
Festuca roemerii Common Garden Study

FINAL REPORT
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This report is the result of a cooperative Challenge Cost Share project between the Institute for Applied Ecology (IAE) and the Bureau of Land Management. IAE is a non-profit organization dedicated to natural resource conservation, research, and education. Our aim is to provide a service to public and private agencies and individuals by developing and communicating information on ecosystems, species, and effective management strategies and by conducting research, monitoring, and experiments. IAE offers educational opportunities through 3-6 month internships.

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EXECUTIVE SUMMARY

- The *Festuca roemerii* common garden study investigated the genetic variability of Roemer's fescue across its geographic range in order to define seed transfer zones.
- Seed of *Festuca roemerii* from 47 wild populations was planted in a common garden at the NRCS Plant Materials Center, Corvallis, Oregon. Morphology, phenology, survival, and yield were monitored in this common environment over a three year period.
- Principal components analysis was used to detect structure in the data and relate the observed variation to environmental variables
- Genetic variation is driven by temperature and precipitation
- Variation is strongly correlated with elevation and latitude.
- We recommend that the Puget Lowland, Willamette Valley, and Klamath Mountains EPA Level III Ecoregions be used as 3 seed transfer zones for Roemer's fescue.
- Seed movement within these zones presents minimal risk of maladaptation
- The NRCS is preparing releases of Roemer's fescue for the Willamette Valley, Puget Lowland, and Siskiyou ecoregions.

BACKGROUND

The Common Garden Study

In 2001, Native Seed Network (NSN), the U.S. Department of Agriculture – Natural Resource Conservation Service (NRCS) and the Oregon Bureau of Land Management (BLM) combined forces to establish a common garden study of *Festuca roemerii*. Currently there is little commercial *Festuca roemerii* seed available in the marketplace. Suppliers are hesitant to grow this grass because restoration workers do not agree on the appropriate geographic boundaries of seed transfer zones.

Intraspecific variation has been noted in Roemer's fescue, but it is not known if this variation is due to phenotypic plasticity or underlying genetic differences. This study was designed to shed light on this issue. Seed from regional populations was planted into a single environment at the Corvallis Plant Materials Center. The goals of this study are to delineate the boundaries for transferring seed between source locations and project out-planting sites.

The Importance of *Festuca roemerii*: Key Component of Grasslands

The bunchgrass *Festuca roemerii* (Roemer's fescue) is a community dominant in the gravel outwash prairies of northwest Washington, grasslands of southern British Columbia and the Willamette Valley, coastal grasslands of Puget Sound, and the serpentine and pine savannas of southwest Oregon and northwest California. Before European settlement, Roemer's fescue grew in large interconnected populations North from British Columbia, throughout western Washington, Oregon and Northern California. Populations south of Douglas County, Oregon have been described as a distinct subtaxon, Klamath Roemer's fescue, *Festuca roemerii* var. *klamathensis* (Wilson 1999). Our study focuses on northern Roemer's Fescue because this taxon has the greatest restoration potential and cultivation demand in Oregon and Washington.

As a dominant matrix species of native grassland ecosystems, *Festuca roemerii* is highly desirable for restoration, rehabilitation and revegetation projects west of the Cascades from the Georgia Basin in the north and ranging as far south as San Francisco Bay. This deep-rooted perennial stress-tolerator (*sensu* Grime 1977) has significant erosion control properties and xeriscape capacity.

Taxonomic Difficulties

Festuca roemerii has been beset by identification difficulties and taxonomic confusion. Initially, populations in Washington and northwest Oregon had been misunderstood as *Festuca idahoensis* Elmer populations. Roemer's fescue was first described as a variety of *F. idahoensis* (Pavlick 1983). Most commonly, Roemer's fescue is confused with Red fescue (*Festuca rubra* L.) Red fescue is a morphologically similar but phylogenetically distinct grass. Therefore, *Festuca rubra* was long accepted as the dominant native grass of upland grasslands of Oregon and Washington (Franklin & Dyrness 1973).

The taxonomic difficulties surrounding the fine-leaved fescues of the Western Valleys are extraordinary. The conspecific grasses of southwest Oregon and northwest

California have been variously identified as *F. idahoensis* Elmer, *F. ovina* L., *F. idahoensis* X *F. occidentalis* Hook. hybrids, *F. idahoensis* var. *oregona* (Hack.) C. L. Hitchc., and often *F. rubra* L. Many authors simply reported *Festuca* sp. (Atzet unpubl. data, Copeland 1978, Frenkel & Kiilsgaard 1984, herbarium specimens). The recognition of *Festuca roemerii* as a taxonomically separate entity occurred first when Pavlick (1983) described it as a variety of *F. idahoensis*, and 2 years later its status was elevated to that of a distinct species (Alexeev 1985). *Festuca roemerii* is now described as consisting of two subtaxa: the true species *F. roemerii* var. *roemerii* to the north of Douglas County, Oregon, and the variety *klamathensis* to the south (Wilson 1999).

Presently ITIS, the Integrated Taxonomic Information System, recognizes *Festuca roemerii* (Pavlick) Alexeev as an accepted taxon, with *Festuca idahoensis* var. *roemerii* Pavlick as a synonym. The USDA PLANTS Database, however, recognizes Roemer's fescue as a subspecies of Idaho fescue (*Festuca idahoensis* Elmer ssp. *roemerii* (Pavlick) S. Aiken). Recognized by USDA PLANTS as synonyms are *Festuca roemerii* (Pavlick) Alexeev and *Festuca idahoensis* Elmer var. *roemerii* Pavlick.

Distinction Between Varieties of *Festuca roemerii*

Northern Roemer's fescue (*F. roemerii* var. *roemerii*) has few, short hairs on the inner (adaxial) leaf surface and has a characteristic pattern of malate dehydrogenase (MDH) isozymes. Its range extends from British Columbia through western Washington and northwest Oregon south to the Douglas/Jackson County line (2002 unpubl. report to Bureau of Land Management Roseburg District) and south along the coast as far as San Francisco. Klamath Roemer's Fescue (*F. roemerii* var. *klamathensis* B. L. Wilson ined.) grows in southwestern Oregon and northwestern California, between the ranges of *F. roemerii* var. *roemerii* and *F. idahoensis*, except along the coastline where it is absent. Its many long hairs on the inner leaf surface and MDH isozyme pattern resembled *F. idahoensis*, but the phenotypic plasticity of its leaf shape resembled *F. roemerii* var. *roemerii*. Both varieties occur on serpentine as well as non-serpentine substrates. Our current study concentrates on northern *F. roemerii* var. *roemerii*, however, four populations of *F. roemerii* var. *klamathensis* are included for balance in the experimental design.

Once *F. roemerii* could be named and identified, its importance in native plant communities was quickly recognized (Wilson 1997). *Festuca roemerii* var. *roemerii* population groups are united by similar habitats and/or geographic location. Included in this study are populations from Puget Sound, Olympia, the southern Willamette Valley, high elevation sites in the Coast Range, the foothills of the Cascade Range, and coastal sites (Figure 1). With increasing knowledge about the taxonomy and range of *Festuca roemerii*, potential barriers to appropriate seed transfer became apparent. This study was designed to address those questions concerning genetic uniformity or dissimilarity between populations.

METHODS

Study Design

The USDA's Plant Material Center in Corvallis, Oregon, was chosen as the site for the *Festuca roemerii* common garden. This site is located within the approximate center of a cluster of small remnant populations. Also, the issue of *F. roemerii* seed transfer is more

critical in Oregon than in northwestern Washington. In Washington, the relatively large remnant prairies provide potentially adequate sources of local seed. In Oregon, prairie remnants are small and more likely to suffer from inbreeding depression. Also, *F. roemerii* often grows in mixed populations with introduced *F. rubra*, making it difficult to collect pure seed (Wilson 1997). Therefore, the demand for *F. roemerii* seed in Oregon could be filled by transferring seed from northwestern Washington more easily than the demand for seed in Washington could be filled with seed from Oregon.

