Evaluating Suitability of Prairies for Golden Paintbrush (*Castilleja levisecta*) Recovery by Experimental Outplanting in South Puget Sound

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Abstract
The suitability of South Puget Sound prairie sites for supporting golden paintbrush plants was assessed by outplanting paintbrush plugs in the field and observing growth and survival. A total of 5478 plants, coming from 5 different sources, were installed in 6 prairies in fall, 2007. Plants were inspected in spring, 2008, and rated on several characteristics of vigor. Associated species were recorded within outplanting plots, and in similar plots associated with extant paintbrush plants at Rocky Prairie. We also examined soil characteristics associated with microsites at Glacial Heritage and Mima Mounds where outplantings survived and/or successfully reproduced. Overall, first-year survival of paintbrush plants ranged from 77-92%, and flowering ranged from 4-11%. Plugs grown from seed gathered at the Naas site had the highest flowering rate (average=22%). Based on both survival and flowering, Glacial Heritage and Mima Mounds ranked highest among the 6 sites. Where portions of sites had been recently burned, paintbrush generally performed better. Soils associated with successful outplantings in 2002-2005 had higher mean levels of magnesium, calcium, potassium, sodium, cation exchange capacity (CEC) and pH than soil gathered near plots that had no surviving paintbrush plants. These results should only be regarded as preliminary, since they are based on only a single growing season. However, they provide an indication that all the sites offer some likelihood as suitable locations for restoring paintbrush populations, and that burning and perhaps nutrient manipulations further enhance site suitability.

Background
Golden paintbrush (*Castilleja levisecta*) is listed as a threatened species under the U.S. Endangered Species Act. It is limited to fewer than a dozen sites in the Pacific Northwest, has been extirpated entirely from Oregon, and has disappeared as well from all but one of the prairies in south Puget Sound. The Federal Recovery Plan for this species (USFWS 2000) assigns it a recovery priority of 2 on a scale of 1 to 18, reflecting a high degree of threat, a high potential for recovery, and its status as a full species. Furthermore, the Plan identifies the establishment of new populations of this species as a primary strategy necessary to reach the recovery goal of at least 20 self-sustaining populations.

Since the Recovery Plan was written, progress has been made in several key areas that were identified as essential for successfully establishing new populations. A Reintroduction Plan (Caplow 2004) has been prepared that recommends approaches for more efficiently and successfully reintroducing this species to new sites. Characteristics of sites where golden paintbrush currently occurs have been gathered and summarized (Chappell and Caplow 2004), and an evaluation has been carried out for many sites being considered for potential paintbrush reintroduction in the South Puget Sound (Caplow and Chappell 2005). The suitability of various sites has continued to be evaluated by Joe Arnett (Dunwiddie and Arnett 2009). Experimental introductions have taken place at several sites on Whidbey Island (Swinerton 2003, Wayne 2004), as well as at Mima Mounds Natural Areas Preserve and Glacial Heritage Preserve in the South Puget Sound (Pearson and Dunwiddie 2003, 2006).

Most species do not occur uniformly across entire sites. Rather, they tend to occur more or less discontinuously, with the degree of clustering, as well as the size and extent of patches, varying widely among species and sites. Small-scale variability in soil characteristics, competition with other already-established plants, differences in type, timing, and scale of disturbances across the site, and a host of other factors combine to produce a landscape that is highly heterogeneous in terms of its suitability for establishment of a given species. Previous studies with golden paintbrush suggest that variability of sites at the microsite level has important implications, both for the assessment of potentially suitable sites for restoration, and for the successful establishment of the species on a site. For example, in a study begun in November, 2000 by Wayne (2004), of over 1000 plants outplanted at a recovery site at Ebey's Landing, only 21 have survived over 2 years. However, most of these surviving plants occurred within a few meters of one another in a small portion of the overall outplanting site, which extended over 1 hectare. Despite the overall high mortality rate, many of this small surviving cohort continued to thrive for at least 8 years (Figure 1). In another example, golden paintbrush was seeded into 116 experimental plots at Mima Mounds and Glacial Heritage in South Sound prairies between 2002-2005 (Pearson and Dunwiddie 2003, 2006). Although 1000 seeds were sown in each plot, only 40% of the plots had any seedlings germinate at all, and only 13% had ≥10 seedlings. Yet in several areas at both Sound Sound prairie sites, small groups of individuals have continued to thrive and successfully reproduce (in 2008) from seeds and plugs sown or outplanted in 2003, 2004, and 2005 (David Wilderman, personal communication). These experiments suggest that only portions – and in some cases only very small portions – of sites that appear generally appropriate for growing golden paintbrush may actually offer suitable conditions for this species to germinate and grow.

