Shrub-Steppe Species Germination Trials and Survival after Outplanting on Bare Soils

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Abstract: Work has been initiated to restore native vegetation on the soil and base gravel layers that were once underneath constructed facilities at the Umatilla Chemical Depot (UMCD) in eastern Oregon. Propagules were collected from native plant species found around the UMCD. Germination success ranged from 0% to 75% for the species tested. Ten species were successfully propagated in sufficient numbers to use in an outplanting study to monitor species survival. After three growing seasons, survival ranged from 100% for *Opuntia polycantha* (pricklypear) to 5.6% for *Lupinus sericeus* (silky lupine) with average survival over all species at 50%. Further testing is needed to determine what species are best adapted to local environmental conditions.

Keywords: ecological restoration, shrub-steppe, germination

Introduction

As the Umatilla Chemical Depot (UMCD) in eastern Oregon is decommissioned, planning is currently underway to restore the associated disturbances. Returning ecosystems to a natural, self-sustaining condition is complex. In the semi-arid shrub-steppe region, little knowledge has been published on how to restore soil disturbances to ecologically sustainable conditions dominated by native plants.

Because a large number of disturbances will be associated with the removal of facilities underlain by gravel beds, this study focused on a restoration site with characteristics similar to the gravel beds under the facilities. The study site was an old parking lot that had the asphalt removed, leaving a substrate composed of a mixture of sand and gravel.

The primary study objective was to implement a trial restoration project and determine outplanting success after 3 years. The results will help land managers plan larger-scale ecological restoration on similar sites. Our trial included collection of native shrub-steppe seeds, germination tests, production of viable plants, site preparation, outplanting, and monitoring plant survival.

The expected survival rate for establishing container seedlings in western ranges and wildlands can be highly variable by species. Stevens (2004) notes that bitterbrush (*Purshia tridentata*) are expected to be successful in about 40% of container-grown stock plantings, lupine seedlings (*Lupinus* spp.) in about 60%, and yarrow (*Achillea millefolium*) and bunchgrass nearly 100%. Other than these species, little is known about the germination and survival of many shrub-steppe species following restoration outplanting. Therefore, a secondary objective of this study was to investigate survival differences among the chosen species. Also, in accordance with US Department of Army Regulation 200-3 for preparation and implementation of integrated natural resource management plans, a third objective of this study was to assist the US Army in implementing ecological restoration efforts at the UMCD.

Materials and Methods

Species Identification, Seed Collection, and Processing

Background information on the types and distribution of plant species native to the study area (TTEM 2002) was reviewed to select the appropriate target plants. From 30 March through 16 September 2007, seeds from a subset of these native species were collected at the UMCD. Fruits and seeds were collected by hand and stored in paper bags until they were manually cleaned and processed at the laboratory using a series of screens and various tools. Ease of seed extraction was highly variable among species.

Seed Germination Tests and Plant Propagation

Two types of germination tests were implemented. In the first, seeds of 22 species (Table 1) were germinated in Petri dishes before being transplanted into containers (test #1). Thirty seeds from each species (except where noted otherwise) were placed in Petri dishes between a layer of paper towel and filter paper. Seeds were wetted with 3 ml (0.1 oz) of distilled water, covered, and kept at a constant temperature of 20 °C (68 °F) in the dark for 3 days before being exposed to natural light (approximately 10 hours per day) at 20 °C (68 °F). Each Petri dish was checked daily for radical emergence and recorded. Following emergence, germinants were transplanted into containers and survival was monitored.

The second test investigated seed germination of 14 species sown directly into container tubes (test #2). Seeds were sown directly into 164 cc^3 (10 in^3) containers filled with wetted potting medium consisting of 45:45:5:5 potting soil:washed coarse sand:perlite:vermiculite (v:v). Sowing date, number of seeds, and germination percentage were recorded (Table 2).

Table 1. Seed collection dates and germination data for target restoration species at the Umatilla Chemical Depot. Seeds were germinated and counted in Petri dishes prior to being transplanted into pots. Survival was measured following transplanting in 2007.

