomerata*)
- Perennial ryegrass (either British or Italian)

Rush:
- Common Rush (*Juncus effusus*)

Trees:
- Garry Oak (*Quercus garryana*)
- Some variety of fir

Shrubs:
- Scotch Broom**

* Observation of plant species in the "Morken Meadow" began on the 20th of June, 2012 and has continued until the end of August 2012. Any plants that bloom before this period were not recorded. From discussing with others (specifically Dr. Haberle) about the plant community, it seems that a majority of the early-blooming plants are also invasive.

** A few Scotch Broom plants have sprouted up in the field throughout the summer, but they have not been a large problem. With frequent weeding, the plants are easy to manage.

Index 3: Native Seeding Rates

This table outlines the amount of native seeds added to subplots in the Stanley *et al.* experiment. These species were chosen for their relative abundance throughout the WPG eco-region, and therefore, for their general availability throughout the region.

Mass of Native Seeds Added per Subplot: the first year of planting occurs during the experimental period (of phase one and phase two) while the second year of planting occurs during the long-term management phase. For seeding for phase two, multiply each quantity by 1.5 to determine the amount of seeds necessary in each subplot. For phase three, divide the total remaining area up into 10 ft^2 subplots, and then plant the same amount as in phase one.
-Measured in $g\ m^{-2}$

Species	Common Name	Year One	Year Two
Achillea millefolium	common yarrow	.046	.056
Balsamorrhiza deltoidea	arrowleaf balsamroot	0	.845
Danthonia californica	California oatgrass	.627	1.117
Eriophyllum lanatum	Oregon sunshine	.061	.104
Festuca roemeri	Roemer's Fescue	.378	.378
Lomatium nudicaule	barestem biscuitroot	2.056	1.107
Lomatium utriculatum	common lomatium	.234	.1168
Plectritis congesta	seablush	.064	.064
Ranunculus occidentalis	western buttercup	.32	.35

Seed Acquisition:
Here is a list of local seed resources.

1. Rod Gilbert
    - JBLM prairie biologist (12).
    - Available Plants:
        - Roemer's Fescue: Last I talked with Rod, he said that he would donate some seed to our restoration efforts. I am not sure how long this invitation will last into the future or how much he would be able to donate. Whenever we end up contacting him, we should offer to buy the seeds.
    - Contact Info:
      roderick.c.gilbert.ctr@mail.mil
      360-918-1973
2. South Sound Prairies (13)
    - Available Plants:
        - At their two nurseries south of Olympia, the Center for Natural Land Management grows a variety of different native plant species. I am not exactly sure about the complete list of plant varieties, but they should have all of the plants we need for the phased-implementation experiment. I am not sure if they will be willing to sell seeds to us, but

when I volunteered with them last summer, they seemed open to the possibility.

- Contact Info:
  - Sierra Smith - Conservation Plant Nursery Manager
    ssmith@cnlm.org
    360-357-6280
  - Angela Winter – Native Plant Propagation
    awinter@cnlm.org
    360-464-0540

3. Fourth Corner Nurseries
   - Contact Info:
     5652 Sand Rd.
     Bellingham, WA 98226
     (360) 592-2250
     http://www.fourthcornernurseries.com/
4. Heritage Seedlings, Inc.
   - Contact Info:
     4194 71st Ave SE
     Salem, OR 97317-9208
     (503) 585-9835
     http://www.heritageseedlings.com/index.htm
5. Inside Passage
   - Contact Info:
     PO Box 639
     Port Townsend, WA 98368
     (360) 385-6114
     www.insidepassageseeds.com
6. Native Plant Salvage Alliance
   - Contact Info:
     http://www.ssstewardship.org/index.htm
7. Native Plant Salvage Foundation
   - Contact Info:
     4131 Mud Bay Rd W
     Olympia, WA 98502
     (360) 867-2166
     http://www.nativeplantsalvage.org/index.php
8. Native Seed Network
   - Contact Info:
     www.nativeseednetwork.org
9. Pacifica Restoration
   - Contact Info:
     4625 5th Ave. NW
     Olympia, WA 98502
     (360) 556-4271
     gonetoseed@gmail.com
10. Sound Native Plants