Generalized assessments of site characteristics, such as those carried out by Caplow and Chappell (2005), provide helpful information in prioritizing potential sites for golden paintbrush recovery efforts based on site attributes such as protected status, management, topography, soils, and vegetation. However, this approach as applied in south Puget Sound has several shortcomings. First, only a single golden paintbrush site (Rocky Prairie) remains as a source for comparison, and there is no way of knowing whether this site is typical of other sites that were lost to agriculture or development. It is plausible that this site may actually be uncharacteristic. Therefore, using Rocky Prairie as the standard for suitable habitat may give a misleading picture. Second, it is difficult to know how to weight the different variables that comprise the "index of similarity" used in prioritizing sites, yet how these weights are assigned can significantly alter the assessment of site suitability. Finally, the coarse scale at which sites were assessed fails to account for the microsite variability that the studies described above suggest may be important for this species.

Clearly, we must use a variety of approaches to provide more detailed information to help identify new sites that will sustain viable populations of golden paintbrush, and to develop the most successful approaches for establishing this species to these sites. Ultimately, of course, we need to ascertain whether golden paintbrush can actually grow and thrive at a particular site. Yet prairies that appear to offer potential habitat for recovering this species may be rejected from consideration if reintroduction efforts fail because plants were only introduced into unsuitable microsites. The past efforts described above suggest that numerous variables may render significant portions of a site unsuitable. Furthermore, considerable effort and resources may be wasted in reintroduction attempts if plants or seed are placed in microsites unsuitable for this species. Therefore, it is critical that we be able to more accurately define the characteristics of microsites capable of sustaining golden paintbrush so that they can be identified in the field before sowing seed or outplanting plugs.

In this report, I describe the results of a project funded by the U.S. Fish and Wildlife Service designed to provide information for assessing the suitability of potential golden paintbrush recovery sites in South Puget Sound.

<u>Objectives</u>
The project had three primary objectives:
1) Compare the relative suitability of different prairies in the South Puget Sound for golden paintbrush by experimentally outplanting paintbrush and sowing paintbrush seed into a wide array of microsites across a suite of prairies that have already been identified as potential reintroduction sites,
2) Gather data on germination rates and the survival and vigor of outplantings,
3) Relate vegetation and soil characteristics of the propagation sites to the success of the seeding and outplanting experiments.

Methods
We had originally proposed to outplant at least 100 golden paintbrush plants in each of several prairies in the South Puget Sound in fall, 2006. Up to 10 sites were proposed to be included in this study, pending approval of managers of the various sites. Sufficient seed had already been collected from Rocky Prairie to produce 1000 plants for this project. As originally planned, Rocky Prairie was to be the only source of seed used in the experiment. The seed was sown into pots, and plants were to be grown out over the summer of 2006 for outplanting in the fall. Additional seed was to be collected from Rocky Prairie in late summer, 2006, to sow in test plots along with the outplanted individuals. However, these plans had to be modified following the near-complete lack of germination of golden paintbrush seed collected from Rocky Prairie in 2005 and 2006.

After consultation with the Golden Paintbrush Technical Team, we decided to use the limited supplies of seed available from several north Puget Sound populations (including Forbes Point, Ebey's – Hill Rd., Naas, and Ft. Casey) to grow out plugs for outplanting in South Puget Sound prairies, and dispense with the seeding portion of this experiment. The seeding trials would have required larger amounts of seed than were available, with little likelihood of success, based on low field germination rates observed in previous experiments (Pearson and Dunwiddie 2006). However, because of the high rate of germination in nursery settings, we were able to produce far more plugs for outplanting than originally proposed, greatly increasing the robustness of this experiment. We ended up with 5478 plugs from five sources that were outplanted at six different sites (Table 1).

Of the sites surveyed by Caplow and Chappell in 2005, six were eventually included in the experimental outplanting that took place in fall, 2007. These included Scatter Creek (south), West Rocky Prairie, Wolf Haven, Glacial Heritage, Mima Mounds, Morgan (Tenalquot). Sites on Ft Lewis were rejected due to a lack of permission to outplant paintbrush on the sites at this time. Managers of all sites included in the experiment were consulted to determine general locations where outplanting would not interfere with other management activities planned at the sites. Attempts were made to make the outplanting area in each prairie as large as possible, given the various constraints at each site. In this way, the experiment provided a better overall assessment of the suitability of each site, rather than of a small area that may not be representative of the entire range of habitat variability.