Collected seed also provides important data for describing the genealogy of *Festuca roemerii*. Lemma and awn length, for example, have been identified as two morphological traits valuable for comparisons of fescues. Seed has been processed and weighed to determine variability between populations. Yield data not only helps us understand differences between populations, but is also useful information in planning for production of *Festuca roemerii* seed on a commercial scale.

Seed Collection

Festuca roemerii seed was collected from 54 populations during 2001 and 2002. Seed collection was extended over a second seed season because 2001 was a drought year and many *F. roemerii* populations set little or no seed. Latitude, longitude, and elevation were documented for all seed collection sites.

Seed from individual plants was collected and kept separately in coin envelopes. This seed represents half-sib plants, with a common mother plant and unknown pollen source. More than 30 seeds were collected from at least 8 mother plants at each population.

Because *Festuca roemerii* is easily confused with *F. rubra*, sample identification was checked by cutting leaf cross sections from the central third of a leaf from at least one of every five families collected, plus other samples which deviated from expected *F. roemerii* morphology. Leaf cross sections were drawn freehand and stored as a record of identification. Leaves will be stored at the Institute for Applied Ecology until the end of the study.

Seed Sorting

Lemmas with filled seed were sorted from empty lemmas by hand using a light box. Lemmas were considered to contain filled seed if the seeds were opaque and stiff. Most filled seeds were also somewhat plump.

Samples from the Drano Lake, Duncan Spring, Edgewood-Weed Road, Glacial Heritage Park, San Bruno Mountain, and Skinner Butte populations became severely infested with the fungus *Aspergillus*. One week before planting (Dec. 8 & 9), these seeds were soaked in 1.5% sodium hypochlorite solution for 20 [to 50] minutes, then rinsed with distilled water and air dried. (200 ml 6% sodium hypochlorite solution (bleach) + 600 ml H₂O.)

Sowing

Seeds from 47 of the 54 *Festuca roemerii* populations sampled were sufficiently mature for inclusion in the study (Figure 1). Eight families per population were used (except where fewer were available, such as Abiqua Road, Memaloose Park, and Glacial Heritage Park; see Table 1). The study design included 8 individuals for each family. When sufficient seed was available, we planted three seeds in each of twelve tube

containers for each family. When fewer than 36 seeds were available for a family, the number of seeds/container was adjusted downward, to a minimum of 1 seed in each of eight containers. A total of 4534 containers were sown with 12889 seeds.

Seeds were planted December 16 and 17, 2002 at the USDA-NRCS Corvallis Plant Materials Center. Flats were watered Dec. 17 and stored at 3°C in the dark until January 6, 2003, when they were placed in the greenhouse. The greenhouse was set with a 14 hour day-length. Daytime temperatures were 21°C (70°F) and nighttime temperatures were 18°C (65°F).

Thinning

In order to assure a sufficient number of plants would develop to be planted into the garden, multiple seeds were sown into each container. We did not wish for complications to arise from the presence of more than one individual in the same container, such as competition. To prevent bias in our selection for any particular trait, such as the biggest or earliest-emerging individual, excess seedlings were systematically removed based on their position relative to a marking made on the side of each container, leaving a single individual in each container.

After ten weeks in the greenhouse, plants were moved to a shade house for several weeks to harden off before being planted in the field.

Field Preparation and Planting

Plugs of *Festuca roemerii* were planted into a fallow field. A standard regimen of herbicide application was implemented to eliminate the existing seed bank. The field was then covered with three inches of bark mulch to aid in weed suppression. Slow-release fertilizer (Osmocote) was measured into each hole prior to planting each *F. roemerii* plug. Planting occurred over five days from May 8 to May 12, 2003. In total, 3009 plugs were planted into the common garden. Of these, 2767 were plants under study and 242 were planted as a border row to provide a buffer against edge effects.

Field Maintenance

The field was irrigated approximately once each month in 2003 to help the plants establish during the first summer. Fungicide was applied periodically to prevent rust infection from severely inhibiting plant growth in 2003 and 2004. In 2005 no fungicide was applied in order to assess the vulnerability of the plants to fungi.

The field was routinely inspected and weeds were controlled periodically as needed throughout the term of the study. All weed control was done by hand.

Data Collection

For a summary of all data collected, see table 2.

Germination & Early Growth

The greenhouse was checked daily for germination. Emergence date was recorded for each seedling. This required inspecting all 4534 containers for newly-emerged cotyledons every day over several weeks.

Albino seedlings were noted and recorded. Rate of albinism may be an indicator of population health. Albinos indicate a lack of reproductive success and possibly negative consequences of inbreeding.

Morphological Data

Before out-planting to the field, early growth measurements were taken. The length of the third-longest leaf and the width of the young plants were measured and recorded.

Plants in the common garden were evaluated again between July 28th and August 1st, 2003. This occurred 29 weeks after the seed began to emerge, and near the end of the first full growing season. In order to measure plant growth, the leaf length and crown diameter were measured. Plants were rated for the color of their foliage, which ranged between yellow-green and deep blue. Despite the application of fungicide, some plants showed signs of rust infection. These were noted, as well as plants with senescent foliage, indicating dormancy. Record was made of those plants that did not survive past this period.

In June 2004 plants were again measured for their size and scored for their production of leaves and culms. The width of the crown was measured to the nearest centimeter, as was the length of the longest (tallest) culm. Early June was selected because plant growth was essentially complete for the season, and culms had attained their natural maximum length. Estimates of leaf and culm abundance were also recorded at this time. These were relative measures, scored on a scale of one to ten.

In June 2005 the plants were assessed for the abundance of the foliar fungal pathogen *Puccinia*. Leaf and culm abundance were again recorded.

Phenological Data

From March to November, 2004, all plants were evaluated for their stage of growth. Each plant was scored according to the scale in table 3. Between March and August, the plot was monitored weekly. In August, after plants had reached seed maturity, sampling frequency was reduced to every two weeks. Biweekly sampling continued into the fall to monitor plant dormancy.

Seed Data

Seed was harvested selectively on a plant by plant basis at the optimal time to maximize the amount of seed collected from each plant. As plants demonstrated considerable variability, seed ripening was asynchronous throughout the plot. There is a narrow window in which the seed is mature enough to harvest but not yet so ripe that it shatters and is lost on the ground. Considerable care was taken to harvest each plant at this critical time. Having such a diverse planting as the common garden required frequent monitoring and harvesting on a plant-by-plant basis over a seven week period.

From June 3 until July 20, 2004 (typically every Monday, Wednesday, and Friday), a team of workers walked through the field and identified plants with mature seed. Seed from each plant was harvested and placed in labeled paper bags. These bags were stored in the greenhouse at the Plant Materials Center for several days until the seed moisture was low enough to ensure safe preservation.

Florets were extracted from each bag of harvested seed and retained for floret and seed morphological analyses. Later in 2004, measurements of the following were taken on three randomly-selected individuals per family: lemma length, awn length, palea length, upper and lower glume lengths, distance between the lowest branches of the

inflorescence, and total inflorescence length. Seed was bulked and weighed for all individuals from the same family.

Data Analysis

All data were entered into Excel spreadsheets, managed in an Access database, and analyzed by SAS statistical software. A summary of traits measured is presented in table 3. In addition to the traits measured in the common garden, several other pieces of information were critical to the analysis. These include the latitude, longitude, and elevation of the source populations, and climatic data corresponding to those source locations.