Scientific name	Common name	Collection date	Sow date	Collection location	Number of seeds/ pads sown	Germination (%)	Transplant survival (%)
Achillea millefolium	Yarrow	6/29	6/29	UAD NE	30	50	50
Antennaria dimorpha	Pussytoes	3/30	4/6	Gazebo	30	0	0
		5/11	6/14	UAD	30	0	0
Astragalus succumbens	Columbia milkvetch	6/29	6/29	C-1114 & 5	30	13	0
Balsamorhiza sagittata	Arrowleaf balsamroot	6/11	6/14	UAD	30	13	0
		6/29	6/29	Gazebo	30	0	0
Chrysopsis villosa	False goldenaster	3/30	4/6	UAD2	30	10	3
		9/16	9/16	Study Plots	30	10	7
Chrysothamnus viscidiflorus	Yellow rabbitbrush	3/30	4/6	UAD2	30	0	0
Crepis atribarba	Slender hawksbeard	6/11	6/14	UAD4	15	33	0
Crocidium multicaule	Common spring-gold	3/30	4/6	UAD1	30	0	0
Elymus elymoides	Squirreltail	6/11	6/14	UAD1	30	73	63
		6/29	6/29	D-1281	30	23	23
Epilobium brachycarpum	Willowherb	9/16	9/16	D-1284	30	0	0
Fritillaria pudica	Yellow fritillary	6/11	6/14	UAD2	10	0	0
Hesperostipa comata	Needle and thread grass	6/11	6/14	UAD	31	6	6
Lomatium macrocarpum	Bigseed biscuitroot	6/11	6/14	UAD4	14	14	0
		6/29	6/29	D-1278	30	0	0
Lupinus sericeus	Silky lupine	6/11	6/14	UAD3	12	75	42
		6/29	6/29	UAD NE	30	0	0
Oenothera pallida	Evening primrose	6/29	6/29	D-1277	30	0	0
Opuntia polyacantha	Pricklypear	3/30	4/4	UAD1	5	NA	100
		6/11	6/16	UAD1	17	NA	100
		6/29	7/3	D-1277	15	NA	93
Phlox longifolia	Longleaf phlox	6/11	6/14	UAD1	32	75	69
		6/11	6/14	UAD4	30	7	7
		6/11	6/14	UAD2	30	54	43
Plantago patagonica	Woolly plantain	6/29	6/29	D-1294	30	43	43
Poa secunda	Sandberg bluegrass	5/11	6/14	UAD	30	0	0
Poa secunda		5/15	6/14	UAD	30	0	0
Psoralea lanceolata	Lemon scurfpea	6/29	6/29	D-1278	30	0	0
Pseudoroegneria spicata	Bluebunch wheatgrass	6/29	6/29	Gazebo	30	57	57
Purshia tridentata	Bitterbrush	6/11	6/14	UAD1	30	67	13
		6/11	6/14	UAD4	30	10	10
Sporobolus cryptandrus	Sand dropseed	9/16	9/16	D-1283	30	0	0

Table 2. Sow date, seed collection location, and germination success of species sown directly into tubes containing medium.

Species	Sow date	Collection location	Number of seeds sown	Germination (%)
Achillea millefolium	6/29/07	UAD NE	189	76
Astragalus succumbens	6/29/07	C-1114&5	133	8
Chrysopsis villosa	9/16/07	Study Plots	90	56
Crepis atribarba	6/11/07	UAD4	4	75
Elymus elymoides	6/11/07	UAD1	231	85
Hesperostipa comata	6/11/07	UAD	147	27
Lomatium macrocarpum	6/11/07	UAD4	49	0
Lupinus sericeus	6/11/07	UAD3	84	27
Phlox longifolia	6/11/07	UAD1	98	65
Plantago patagonica	6/29/07	D-1294	175	69
Poa secunda	5/15/07	UAD	196	26
Pseudoroegneria spicata	6/29/07	Gazebo	245	38
Purshia tridentata	6/11/07	UAD1	147	61
Sporobolus cryptandrus	9/16/07	D-1283	30	0
		Total	**1818**	**49**

Once germinants became established in containers, they were fertilized weekly with liquid fertilizer ($12N:4P_2O_5:8K_2O$) at a rate of 1.3 ml/l (fertilizer/water; 150 ppm N) during August, September, and October 2007. Fertilizing was discontinued when nightly temperatures in the greenhouse dropped well below freezing.

Pricklypear (*Opuntia polycantha*) was the only species not propagated from seeds. Cactus pads were harvested from the field and hardened for 5 days prior to planting into containers.

Study Site and Preparation

The study area is located on the Umatilla Chemical Depot site in Morrow and Umatilla counties in northeast Oregon. The trial was conducted on an old parking lot built in the 1940s (Figure 1). The soil at the site is a Quincy loamy fine sand with a gravelly substratum and the vegetation community is Bitterbrush-Sandberg Bluegrass-Cheatgrass (TTEM 2002). The asphalt had been removed from the planting area during the last week of December 2007. The study area was 19.5 m (64.0 ft) long, 9.2 m (31.2 ft) wide on the north side, and 7.2 m (23.6 ft) wide on the south side (trapezoidal in shape). Six replicated study plots were established; each plot was 8.2 m (27.0 ft) long and 3 m (9.8 ft) wide, with a buffer strip about 0.3 m (1.0 ft) wide between each plot.

Outplanting

A total of 508 plants of ten species were outplanted during 4 days in January and February 2008 (Table 3). Within each plot, seedlings were outplanted in different patterns, by

Figure 1. The outplanting site was located in a parking lot near the south entrance of the Umatilla Chemical Depot (UMCD).

Table 3. Native plant species outplanted at the Umatilla Chemical Depot.