For this experimental outplanting, a standard protocol was followed at all six sites with only minor variations, usually dictated by constraints imposed by the shape, size, or composition of individual sites. The basic design was to designate a long transect at each site, with outplanting quadrats arrayed along the transect at points designated at regular (5 or 10m) intervals. Points were marked with colored plastic whiskers. At each point, 2, 1-m square quadrats were located. Five plants were outplanted in each quadrat in a regular pattern, producing 10-plant arrays in 1x2m blocks. Plants originating from each source were always located in the same position in the quadrats to facilitate relocation and identification of the plants.

At each of the six sites, a total of ca. 940 golden paintbrush plugs were outplanted. Five plants sources were used in the experiment, and came from four sources of seed: Ebey's Landing (grown at Jarisch's), Ebey's Landing (grown at 4th Corner Nursery), Naas, Ft. Casey, and Forbes Point. The 10-plant arrays (2 plants from each of the five sources) were replicated in ca. 76 blocks at each site, yielding a sample size of 760 plants used at each site and summarized in the attached tables. Since unequal numbers of plants were available from the five sources, extra plants were outplanted at each site at additional points along the transect line(s). Most of these were from Forbes Point. Data from these extra outplantings are not included in Table 1.

All outplanted paintbrush plugs were monitored in May, 2008. Each plant was recorded as vegetative, flowering, or dead/missing. Vegetative plants were categorized as "weak" or “robust”. For flowering plants, the number of flowering stems was recorded. Finally, the 3 dominant plant species (including moss) were recorded in each quadrat.

To better understand what plant species are most associated with thriving golden paintbrush plants, we collected percent cover data on all species found within 1m square quadrats centered around robust paintbrush plants (or groups of plants) at Rocky Prairie. A total of 37 quadrats were evaluated in May, 2006.

To investigate possible relationships between paintbrush success and soil characteristics, soil samples were collected in close association with quadrats at Mima Mounds and Glacial Heritage where paintbrush had been outplanted or seeded in 2002-2005 during a previous study (Pearson and Dunwiddie 2006). Analyses were carried out on various parameters from samples taken where plants persisted in significant numbers, and often successfully reproduced. These were compared with data from samples collected from nearby quadrats where no success was observed.

Results

A summary of growth and survival of outplanted paintbrush at the six sites is presented in Table 1. In interpreting the results, it is important to note that some of the blocks at two of the sites – Glacial Heritage and Morgan – had been burned in previous years. At Glacial Heritage, 12 blocks were in areas that had no history of burning, 11 had been burned in 2005, 28 had been burned in 2006, and 24 had been burned in 2007. At Morgan, 19 blocks had been burned just prior to outplanting in 2007, and 57 had no history of burning. This difference in management history makes simple comparisons of suitability among the six sites more difficult, since the data discussed below seem to suggest that recent burning enhances – at least to some extent – the vigor and (perhaps to a lesser extent) the survival.

Survival – Sites

Overall, first-year survival of CALE plants, regardless of source, ranged from 77% (Wolf Haven) to 92% (Glacial Heritage). The overall best sites (Glacial Heritage, Mima Mounds) were generally also the best sites regardless of the source of the plants. On the other hand, Wolf Haven was generally the worst site regardless of source, ranking 5th or 6th for all sources. West Rocky, Morgan, and Scatter Creek were more variable, but tended to be intermediate.

Survival – Sources

The different sources of the plants varied little in terms of survival rates. When averaged across the six sites, survival ranged from 82% (Ebey’s Jarisch) to 92% (Naas). The two Ebey’s sources (Jarisch and 4th Corner) had similar survival rates (82% versus 85%).

Flowering

Reproductive vigor, as indicated by the percentage of plants that flowered, averaged 7% over all sites. As with survival, the lowest was at Wolf Haven (4%). However, the highest % flowering was at Glacial Heritage (11%) and Morgan (10%), with Mima, West Rocky, and Scatter Creek intermediate (5-7%).

The different sources for the outplanted plugs had markedly different rates of flowering. Plants from Naas were by far the highest (ave. = 22%), Ebey's-Jarisch was a distant second at 6%, followed by Ft. Casey (4%), Forbes Point (2%), and Ebey's-4^{th} Corner (1%). The maximum flowering rate was observed among the Naas plants at Glacial Heritage (32%), closely followed by Naas plants at Morgan (30%).