Pair-wise correlations were performed to check variables for redundancy. Univariate correlations of all variables with latitude, longitude, and elevation of the source locations were also conducted. Principal components analysis (PCA) was used to reduce the numerous measured traits to fewer traits which represent combinations of all traits. PCA was performed on three subsets of the data: (1) morphological and phenological traits for all populations; (2) morphological, phenological, and fitness data for all populations; and (3) populations from the Willamette Valley, Oregon. Correlations of principal component axes with measured variables were evaluated, as were correlations with latitude, longitude, and elevation. Regressions of principal components with climate variables were performed to assess the strength of these associations and gain insight into what mechanisms may be influencing the observed variation. We examined scatterplots of principal components to look for clustering of populations and determine groupings that are similar or dissimilar. Groupings detected by PCA were plotted on latitude-longitude coordinate axes to assess geographic patterns of the genetic data.

RESULTS

Seedling germination trends did not show significant variation. Most seed emerged uniformly and rapidly after the seeds were brought into a favorable environment. Late-emerging seed may have been planted deeper, and therefore required more time for the germinants to become visible. Seedling emergence peaked on January 10th, four days after flats were brought into the greenhouse (Figure 2). Rates of albinism varied widely between populations. Table 4 displays summarized emergence and albino data for ecological groupings of populations in the common garden study.

Survival rates overall in the common garden were very high, until early 2006 (Figure 3). Of the 2767 specimens planted, only 17 were lost during the first year. Curiously the four populations that fared the worst were all Willamette Valley source. In the summer of 2004, over 95% of plants were still growing, and by 2005 nearly 75% remained. Population survival rates in 2005 ranged from a low of 29% (Hurricane Ridge, Olympic National Park) to a high of 98% (Cummins Creek Trail, coastal Oregon). During the winter of 2006 the common garden plot experienced severe flooding and the plants were inundated continuously for several weeks. Only 181 plants (6.5%) survived these conditions. Those populations that had the highest survival rates were from the Oregon coast and the Olympia region (11%). Again, Willamette Valley populations demonstrated that the most local seed sources aren't always the best adapted – they had the lowest survival rate of all groups in the garden (2.3%).

Growth measurements of plants in the common garden show population level differences. Plant height and width were correlated with latitude and elevation, particularly in 2003, their first year of growth. High elevation and high latitude plants were more compact, with shorter leaves and wider crowns. Plants from lower elevations and latitudes were variable, but generally longer-leaved and with narrower crowns. In 2004 culm length was measured on those plants that flowered. This data mirrored the plant height (i.e. leaf length) data, as plants from higher elevations had shorter culms than plants from low elevations. No significant correlations or trends were found for foliage in year 2004 or 2005; tiller abundance was correlated with latitude in 2004 (Table 7).

The phenological status of each plant was recorded at regular intervals from March 9 to November 9, 2004. We were surprised to see certain plants beginning to flower as early as March, and others continued flowering into June. The earliest flowering specimens were from the inland populations of Jackson County, Oregon. Seed harvest began June 3, 2004 and continued regularly until July 20, 2004 (Figure 4). Seeds matured over a longer window of time than we had anticipated. The peak harvest date for the entire garden was June 18. Within the garden, however, different ecological groupings of the plants matured at different times (Table 5). The average seed maturity dates for each ecological grouping were unexpected. Other studies have found latitudinal and elevational clines in phenology, but our data do not reflect this trend.

Anthesis and seed shatter were both significantly correlated with latitude and elevation; linear regression of these traits shows that both occur earlier in higher elevation populations, at a rate of 1.6 days per 1000' elevation (anthesis) and 0.9 days per 1000' elevation (seed shatter). Inland populations matured first, followed by high elevation sites. Willamette Valley and Puget Sound populations matured about the same time, approximately one week after the high elevation populations; plants from the Columbia Gorge were the last to mature.

We continued to monitor and rate the phenological status of the plants throughout the summer and fall, as each week we observed changes in the plants and wanted to capture the differences in the duration of their greenness and when they became dormant. Nearly every population was composed of a combination of plants that in 2004: did not flower (7%); set seed and proceeded to go dormant (15%); and set seed but did not go dormant (78%). The Cummins Creek Trail population (from the coast of Lincoln County, Oregon) was unique in that every plant flowered and set seed, but none became dormant.

Foliage color showed a high level of heritability with significant family and population differences, but the trait was not correlated with latitude, longitude, or elevation. Higher elevation populations did have a higher tendency to be blue (glaucous), but mid- and low-elevation plants displayed the full range of leaf color, from blue to green.

We expected many plants would contract rust infections over the course of the study. Rust (*Puccinia* spp.) is a fungal pathogen common to grasses in western Oregon and is known to occur on Roemer's fescue. Rust susceptibility may be an important consideration in recommending seed sources as it is a controlling factor in plant establishment and plant health in restoration settings. We monitored infection rates in the garden periodically throughout the growing season. Fungicides were applied as warranted during 2003 and 2004 in order to aid plant establishment and growth. Despite

this, in 2003 when fungicides were being applied, many plants were infected nonetheless, yielding useful information about susceptibility (Figure 5).

Rust infection rates (2003) were correlated with latitude and highly associated with summer precipitation. Rates were low on southern and northern populations, and highly variable on middle latitudes (44-45 degrees North). Rust incidence was highest on populations from areas of lower summer precipitation. It is possible that populations from wetter sites have had more exposure to rust and have increased resistance. It is also noted that populations most vulnerable to rust were those from the same latitudes as the common garden plot (44-45 degrees north). It is possible that populations from farther away are less susceptible to our local strains of rust.

For the 2005 growing season we stopped all applications of fungicide to assess the vulnerability of the plants. 2005 was an unusual year, however, as the plants did not become visibly infected with rust. The uniformly low infection rates provided us with no additional information about the relative susceptibility of garden specimens to rust infection.

The first run of principal components analysis was based on physical traits and seasonal growth of all populations. The first three principal components (PCs) accounted for 70 percent of the total variation (PC1 – 29.0%, PC2 – 22.5%, PC3 – 18.5%). These three principal components were analyzed in more detail. Plant width, tiller abundance, date of anthesis, late March phenological score, and form (height to width ratio) were strongly associated with PC1. PC2 is highly correlated with height, form and shatter date. PC3 was strongly correlated with height, foliage abundance, and anthesis date (Table 6).

Latitude, longitude and elevation of the seed sources were used to evaluate geographic patterns of the data. Many traits had significant correlations with latitude and elevation, in particular (Table 7). All three principal components had significant correlations with elevation, demonstrating its profound influence (Table 8). A linear regression model was created to estimate the impact of latitude, longitude, and elevation on the PC values (Figure 6). Very little of the variation in PC1 was explained by the simple model (17%), but 40% of the variation in PC2 and PC3 was explained.

Using climatic data we were able to increase the amount of variation in the data explained by the models (r-squares); the best 4-variable models yielded r-squares of 0.50 for PC1, 0.64 for PC2, and 0.70 for PC3. PC1 was driven mostly by late summer temperatures. The best 4-variable model included latitude, August minimum and maximum temperatures, and spring frost date. PC2 was driven mostly by precipitation, with some winter temperature influence; the best 4-variable model included May and July precipitation, and February and December maximum temperatures. PC3 was driven by cold, as winter temperatures and spring and fall frost dates were important. The best 4-variable model explaining PC3 included April and August minimum temperatures, spring frost date, and June precipitation.

We then examined the scatter plots of the three principal components and found what appeared to be 4 clusters in the plot of PC2 by PC3 (Figure 7). The “A” clusters only included high elevation sources. When the clusters were plotted on latitude and longitude coordinates (Figure 8), it became evident that the “B” clusters are predominately in Oregon and the “C” clusters in Washington. The few “B” populations in Washington were low elevation sources and the “C” populations in Oregon were higher

elevation sources. The fourth cluster, “D,” represents many of the southern populations except those from the highest elevations.

To quantify the impact of elevation we looked at the regressions of latitude, longitude, and elevation on the principal components. A change of 1,000 feet elevation altered the PCs by 4.0, 2.4 and 5.7 units. Thus moving 1,000 feet will change the population mean 0.36, 0.31 and 0.75 genetic units, where these are expressed in units of within-population genetic standard deviation units.