- Contact Info:
  PO Box 7505
  Olympia WA 98507
  (360) 352-4122
  www.soundnativeplants.com

11. Washington Native Plant Society
    - Contact Info
      List of nurseries:
      www.wnps.org/landscaping/nurserylist.html

Bibliography:

1. Apostol, Dean, and Marcia Sinclair. *Restoring the Pacific Northwest: The Art and Science of Ecological Restoration in Cascadia*. Washington, DC: Island Press, 2006. Print.
2. Stanley, Amanda G., Peter W. Dunwiddie, and Thomas N. Kaye. 2011. *Restoring Invaded Pacific Northwest Prairies: Management Recommendations from a Region-wide Experiment.* Northwest Science 85(2): 233.
3. Kirkpatrick, H. Elizabeth and Kaitlin C. Lubetkin. 2011. *Responses of Native and Introduced Species to Sucrose Addition in Puget Lowland Prairies*. Northwest Science 85(2): 255.
4. Dennehy, Casey, Edward R. Alverson, Hannah E. Anderson, David R. Clements, Rod Gilbert, and Thomas N. Kaye. 2011. *Management Strategies for Invasive Plants in Pacific Northwest Prairies, Savannas, and Oak Woodlands*. Northwest Science 85(2): 329.
5. Dunwiddie, Peter W., Jonathan D. Bakker. 2011. *The Future of Restoration and Management of Prairie-Oak Ecosystems in the Pacific Northwest.* Northwest Science 85(2): 83.
6. Mitchell, Rachel M., Jonathan D. Bakker. 2011. *Carbon Addition as a Technique for Controlling Exotic Species in Pacific Northwest Prairies*.
7. Dunn, Patrick. 1998. *Prairie Habitat Restoration and Maintenance on Fort Lewis and within the South Puget Sound Prairie Landscape*. The Nature Conservancy of Washington. From: http://w.southsoundprairies.org/documents/FtLewisFinalReport.pdf.
8. Hamman, Sarah T., Peter W. Dunwiddie, Jason L. Nuckols, and Mason McKinley. 2011. *Fire as a Restoration Tool in Pacific Northwest Prairies and Oak Woodlands: Challenges, Successes, and Future Directions*. Northwest Science 85(2): 317.
9. Evans, G. J., Bellinder, R. R.. 2009. *The Potential Use of Vinegar and a Clove Oil Herbicide for Weed Control in Sweet Corn, Potato, and Onion.* Weed Technology 23(1): 120-128. From: http://www.bioone.org/doi/abs/10.1614/WT-08-002.1.
10. Arbico Organics website: http://www.arbico-organics.com/product/Natures-Avenger-Organic-Herbicide/natural-organic-weed-control.
11. The Greenhouse Catalog website: http://www.greenhousecatalog.com/product/natures-avenger-organic-weed-killer/weed-control.
12. Interviews with Roderick Gilbert.
13. South Sound Prairie website: http://www.southsoundprairies.org/
14. De Roos, Anneclaire J., Aaron Blair, Jennifer A. Rusiecki, Jane A. Hoppin, Megan Svec, Mustafa Dosemeci, Dale P. Sandler, and Michael C. Alavanja. 2005. *Cancer Incidence among Glyphosate-Exposed Pesticide Applicators in the Agricultural Health Study*. Environmental Health Perspectives 113(1): 49-54. From: http://www.jstor.org.ezproxy.plu.edu/stable/3435746?&Search=yes&searchText=among&searchText=Glyphosate-exposed&searchText=incidence&searchText=Cancer&list=hide&searchUri=%2Faction%2FdoAdvancedSearch%3Fq0%3DCancer%2Bincidence%2Bamong%2BGlyphosate-exposed%26f0%3Dall%26c1%3DAND%26q1%3D%26f1%3Dall%26acc%3Don%26wc%3Don%26Search%3DSearch%26sd%3D%26ed%3D%26la%3D%26jo%3D&prevSearch=&item=1&ttl=7&returnArticleService=showFullText.