Vigor – Vegetative plants
Vegetative plants were scored as "weak" or "robust" at all sites, depending on the number and length of stems. Thus all living plants were recorded in one of three categories – vegetative/weak, vegetative/robust, or flowering. Therefore, another measure of vigor was calculated by combining the number of "robust" and flowering plants. Overall, an average of 35% of plants fell into one or the other of these categories, with a range from 28% (Morgan) up to 41% (Glacial Heritage). As with survival, Glacial Heritage (41%) and Mima Mounds (40%) had the highest vigor ratings.

Within-site variability
The high rate of percent flowering at Glacial Heritage and Morgan reflects, at least to some extent, the fact that portions of the outplanting transects at both sites crossed areas that had been recently burned. At Glacial Heritage, in blocks that had been burned in 2007, 14% of the plants flowered, compared with 9% of the plants flowering in blocks burned in 2006, 11% of the plants flowering in blocks burned in 2005, and only 8% of the plants flowering in blocks that had never been burned (Table 2). At Morgan, 22% of the plants flowered in blocks burned in 2007, whereas only 6% of the plants flowered in blocks that were unburned. A similar but less pronounced pattern was reflected in survival, which was slightly higher in burned blocks than in the unburned controls at Glacial Heritage (but not at Morgan). Among vegetative plants, there also was a tendency for weak plants to be larger percentage of the total in the unburned controls in contrast to the burned blocks, where more plants were either robust-vegetative or flowering. Thus there is a strong suggestion in the data that burning of sites prior to outplanting increases the likelihood that the plugs will flower or grow more robustly.

Vegetation associated with successful golden paintbrush sites
Vegetation data collected from quadrats at Rocky Prairie centered on vigorous paintbrush plants are depicted in Table 3. A total of 64 species were recorded. Taxa exhibiting the highest percent cover included *Dicranum scoparium* (28%), other moss (27%), *Festuca roemeri* (10%), lichens (6%), *Anthoxanthum odoratum* (6%), and *Lupinus albicaulis* (5%). These also tended to be taxa with high frequency values. Several others also were frequently associated with paintbrush, but had lower cover values, including *Carex inops, Agrostis alba, Camassia quamash,* and *Teesdalia nudicaulis*.

Soil characteristics
Analyses of soil characteristics of sites where paintbrush grew better in the Pearson and Dunwiddie (2006) study provide some insight into soil properties which may increase the rate of survival and subsequent vigor of paintbrush seedlings. ANOVA tests concluded

that locations where paintbrush plants survived (those which had ≥1 paintbrush plant present in 2008) had higher mean levels of magnesium, calcium, potassium, and sodium than soil gathered near plots that had no surviving paintbrush pants (Table 4; Figures 1-3). The largest differences were seen in levels of magnesium and calcium. Considering that the level of these macronutrients is higher in close proximity to successful plots, it is not surprising that the cation exchange capacity (CEC) in these locations is also greater. Higher CEC levels may be a result of greater levels of organic matter (somewhat higher near successful plots) or higher quantities of fine, clay particles in the soil in these areas (not tested). Finally, pH levels were found to be slightly more alkaline in soil near plots which had surviving paintbrush, though differences were small.

Discussion

We proposed to assess the suitability of different prairies for growth of golden paintbrush at three scales. These include 1) comparisons of prairies with one another, 2) evaluations of the variations in the suitability of conditions across a single site, and 3) detailed assessments of sites at the microsite level to identify specific locations that are most suitable for germinating and supporting golden paintbrush.

Inter-prairie comparisons

The high first-year survival rate at all sites – in excess of 75% - makes it difficult to draw any firm conclusions regarding the relative suitability of some sites over others after a single year. Past experience with other outplantings suggests that higher – and differing - mortality rates in succeeding years may begin to separate some sites from others, and may give a better indication of site suitability. After this first growing season, measures of survival, flowering, and vigor ("robust"+flowering) all suggested that Glacial Heritage was the highest ranking site; Mima Mounds also ranked high in survival and vigor. Scatter Creek and Wolf Haven were generally lowest in most categories. However, these results should be considered only as preliminary indications of relative suitability, and none of the sites should be excluded from further consideration for paintbrush outplanting based on these data.