Principal components analysis was also performed on the entire set of data collected, including the fitness measures of survival and yield in the common garden. This analysis did not aggregate the populations into clearly discernable groupings. The groupings detected in the prior analysis based on phenological and morphological traits were less evident.

Similarly, PCA was conducted on a geographic subset of the data, looking only at populations from the Willamette Valley. No clustering was evident in this analysis and there were no correlations with latitude, longitude, or elevation.

Based on the data, we have delineated three low elevation seed zones for Oregon and Washington: Puget Sound region, the Willamette Valley and surrounding mountain ranges up to 2000 feet elevation, and the Klamath Mountains.

DISCUSSION

The Roemer's fescue Common Garden looked spectacular. The amount of variation was stunning. Since the plants were arranged randomly in the field, it was not easy to recognize patterns of plant characteristics. Had the plants been arranged by their family and source population, however, it would have largely given the same impression. Much of the variation observed was present within each population and even within many families.

The data collected allowed us to understand a great deal about the intraspecific variation observed in *Festuca roemerii*. Morphological and phenological traits are genetically variable among our study populations and were especially useful in detecting and describing patterns. The variation among populations was strongly associated with elevation and latitude, and only weakly related to longitude.

Genetic variation between populations corresponds to geographic position when considered at the regional scale. Including populations from diverse elevations and latitudes allows us to detect this structure. Restricting our analysis to a limited geographic area with a more uniform environment such as the Willamette Valley or Puget Lowland, we no longer detect interpretable patterns in the genetic variation. Phenotypic patterns were strongest at the regional scale, indicating that genetic variation is also organized at a broader scale.

The most obvious cluster to emerge from our analyses is the high elevation populations. Despite the considerable difference in latitude, all of the highest elevation populations cluster together. High elevation plants have many traits in common with each other and

are different from plants studied that came from lower elevation. The high elevation populations were differentiated from the others along the axis of principal component 3, which is strongly driven by cold (winter minimum temperatures and spring and fall frost dates). Not surprisingly, these variables are highly correlated with elevation. In general high elevation plants tend to be wider and shorter than low elevation plants, which include narrower and taller specimens in addition to the more compact form. The magnitude of these differences is not that great, but the large number of plants measured allowed us to detect significant differences. Similarly, plants from high elevation tend to be more glaucous and therefore bluish in color than their low elevation counterparts. Low elevation populations contain a mixture of bluish plants and also greener, non-glaucous specimens.

Also evident in the plot of PC2 by PC3 is the cluster of populations labeled “B.” The geographic plot of cluster B populations shows that these are nearly all from the Puget Sound region. The nine populations from the Olympia, Washington area showed a high degree of similarity to each other and a small amount of difference from Willamette Valley populations. The Willamette Valley and Puget Sound clusters are divergent along PC2, which is strongly influenced by summer precipitation and winter maximum temperature. While the Puget Sound area and the Willamette Valley both enjoy mild winters and dry summers, the Willamette Valley has somewhat warmer winters and receives less summer rainfall (figures 9a and 9b).

There is also a difference in land use history between Olympia area populations and Willamette Valley populations that may be impacting their genetic makeup. Each of the Olympia area populations is relatively large, consisting of several thousand individuals, and has been intact for centuries. Presumably gene flow has been high enough within each population, and perhaps among populations, to maintain plants that are relatively uniform in size, shape, color, phenology, and yield.

Populations from the Willamette Valley and surrounding foothills showed much higher variance than the Olympia populations. These populations are much smaller than those found in the Puget Trough, and have been small and isolated for approximately 150 years, since the native prairies of the region were converted to agricultural use. Extant Willamette Valley populations are found on balds, bluffs, and other sites with thin soils that were not suitable cropland and escaped the plow.

When we restrict our analysis to the subset of populations from the Willamette Valley, the significant relationships disappear. While considerable genetic variability exists within Willamette Valley populations, it is not correlated with geographic and climatic variables. Lacking an apparent meaningful pattern to the variability among Willamette Valley populations, we propose that the population differences observed among this group are due to founder effects. Seed yield for these populations is variable but generally low, which may be a result of inbreeding depression in this highly outcrossing species.

Although less obvious, there appears to be segregation of two clusters along PC3, labeled “C,” and “D.” Just as the high elevation populations were distinct from all others, the Klamath populations are largely distinct from the Willamette Valley populations. The more southern populations are sufficiently different in their temperature and precipitation.

Physical traits indicate that there is genetic variation in plant form and seasonal growth that meaningfully corresponds to geographic location. PCA of all traits, including survival and yield, was less descriptive than analysis of the morphology and phenology data. Addition of these fitness-related traits made the patterns less clear. These measures indicate that some plants were more fit than others in the common garden, but their inclusion in the analysis did not enhance our understanding of how the genetic data is structured.

Most of the genetic variation measured in the common garden is well explained by differences in elevation and latitude; elevation is particularly significant. Important factors related to these variables include end of summer temperatures, frost dates, and annual precipitation. We recommend restricting seed movement based on these factors. Our findings agree well with the EPA Level III Ecoregions and other classification schemes such as cold hardiness zones. The Willamette Valley and Klamath Mountains ecoregions are different enough that we do not recommend moving seed between them. We find movement of seed within each of these regions to be genetically appropriate. While the Willamette Valley and Puget Lowland are quite similar in many regards, we recommend the development and use of distinct germplasms for each area.

In 2006 the Natural Resources Conservation Service – Corvallis Plant Materials Center (PMC) began establishing seed increase blocks for Roemer's fescue. The intent of the PMC is to provide genetically diverse but ecologically appropriate germplasm. Utilizing information derived from this study, separate blocks were initiated for a Puget Sound germplasm, San Juan Islands germplasm, Willamette Valley germplasm, Siskiyou germplasm, and a Coastal germplasm. Each of these composites will be released as a natural-track, selected class germplasm. Factors of importance to the PMC in selecting populations for each selection include the flower date (will the various collections cross-pollinate?); seed production (will the plants produce a crop?); plant size and health (will the plants be vigorous and survive?); and stock seed availability (is enough seed available to start now, or do we need to re-collect?). Each increase block is planted in a Latin square design to maximize cross-pollination and will be used to produce genetically diverse germplasm. Crossing blocks have been established in various locations at the Corvallis Plant Materials Center, maintaining at least a 900 feet isolation distance between each block. Blocks are isolated to protect their genetic integrity by minimizing pollination between blocks for this out-crossing species.