15. Williams, Gary M., Robert Kroes, and Ian C. Munro. 2000. *Safety Evaluation and Risk Assessment of the Herbicide Roundup and its Active Ingredient, Glyphosate, for Humans.* Regulatory Toxicology and Pharmacology 31: 117-165. From: http://www.ask-force.org/web/HerbizideTol/Williams-Safety-Evaluation-Glyphosate-2000.pdf.
16. Tsui, Martin T.K., L.M. Chu. 2003. *Aquatic toxicity of glyphosate-based formulations: comparison between different organisms and the effects of environmental factors*. Chemosphere 52: 1189-1197. From: http://144.206.159.178/FT/166/184176/4705802.pdf.
17. Goldburg, Rebecca J. 1992. *Environmental Concerns with the Development of Herbicide-Tolerant Plants.* Weed Technology 6: 647-652. From: http://www.jstor.org.ezproxy.plu.edu/stable/3987227?&Search=yes&searchText=sethoxydim&searchText=Environmental&searchText=Plants&searchText=Herbicide-Tolerant&searchText=concerns&list=hide&searchUri=%2Faction%2FdoBasicSearch%3FQuery%3D%2528Herbicide-Tolerant%2BPlants%2BEnvironmental%2Bconcerns%2Bsethoxydim%2529%26gw%3Djtx%26acc%3Don%26prq%3D%2528Herbicide-Tolerant%2BPlants%2BEnvironmental%2Bconcerns%2529%26Search%3DSearch%26hp%3D25%26wc%3Don&prevSearch=&item=1&ttl=9&returnArticleService=showFullText.
18. Sethoxydim. Extension Toxicology Network (EXTOXNET). From: http://extoxnet.orst.edu/pips/sethoxyd.htm.
19. Glyphosate General Fact Sheet. National Pesticide Information Center. 2010. From: http://npic.orst.edu/factsheets/glyphogen.pdf.
20. Stapleton, James J., Richard H. Molinar, Kris Lynn-Patterson, Stuart K. McFeeters, Anil Shrestha. 2005. *Soil solarization provides weed control for limited-resource and organic growers in warmer climates*. California Agriculture 59(2): 84-89. From: http://ucce.ucdavis.edu/files/repositoryfiles/ca5902p84-69187.pdf.
21. Horowitz, M., Regev, Y., Herzlinger, G. 1983. *Solarization for Weed Control*. Weed Science 31: 170-179.
22. Dennehy, C., Alverson, E.R., Anderson, H.E., Clements, D.R., Gilbert, R., Kaye, T.N. 2011. *Management Strategies for Invasive Plants in Pacific Northwest Prairies, Savannas, and Oak Woodlands.* Northwest Science 85: 329-351.
23. Education Design Showcase. http://www.educationdesignshowcase.com/view.esiml?pid=101
24. Burton, T., Weisz, R., York, A., Hamilton, M.. Organic Weed Management. North Carolina University Extension Service. http://www.organicgrains.ncsu.edu/pestmanagement/weedmanagement.htm
25. Noland, S., Carver, L. 2011. Prairie Landowner Guide for Western Washington. http://s3.media.squarespace.com/production/785585/9208254/Prairie-Landowner-Guide-Western-WA.pdf?AWSAccessKeyId=0ENGV10E9K9QDNSJ5C82&Signature=dk4guZpJhKP%2BPH64kcOIDhZB1YM%3D&Expires=1367953133
26. University of Washington Restoration Ecology Network (UW-REN). List of 2012-2013 Capstone Projects. http://depts.washington.edu/uwren/current.html
27. U of W Restoration Ecology Network RFP Form. Oak Prairie Restoration, Pierce College Fort Steilacoom. http://courses.washington.edu/ehuf462/RFPs_2009-10/pierce_oaks_RFP10.pdf

28. Prairies and Oak Savannas. Southeast Wisconsin Fox River Partnership Team. http://fyi.uwex.edu/southeastfox/files/2013/01/prairies.pdf
29. Leopold, A. 1949. A Sand County Almanac. Oxford University Press.
30. Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J. Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J. Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.A. 2009. A safe operating space for humanity. Nature 461: 472-475.