Within-site variability

Comparisons of paintbrush performance within the two sites with a history of recent burning (Glacial Heritage and Morgan) suggest that the effects of these fires enhances the vigor of outplanted plugs, as measured by % flowering and by robust vegetative plants. Effects on survival are less clear, but may also be enhanced over time. The data from Wolf Haven is particularly interesting in this regard. Wolf Haven is very close to an extant population (Rocky Prairie) and almost certainly was part of the same prairie historically. It still supports many of the same species, and appears to be in very good condition overall. Casual observations made at the time data were collected in 2008 suggested that many of the Wolf Haven plugs were being strongly out-competed by the robust vegetation (both vascular plants and moss) at the site. As a result, this site usually ranked at or near the bottom with most of the performance measures. Given the results seen at Glacial Heritage and Morgan, it seems likely that burning could make this site considerably more suitable for supporting paintbrush.

The effects of previous burning – at least during the first several years following a burn – may be greater than the effects of soils, associated vegetation, or other site factors that may also contribute to paintbrush survival and vigor. This raises an interesting and unexpected question regarding interpreting outplanting results to assess the suitability of different sites for golden paintbrush. Although a particular site may have appropriate soils and species compatible with golden paintbrush, it still may be incapable of supporting outplanted paintbrush plugs (much less a viable, self-sustaining population) until further manipulations are carried out (such as prescribed burns) that mitigate particular conditions at the site (such as litter depth, presence of bare ground, abundance of moss, soil nutrient status) that may impede or enhance golden paintbrush establishment or survival. Thus it probably is inappropriate even to rank the relative suitability of these sites to one another at this time, based on this first year's data. Future monitoring of these outplanted individuals may suggest that some sites are more favorable than others. However, it is strongly recommended that burning should be carried out at all of the sites, and paintbrush outplanted in both burned and unburned locations, to more adequately evaluate the sites.

Assessment of microsite suitability
Vegetation data collected from the outplanting blocks remain to be analyzed. This large dataset will be useful in identifying those species most commonly associated with blocks where most paintbrush plants flowered, grew well ("robust"), grew poorly ("weak"), or died. Due to the complexity of the analyses involved, it was decided to carry them out only after more definitive data documenting paintbrush growth and survival were available (after year 2).

The vegetation data collected in association with paintbrush at Rocky Prairie provide more resolution on patterns initially described by Caplow and Chappell (2004) based on their 4-plot sample from the same site. Our data include many more species than reported in this earlier study, and due to a larger sample size, provide a clearer picture of those species that are most often found in association with paintbrush (had higher percent frequency values). It might be concluded from these data that species with high cover and/or frequency (particularly native species) might be possible indicators of suitable microsites for golden paintbrush. Taxa such as *Dicranum scoparium* and other mosses*, Carex inops, Festuca roemeri, Camassia quamash, Eriophyllum lanatum,* and *Fragaria virginiana* seem to be particularly strongly associated. One challenge to this interpretation, however, is that we have no comparable data for unsuitable sites. This proved to be more difficult to gather since, within Rocky Prairie, the absence of paintbrush plants at a particular microsite does not necessarily indicate that the location is unsuitable. Plants could have been growing there in the past and have died out for whatever reason, or the seeds may simply not have reached that location, or did not have conditions that growing season to successfully establish. Thus these vegetation data should only be considered as general indicators of site suitability.

The soils analyses from Glacial Heritage and Mima Mounds suggest that paintbrush, like many plant species, has a greater chance of survival when outplanted in areas of higher soil productivity (e.g. higher levels of macronutrients and organic matter content, and greater CEC and pH). Other studies have also found higher levels of magnesium and calcium in areas where paintbrush is more successful. In their study of paintbrush habitat, Lawrence and Kaye (2006) found higher levels of Ca and Mg in soils from the northern Puget Trough region than in the southern Puget Trough and Willamette Valley. They hypothesized that the levels of Ca and Mg in the northern sites may be attributed to the addition of these nutrients from salt spray. These findings suggest that future research could explore the importance of these nutrients in both paintbrush survival and vigor—possibly experimenting with fertilizing newly planted seedlings. Similar to higher pH levels increasing nutrient availability to plants, prior burning of sites (as mentioned above) may have a similar effect and be beneficial for increasing nutrient levels in the short-term.

Higher levels of CEC are indicative of greater amounts of organic matter and/ or fine particles (e.g. clay) in the soil. Microsites that contain higher amounts of these properties are likely to retain more moisture in the soil during times of drought, which would give seedlings an advantage in extreme weather conditions. This was found to be the case in a study conducted by Sprenger (2008), which found that plots that had surviving paintbrush plants had slightly greater moisture levels during hot, dry conditions than plots that had no surviving paintbrush (Sprenger 2008). However, the fine-scale variability in organic matter and fine particles in the soil at these sites, in combination with the inconsistencies of survival rates within mound locations (top, side, swale) continue to make the determination of ideal microsites by managers in the field difficult.