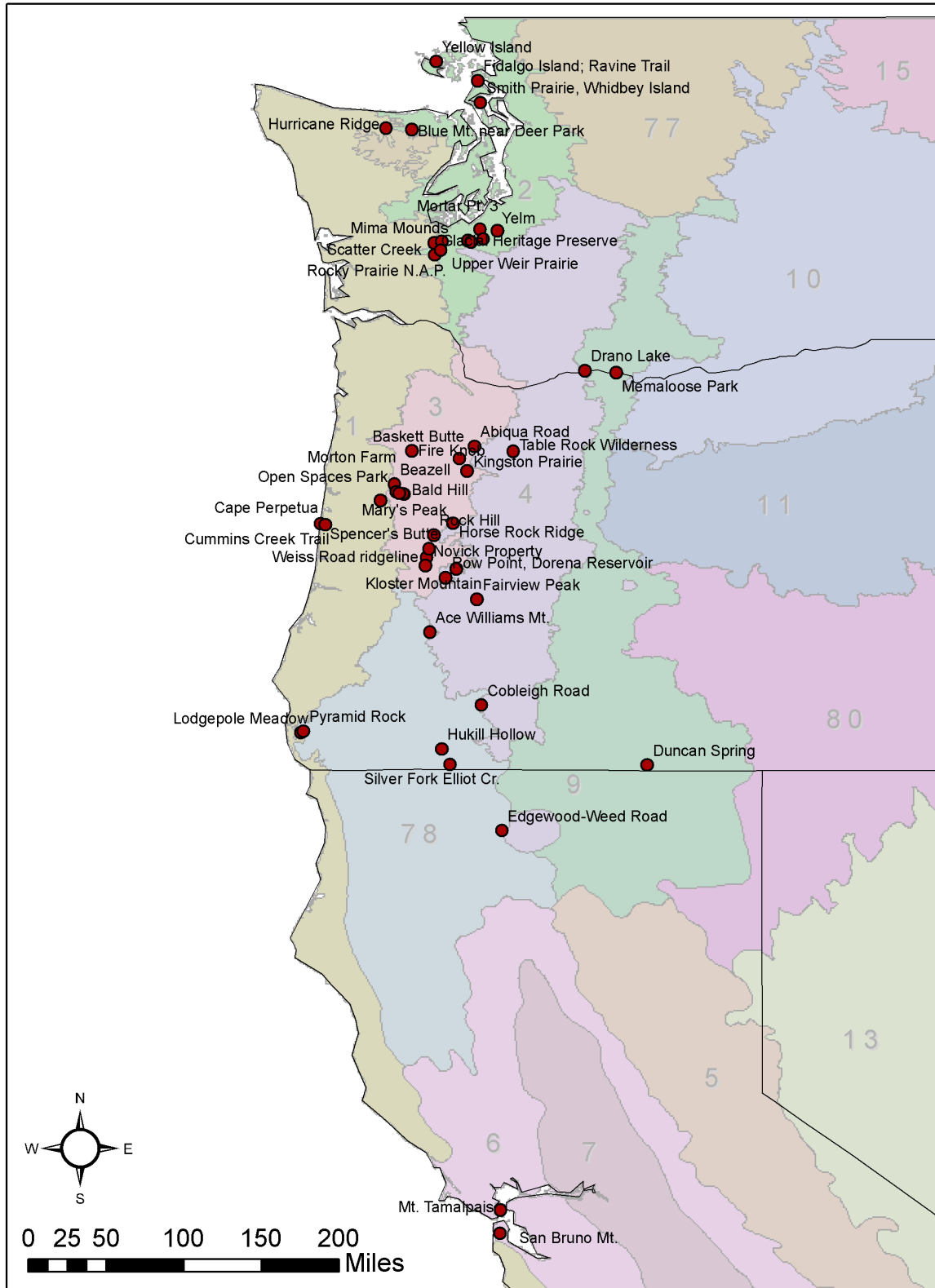


Figure 1. Populations represented in the Roemer's Fescue Common Garden Study.

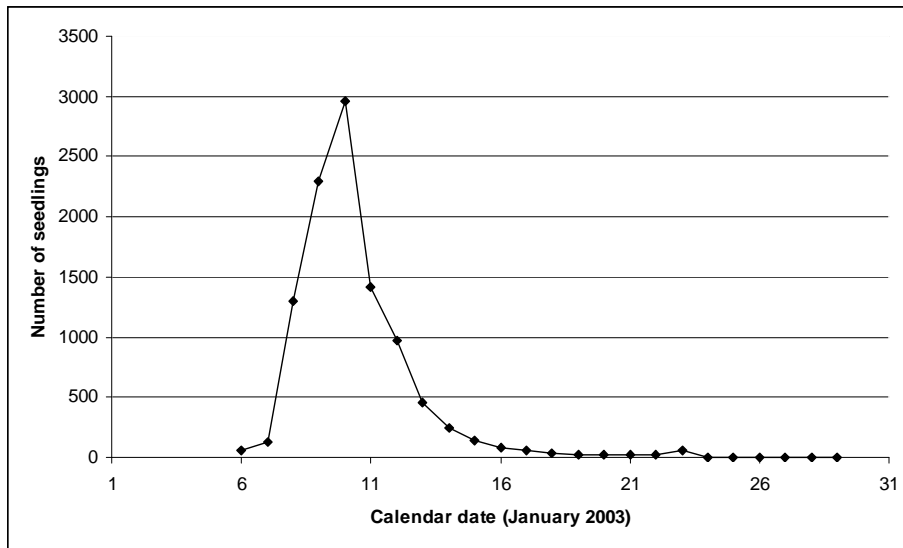


Figure 2. Seedling emergence

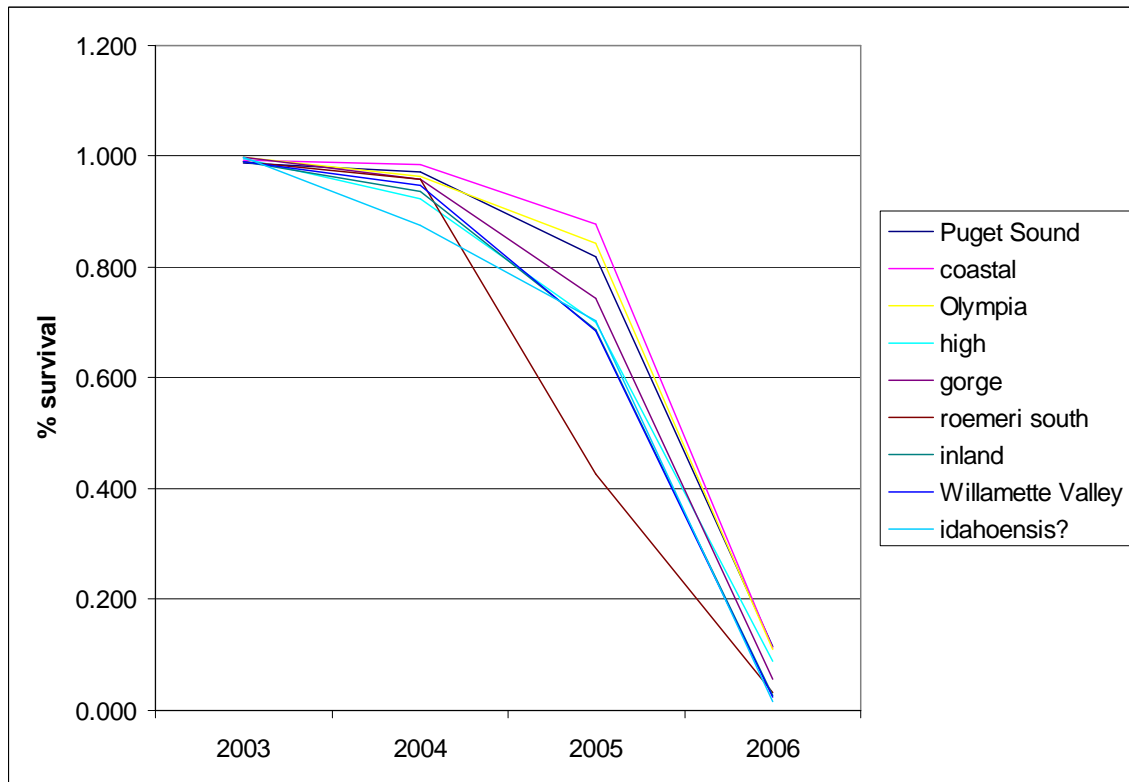


Figure 3. Mean survival values for groups.

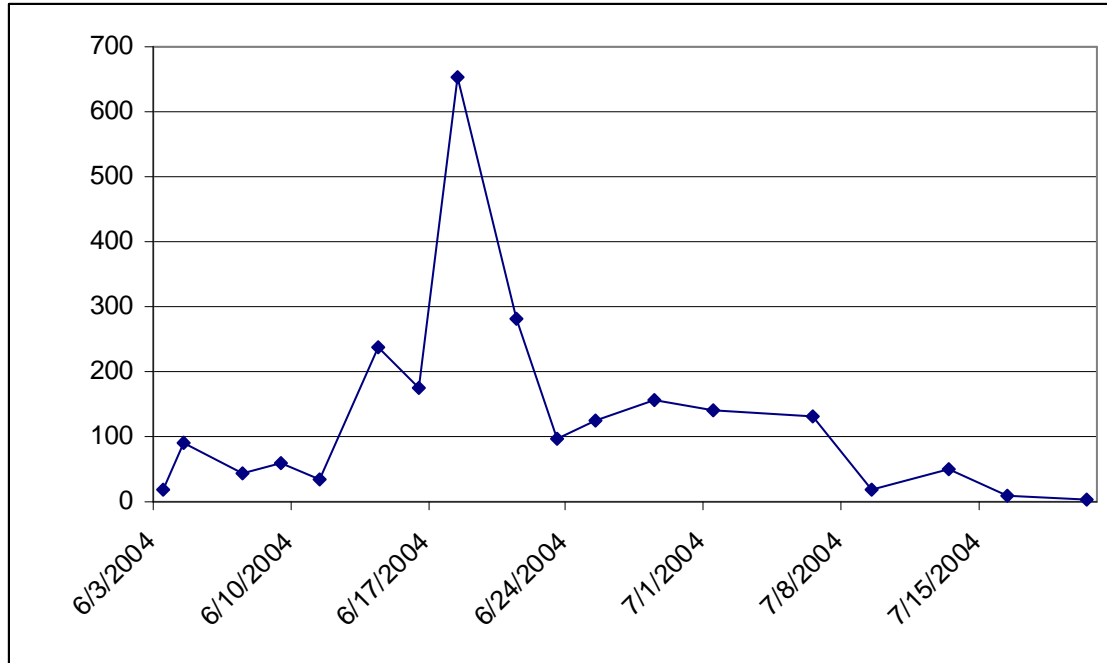


Figure 4. Seed harvest (number of plants).

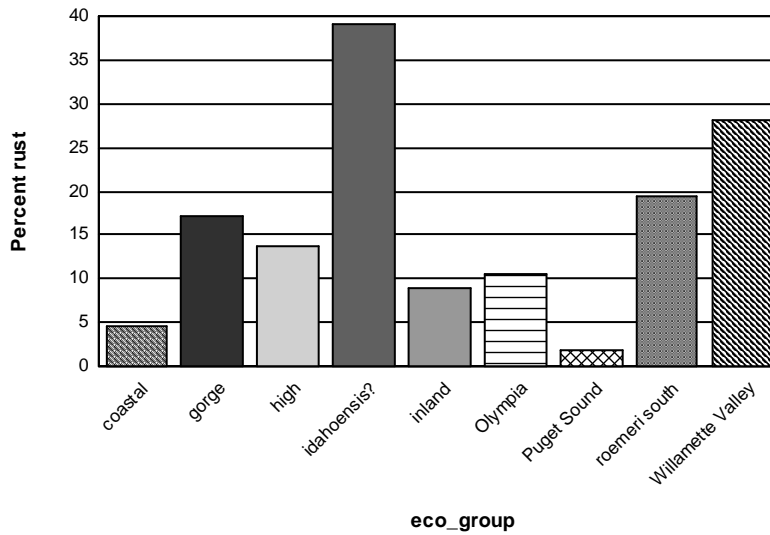


Figure 5. Rust infection rate among ecological groups.

PC1 =	918 -	(0.68×LAT)	+ (7.26×LONG)	+ (0.0040×ELEV)
Prob:	0.13	0.57	0.14	0.02
$r^2 =$	0.17			
PC2 =	552 +	(3.51×LAT)	+ (5.73×LONG)	- (0.0024×ELEV)
Prob:	0.22	0.01	0.12	0.05
$r^2 =$	0.40			
PC3 =	-449 -	(0.25×LAT)	- (3.81×LONG)	- (0.0057×ELEV)
Prob:	0.28	0.76	0.26	0.01
$r^2 =$	0.39			

Figure 6. Linear regressions of principal components on latitude, longitude, and elevation.

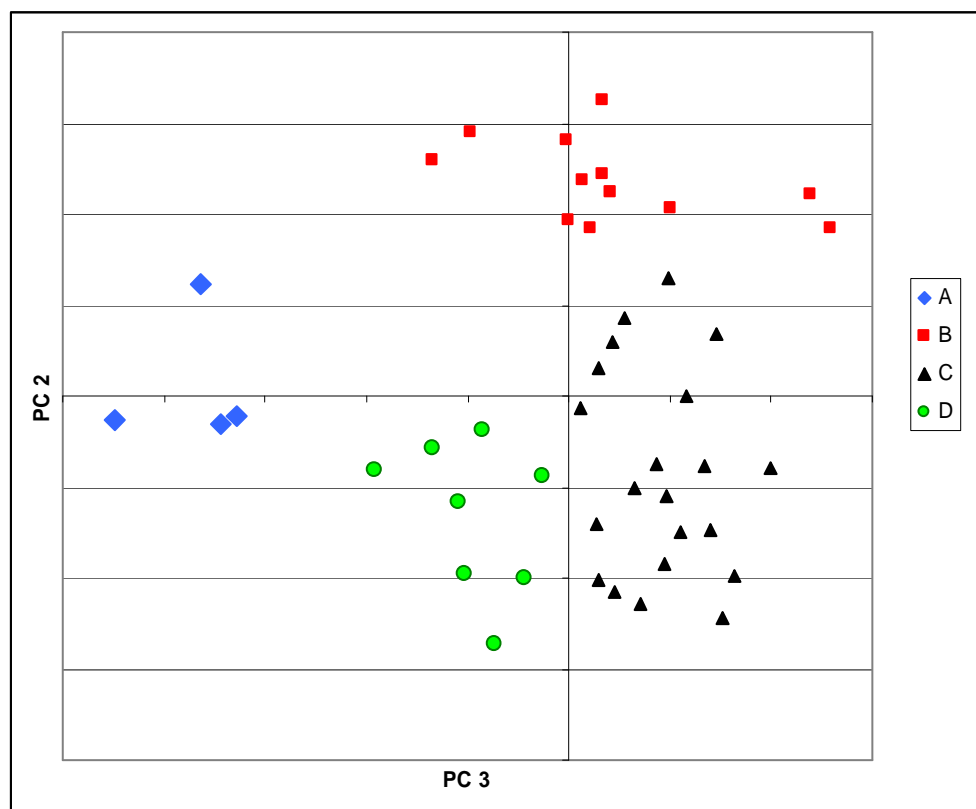
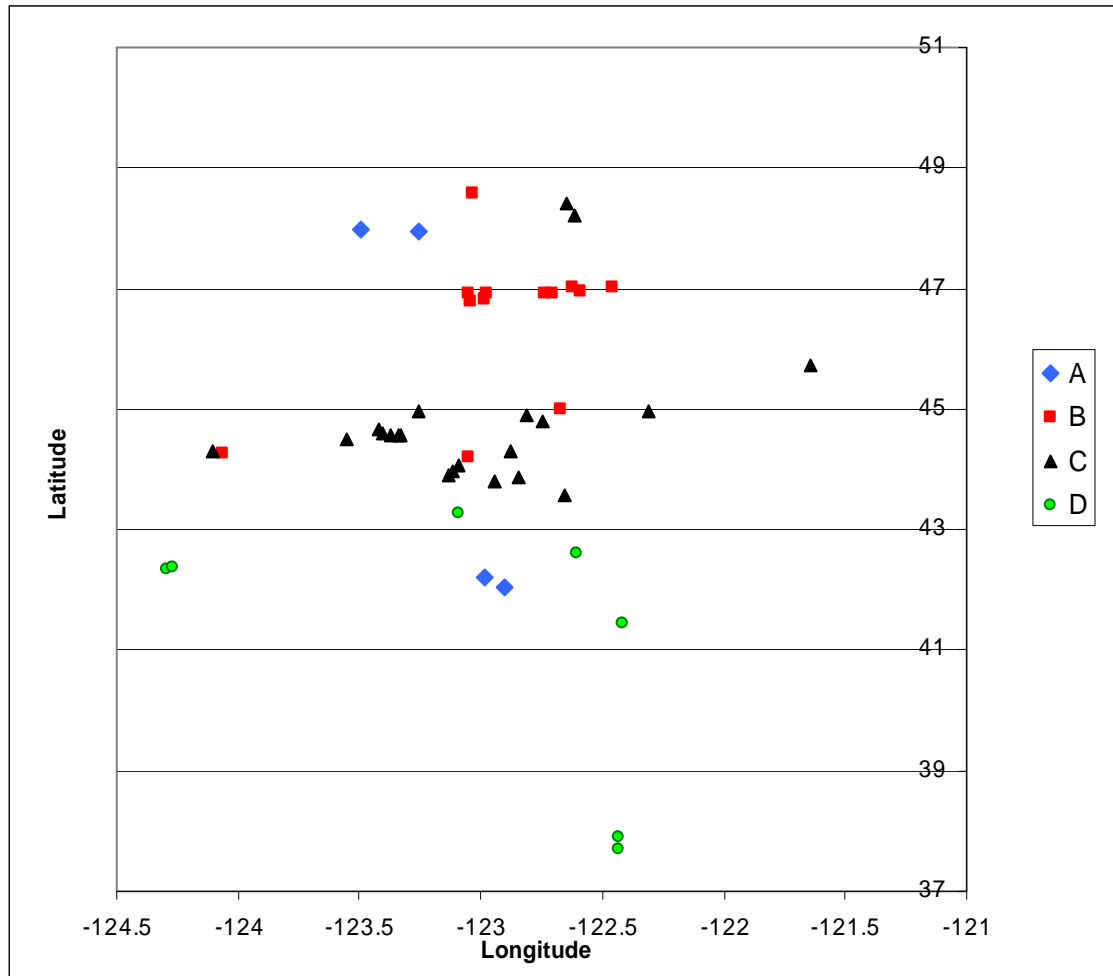