Summary of Project Deliverables

As originally proposed, this project was designed to advance on-the-ground recovery of golden paintbrush in several ways.

1) Plant 1000 golden paintbrush plants in potentially suitable habitat in up to 10 prairies in the South Puget Sound,
    - Despite initial impediments due to low seed viability, this project resulted over 5 times (5478) as many plants being outplanted as planned in 6 of the 10 proposed sites.
2) Sow a total of 50,000 golden paintbrush seeds (500 seeds x10 plots x10 sites) in up to 10 prairies,
    - Recognizing the very low (ca 1%) germination rates in the field, and to make limited seed supplies go further, we decided to grow seed into plugs in the greenhouse and outplant larger numbers of plugs (see #1).
3) Rank these South Puget Sound prairies in terms of their suitability for golden paintbrush growth,
    - There was little difference among the sites in terms of first-year paintbrush growth and survival, making rankings of site suitability relatively meaningless. Further, other factors (fire history and vegetation condition) appeared to be more important determinants of initial growth than physical site parameters. Continued monitoring of plants may enhance the apparent differences among sites.

4) Provide specific criteria for selecting microsites with greater potential for supporting golden paintbrush.
   - Generally, planting in more fertile microsites, with higher levels of macronutrients (especially Mg and Ca), higher cation exchange capacity, and higher pH, appears to result in better growth of golden paintbrush. Planting in recently burned sites may temporarily increase soil fertility, and enhance the suitability of some microsites. Soils with higher organic matter content or greater percentages of clay may retain water better during summer droughts, which also may enhance seedling survival. Collectively, these conditions may combine to increase vigor and flowering of plants, which may in turn enhance future survival and reproduction. It is recommended that future restoration sites include prescribed burning as part of the site management for preparing and maintaining a condition more favorable to growing golden paintbrush.
   - Identification of suitable microsites without detailed analyses of the soils remains problematic. More work is needed to determine if particular plant species can be used as indicators of especially suitable microsites.

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Table 1. Performance of outplanted plugs at six South Sound prairies as measured by percent survival, percent flowering, and percent "vigorous" (defined as the sum of percent flowering and percent "robust" vegetative plants). Sources of plugs coded as follows: EJ= Ebey's (Jarisch), FC=Ft. Casey, FP=Forbes Point, NA=Naas Preserve, E4=Ebey's (4th Corner Nursery).

Survival	EJ	Rank	FC	Rank	FP	Rank	NA	Rank	E4	Rank	Overall Survival	Rank
Glacial Heritage	0.88	2	0.88	3	0.95	1	0.97	1	0.89	2	0.91	1
Mima Mounds	0.90	1	0.89	1	0.84	3	0.95	2	0.91	1	0.90	2
West Rocky	0.74	5	0.89	1	0.86	2	0.92	4	0.88	3	0.86	3
Morgan	0.88	2	0.80	5	0.82	4	0.89	5	0.82	4	0.84	4
Scatter Creek	0.82	4	0.88	3	0.74	5	0.93	3	0.77	5	0.82	5
Wolf Haven	0.66	6	0.64	6	0.69	6	0.82	6	0.77	5	0.72	6
Average	0.81		0.83		0.81		0.91		0.84		0.84	

Flowering	EJ	Rank	FC	Rank	FP	Rank	NA	Rank	E4	Rank	Overall % Flowering	Rank
Glacial Heritage	0.10	1	0.08	1	0.02	2	0.32	1	0.03	1	0.11	1
Morgan	0.09	2	0.07	2	0.01	3	0.30	2	0.01	3	0.10	2
West Rocky	0.08	3	0.05	3	0.00	6	0.18	5	0.03	1	0.07	3
Mima Mounds	0.04	4	0.01	6	0.03	1	0.22	3	0.01	3	0.06	4
Scatter Creek	0.03	6	0.02	5	0.01	3	0.19	4	0.00	6	0.05	5
Wolf Haven	0.04	4	0.03	4	0.01	3	0.12	6	0.00	6	0.04	6
Average	0.06		0.04		0.02		0.22		0.01		0.07	