Figure 7. Scatter plot of PC2 and PC3.



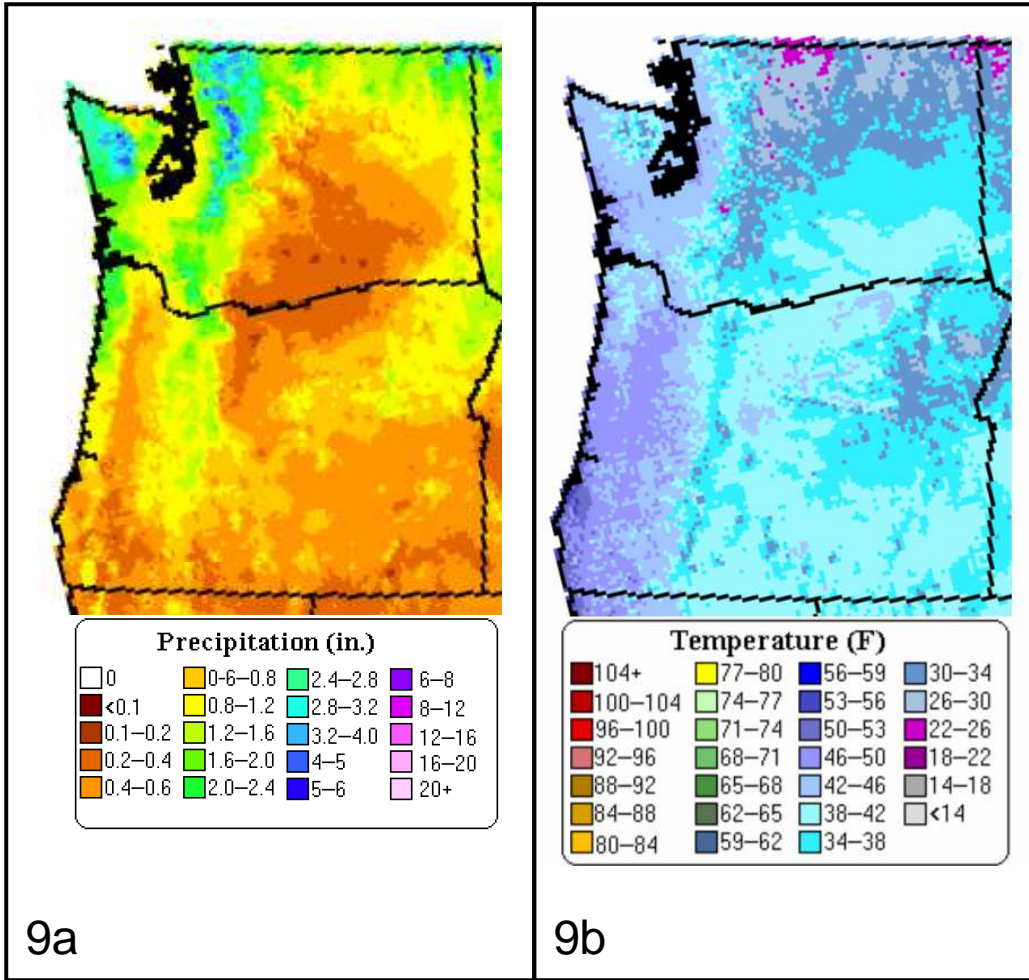


Figure 9a. February precipitation. Copyright © 2006, PRISM Group, Oregon State University, <http://www.prismclimate.org> Map created 6/16/2006.

Figure 9b. December maximum temperatures. Copyright © 2006, PRISM Group, Oregon State University, <http://www.prismclimate.org> Map created 6/16/2006.

Table 1. Plants in the common garden.

<i>Group</i>	<i>Population</i>	<i>County</i>	<i>Number of plants in garden</i>
<i>coastal</i>			
	Cape Perpetua	Lincoln	64
	Cummins Creek Trail	Lincoln	64
	Mt. Tamalpais	Marin	64
	San Bruno Mt.	San Mateo	64
<i>gorge</i>			
	Drano Lake	Skamania	64
	Memaloose Park	Hood River	6
<i>high</i>			
	Blue Mt. near Deer Park	Clallam	64
	Fairview Peak	Lane	64
	Hurricane Ridge	Clallam	56
	Mary's Peak	Benton	64
<i>idahoensis?</i>			
	Duncan Spring	Klamath	64
<i>inland</i>			
	Edgewood-Weed Road	Siskiyou	64
	Hukill Hollow	Jackson	64
	Silver Fork Elliot Cr.	Jackson	64
<i>Olympia</i>			
	Glacial Heritage Preserve	Thurston	55
	Johnston Prairie	Thurston	64
	Mima Mounds	Thurston	64
	Mortar Pt. 3	Thurston	64
	Rocky Prairie N.A.P.	Thurston	64
	Scatter Creek	Thurston	64

Table 1. Plants in the common garden (*continued*).

<i>Group</i>	<i>Population</i>	<i>County</i>	<i>Number of plants in garden</i>
	Thirteenth Division Prairie	Pierce	61
	Upper Weir Prairie	Thurston	64
	Yelm	Thurston	62
Puget Sound			
	Fidalgo Island; Ravine Trail	Skagit	52
	Smith Prairie, Whidbey Island	Island	64
	Yellow Island	San Juan	56
roemerii south			
	Ace Williams Mt.	Douglas	64
	Cobleigh Road	Jackson	60
	Lodgepole Meadow	Curry	62
	Pyramid Rock	Curry	45
Willamette Valley			
	Abiqua Road	Marion	40
	Bald Hill southeast	Benton	64
	Bald Hill west	Benton	64
	Baskett Butte	Polk	64
	Beazell (King's Valley)	Benton	64
	Fire Knob	Marion	32
	Horse Rock Ridge	Linn	64
	Kingston Prairie	Linn	52
	Kloster Mountain	Lane	64
	Morton's property	Benton	19
	Novick property	Lane	59
	Open Spaces Park	Benton	61
	Rock Hill	Lane	64
	Row Point, Dorena Reservoir	Lane	64
	Spencer's Butte	Lane	64
	Table Rock Wilderness	Clackamas	64
	Weiss Road ridgeline	Lane	61

Table 2. Summary of traits measured.

Trait	Description
emergence date	Julian date
germination rate	ratio of seeds emerged:planted
albinism	yes/no
plant height (10 weeks)	length of longest leaf (mm)
plant width (10 weeks)	width of crown (mm)
form 03	ratio of height:width
plant height (29 weeks)	length of longest leaf (mm)
plant width (29 weeks)	width of crown (mm)
form 04	ratio of height:width
leaf color (29 weeks)	score of 1(blue) to 5(green)
rust infection (29 weeks)	score of 1 to 10
dormancy (29 weeks)	yes/no
phenological status (March – November, 2004)	scale of 1 to 10; see table for details
culm height (74 weeks)	height of tallest culm (cm from ground)
crown width (74 weeks)	width of crown (cm)
leaf abundance (74 weeks)	score of 1 to 10
culm abundance (74 weeks)	score of 1 to 10
leaf abundance (126 weeks)	score of 1 to 10
culm abundance (126 weeks)	score of 1 to 10
rust abundance (126 weeks)	score of 1 to 10
lemma length	mm
awn length	mm
palea length	mm
lower glume length	mm
upper glume length	mm
distance to lowest branch of inflorescence	cm
length of inflorescence	cm
spikelets per node	number
Total seed yield for all plants in each family (2004)	grams

Table 3. Phenological scores.

0	dormant or dead
1	vegetative - just green leaves
2	boot - thickened culms visible
3	elongation (jointing) - culms longer than general top of foliage leaves
4	first emergence of inflorescence
5	first anthesis
6	50% anthesis
7	seed milky
8	seed soft dough
9	seeds mature - culm is brown (tan/straw color)
10	dormant

Table 4. Seed data organized by ecological group.

eco_group	planted	emerged	(%)	albino	(%)
coastal	1590	1224	(77.0)	14	(1.1)
gorge	367	233	(63.5)	0	(0)
high	1152	923	(80.1)	15	(1.6)
idahoensis?	288	201	(69.8)	11	(5.5)
inland	855	711	(83.2)	11	(1.5)
Olympia	2436	1916	(78.7)	34	(1.8)
Puget Sound	824	562	(68.2)	10	(1.8)
roemerii south	576	353	(61.3)	13	(3.7)
Willamette Valley	4765	3024	(63.5)	91	(3.0)

Table 5. Average seed maturity date by ecological grouping.

eco_group	avg. seed maturity date
inland	6/13/2004
high	6/16/2004
Olympia	6/17/2004
Puget Sound	6/21/2004
Willamette Valley	6/23/2004
coastal	6/25/2004
roemerii south	6/27/2004
gorge	6/28/2004

Table 6. Correlations of traits with principal components 1-3.

	PC1	PC2	PC3
Height 2003	0.50111 0.0006	0.73341 <.0001	0.01807 0.9084
	0.0052	<.0001	0.0012
Rust infection	-0.29711 0.053	0.00755 0.9617	0.67078 <.0001
Color	-0.3754 0.0131	0.00458 0.9767	0.47535 0.0013
Height 2004	0.59153 <.0001	0.54193 0.0002	-0.13972 0.3715
Width 2004	0.78218 <.0001	-0.00353 0.9821	0.4366 0.0034
Seed shatter date	-0.41389 0.0058	0.29521 0.0546	0.69238 <.0001
Tiller abundance 2004	0.75202 <.0001	-0.07826 0.6179	0.41943 0.0051
Foliage abundance 2004	0.62381 <.0001	0.24391 0.115	0.32089 0.0359
Anthesis date	-0.58254 <.0001	0.44594 0.0027	0.55748 0.0001
Phenological state, March 30, 2004	0.64011 <.0001	-0.3579 0.0185	-0.36721 0.0154
Form 2003	-0.01195 0.9394	0.88862 <.0001	-0.34854 0.022
Form 2004	-0.20015 0.1981	0.22237 0.1518	-0.54824 0.0001
Survival 2005	0.8257 <.0001	0.19617 0.2074	0.01132 0.9426
Survival 2006	0.55208 0.0001	0.32544 0.0332	-0.19609 0.2076

Table 6 (*continued*). Correlations of traits with principal components 1-3.

Foliage abundance 2005	0.50403 0.0006	0.48832 0.0009	0.35241 0.0205
Tiller abundance 2005	0.63818 <.0001	-0.07793 0.6194	0.08727 0.5779
Seed yield	0.82361 <.0001	-0.16763 0.2826	0.30333 0.048
Lemma	0.20147 0.1951	-0.32233 0.035	0.11341 0.469
Awn	0.41557 0.0056	0.04315 0.7835	-0.14232 0.3626
Palea	0.17036 0.2748	-0.32911 0.0312	0.15691 0.315
Glume1	0.0825 0.5989	-0.05914 0.7064	0.06586 0.6748
Glume2	0.00686 0.9652	-0.10727 0.4935	0.08538 0.5862
Inflorescence length	0.58857 <.0001	0.30043 0.0503	-0.17957 0.2492

Table 7. Correlations of traits with latitude, longitude, and elevation.

	Latitude	Longitude	Elevation
Height 2003	0.45414 0.0022	0.21697 0.1622	-0.57142 <.0001
Width 2003	-0.40776 0.0066	-0.02917 0.8527	0.67154 <.0001
Rust infection	-0.34662 0.0228	-0.03288 0.8342	-0.10983 0.4832
Color	-0.10388 0.5074	-0.31879 0.0372	-0.21755 0.1611
Height 2004	0.32479 0.0336	0.32868 0.0314	-0.50392 0.0006
Width 2004	-0.07379 0.6382	-0.00481 0.9756	0.11896 0.4474
Seed shatter date	-0.36268 0.0168	-0.22073 0.1549	-0.32752 0.032
Tiller abundance 2004	-0.24105 0.1194	-0.21075 0.1749	-0.00497 0.9748
Foliage abundance 2004	0.10467 0.5041	-0.01864 0.9056	-0.0872 0.5782
Anthesis date	-0.31089 0.0424	-0.04868 0.7566	-0.50702 0.0005
Phenological state, March 30, 2004	-0.07068 0.6525	0.1893 0.2241	0.315 0.0396
Form 2003	0.55916 <.0001	0.24898 0.1074	-0.77857 <.0001
Form 2004	0.18655 0.231	0.22536 0.1462	-0.32152 0.0355
Survival 2005	0.23249 0.1336	-0.0177 0.9103	-0.0908 0.5625
Survival 2006	0.4257 0.0044	-0.13564 0.3858	-0.1409 0.3675

Table 7 (*continued*). Correlations of traits with latitude, longitude, and elevation.

Foliage abundance 2005	0.21473 0.1667	-0.19226 0.2168	-0.39223 0.0093
Tiller abundance 2005	-0.2306 0.1368	-0.19163 0.2183	0.06132 0.6961
Seed yield	-0.18547 0.2337	-0.15973 0.3063	0.16786 0.2819
Lemma	-0.39005 0.0097	-0.05438 0.7291	0.27262 0.0769
Awn	0.31141 0.0421	-0.06147 0.6954	-0.03825 0.8076
Palea	-0.48223 0.0011	-0.08992 0.5664	0.2457 0.1123
Glume1	-0.20011 0.1982	-0.17739 0.2551	0.05371 0.7323
Glume2	-0.37253 0.0139	-0.17892 0.251	0.09813 0.5313
Inflorescence length	0.27077 0.079	0.23981 0.1214	-0.29525 0.0546

Table 8. Correlations of principal components with latitude, longitude, and elevation.

	Latitude	Longitude	Elevation
PC1	0.12265 0.4333	0.05362 0.7327	0.08646 0.5815
PC2	0.45097 0.0024	0.13272 0.3962	-0.90175 <.0001
PC3	-0.47722 0.0012	-0.30268 0.0485	-0.07397 0.6374

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