"Vigorous" (Flowering or "Robust")	EJ	Rank	FC	Rank	FP	Rank	NA	Rank	E4	Rank	Overall % "vigorous"	Rank
Glacial Heritage	0.45	1	0.37	3	0.27	1	0.72	1	0.21	4	0.40	1
Mima Mounds	0.39	2	0.46	1	0.18	4	0.65	2	0.31	2	0.40	1
West Rocky	0.32	3	0.36	4	0.24	3	0.63	3	0.34	1	0.38	3
Wolf Haven	0.28	6	0.27	6	0.24	2	0.63	3	0.26	3	0.34	4
Scatter Creek	0.28	6	0.41	2	0.12	5	0.63	3	0.05	6	0.30	5
Morgan	0.30	4	0.33	5	0.10	6	0.57	6	0.12	5	0.28	6
Average	0.34		0.37		0.19		0.64		0.21		0.35	

Table 2. Effects of pre-outplanting burning on flowering, survival, and vigor of vegetative plants (robust or weak) at Glacial Heritage and Morgan (outplanting occurred in fall, 2007).

	% Flowering Glacial Heritage	Morgan	% Survival Glacial Heritage	Morgan	% Weak Glacial Heritage	Morgan	n= Glacial Heritage	n= Morgan
Burned 2005	0.11		0.94		0.59		11	
Burned 2006	0.09		0.91		0.46		28	
Burned 2007	0.14	0.22	0.92	0.81	0.48	0.41	24	19
Unburned control	0.08	0.06	0.81	0.85	0.58	0.61	12	56

Table 3. Cover and frequency of species recorded in association with golden paintbrush plants growing at Rocky Prairie. Data recorded by Caplow and Chappell (2005) in four releve plots from the same site are provided for comparison.

		Cover	Frequency	ChappellCover	ChappellFreq
Litter		22.00	100%		
Anthoxanthum	odoratum	6.03	100%	12	75
Castilleja	levisecta	4.14	100%	3	100
Carex	inops	3.46	100%	15	100
Dicranum	scoparium	27.97	97%		
Agrostis	spp.	3.30	97%	5	100
Other Moss		26.54	95%	53	100
Festuca	roemeri	9.70	95%	33	100
Camassia	quamash	1.70	92%	2	100
Teesdalia	nudicaulis	0.97	92%	1	100
Eriophyllum	lanatum	2.57	89%	5	100
Hypochaeris	radicata	3.59	86%	2	75
Hypericum	perforatum	0.97	86%	1	100
Fragaria	virginiana	2.68	78%	2	100
Rumex	acetosella	1.54	76%	+	75
Achillea	millefolium	1.35	76%	1	100
Lichen		6.89	73%	1	100
Solidago	missouriensis	2.59	68%	2	100
Bare		2.11	68%	1	100
Ranunculus	occidentalis	1.16	68%	2	100
Prunella	vulgaris	1.49	65%	1	100
Microseris	laciniata	0.81	65%	1	100
Pteridium	aquilinum	1.51	59%	7	100
Lupinus	albicaulis	5.32	54%	7	75
Hieracium	cynoglossoides	2.51	54%	4	100
Leucanthemum	vulgare	1.41	43%	12	75
Luzula	comosa	0.38	32%	+	100
Potentilla	gracilis	0.59	27%	1	75
Aira	caryophylla	0.32	27%		
Lotus	micranthus	0.27	27%		
Vicia	sativa	0.46	24%		
Viola	adunca	0.43	22%		
Danthonia	californica	0.22	22%		
Aster	curtus	0.95	16%		
Cerastium	arvense			+	75
Erigeron	speciosus			+	50
Sisyrinchium	idahoense			+	75
Solidago	canadensis			1	75
Solidago	simplex			1	75
Taraxacum	officinale			2	50
Trifolium	dubium			+	50

Table 4. A comparison of soil properties between areas where paintbrush (CALE) was planted and *did not* survive and areas where CALE was planted and *did* survive. Mean values are presented with standard deviations in parentheses. Properties listed below are those that were found to be significantly different between the two groups (*p* values stated at the bottom of the table). In all cases, soil gathered from areas where CALE plants survived contained properties indicative of higher productivity: higher levels of macronutrients, higher pH, and slightly greater amounts of organic matter.

	Mg (ppm)	**Ca** (ppm)	**Na** (ppm)	**K** (ppm)	**CEC** (meq/100g)	**pH**	**Organic matter content** (rate)	**n**
Zero CALE seedling Survival	39 (22)	212 (114)	20 (4)	54 (10)	2.6 (1.3)	4.9	23.0 (3.8)	47
≥ 1 CALE seedling survived	72 (34)	408 (170)	23 (3)	61 (14)	4.2 (1.7)	5.1	26.2 (8.1)	21
***p* value**	(<.01)	(<.01)	(<.01)	(<.05)	(<.01)	(<.05)	(<.05)	

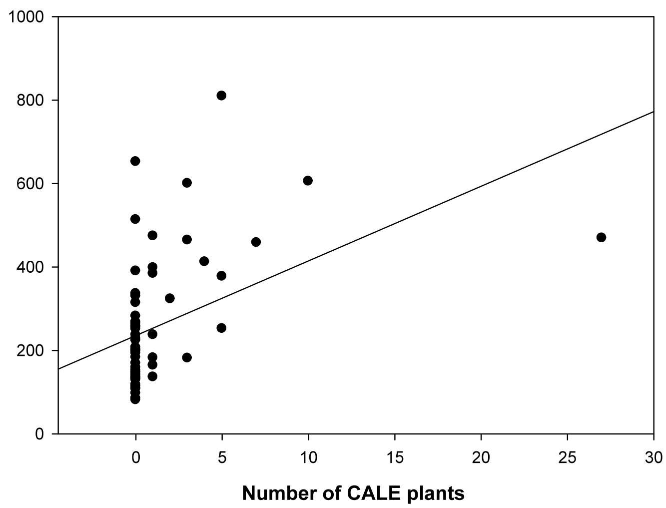

Figure 1. Scatterplot (with simple regression line) of magnesium levels in soil vs. number of paintbrush (CALE) plants recorded in 2008.

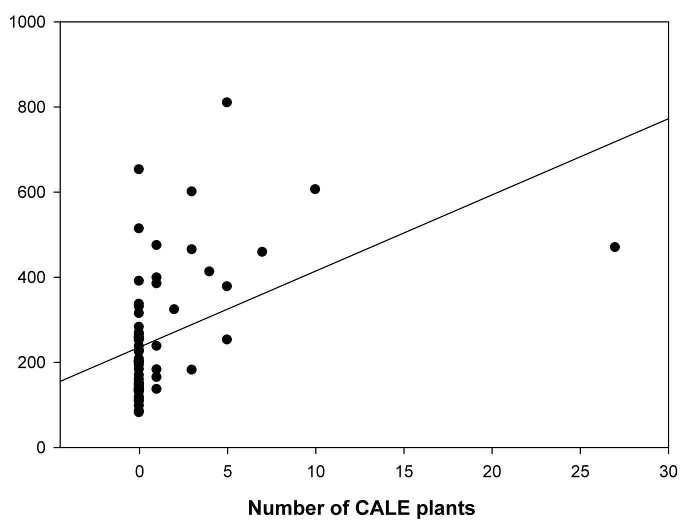

Figure 2. Scatterplot (with simple regression line) of calcium levels in soil vs. number of CALE plants recorded in 2008.

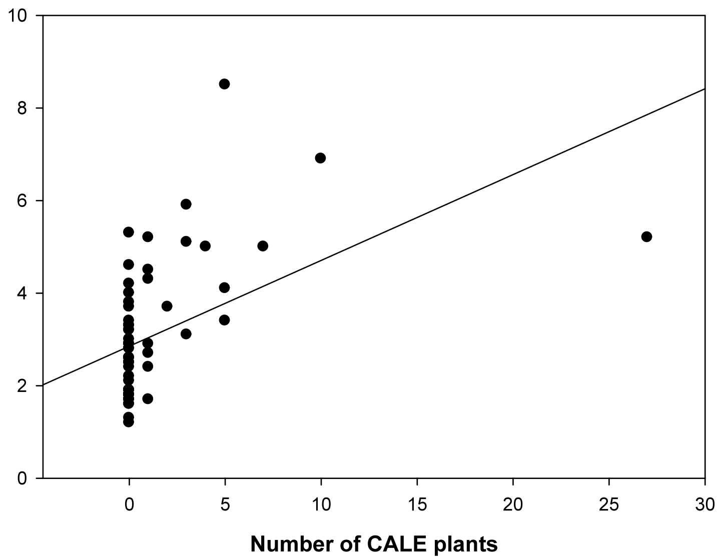

Figure 3. Scatterplot (with simple regression line) of cation exchange capacity (CEC) of soil vs. number of CALE plants recorded in 2008.