Species	Outplanting date	Total seedlings planted	Seedlings planted per plot	Watering (ml)
Achillea millefolium	2/9/08	66	11	
Elymus elymoides	2/4/08	60	10	
Hesperostipa comata	2/12/08	38	6 or 7	100
Lupinus sericeus	2/6/08	17	2 or 3	
Opuntia polyacantha	2/4/08	36	6	
Phlox longifolia	2/4/08	60	10	
Plantago patagonica	2/6/08	58	9 or 10	
Poa secunda	2/6/08	29	4 or 5	
Pseudoroegneria spicata	2/12/08	60	10	100
Purshia tridentata small	2/12/08	42	7	100
Purshia tridentata large	1/18/08	42	7	

species, to facilitate their relocation. For example, pricklypear pads were planted in two rows of three pads each; *Plantago patagonica* (woolly plantain) was outplanted in two rows of five plants each. Larger species, such as bitterbrush, were widely dispersed in each plot.

Outplanting was done in two ways. Pricklypear and woolly plantain were planted close together to mimic their density in natural conditions. This was done by digging a narrow trench with a pick, inserting the seedlings at the edge of the trench, and then packing the soil back into the trench. All other seedlings were planted using a dibble with a planting blade 30 cm (11.8 in) long and 7.6 cm (2.8 in) wide.

Prior to outplanting, seedlings were extracted from the containers using one of several methods. The first involved rolling the container between the hands before gently removing the seedling. The second involved laying the container on the soil surface and gently tapping it until the seedling could be easily extracted. In some cases, larger seedlings, with long and extensive roots, had to be pulled out of the container by carefully pushing the roots through the open end of the tube. After being removed from the container, the seedlings were immediately placed in the planting hole and back-filled with soil. Care was taken to place the entire root system linearly in the hole without turning root tips up. Soil was packed around the seedlings to eliminate air pockets near roots. With the exception of the last planting date (12 February 2008), soils were adequately moist and did not require supplemental watering (Table 3).

Plot characteristics

Plots had variable cover of sand and gravel. Gravel cover percentage was visually estimated using a 0.5 m^2 (5.4 ft^2) gridded frame (1 x 0.5 m [3.3 x 1.6 ft]) divided into 50 squares. This measure was multiplied by two to provide an estimate of percentage cover per m^2. Three sample locations, from the middle and each end of the plot, were used to compute an average cover percentage of gravel per plot.

Monitoring and Data Analyses

Seedling condition and survival were monitored for each species on four dates: 16 May 2008, 28 June 2008, 28 May 2009, and 21 July 2010. Linear and non-linear regression analyses were used to estimate seedling survival rates over time. Linear effects were described as:

$$S = b_0 + b_1 t \quad [1]$$

where S is seedling survival, b_0 is the estimated survival at planting, b_1 is the survival reduction rate, and t is the number of days since planting. Non-linear effects were described in two exponential decay functions:

$$S = b_0 e^{-\lambda t} \quad [2]$$

$$S = b_2 + b_3 e^{-\lambda t} \quad [3]$$

where S is seedling survival, b_0 is the estimated survival at planting, b_2 is the long-term survival plateau level, b_3 is the difference between initial survival and the plateau level, t is the number of days since planting, and λ is the decay constant.

The study plots had varied gravel cover allowing an examination of the effects of gravel cover on seedling survival. The relationship between survival and gravel cover were described linearly as:

$$S = b_0 + b_1 g \quad [4]$$

where S is seedling survival, b_0 is the estimated seedling survival with no gravel, b_1 is the survival rate of change, and g is the amount of gravel.

Mean survival was analyzed using JMP software (SAS 2002). Survival percentage data were transformed (normalized) before statistical analysis (Steele and Torrie 1960). Survival data are presented using untransformed data with error bars for interpretation. Multiple range comparisons were done using the Tukey-Kramer HSD test at α=0.05.

Results and Discussion

Germination and Propagation

The effect of stratification and scarification can be highly variable among species. Many species do not require any pretreatment to achieve high germination success, while others may require stratification, scarification, or both. In our germination efforts; we did not attempt any scarification or stratification prior to sowing. In part, because of this, we experienced low and variable germination success with some species. Germination success of seeds started in Petri dishes (test #1) ranged from 0% to 75% depending on the species, species population, time or location of seed collection, and time of germination trial (Table 1). For seeds that were directly sown into tubes (test #2), germination and establishment success ranged from 0% to 85% (Table 2).

Achillea millefolium—Yarrow (*Achillea millefolium*) had high germination in Petri plates and when directly sown into tubes and did not appear to need stratification or scarification (Luna and others 2008).

Antennaria dimorpha—Pussytoes (*Antennaria dimorpha*) did not germinate even with seed collected at different times and locations. Little work has been done on the germination characteristics of pussytoes, and it may need stratification to germinate.

Astragalus succumbens—Columbia milkvetch (*Astragalus succumbens*) seeds require scarification (Young and Young 1986); germination was therefore low in our study.

Balsamorhiza sagittata—Arrowleaf balsamroot (*Balsamorhiza sagittata*) had low germination in the greenhouse with 0% survival following transplanting. This result confirms the suggestion by Skinner (2004) that the species needs a long cold stratification to germinate well.

Chrysopsis villosa—False goldenaster (*Chrysopsis villosa*) had low germination in the Petri plates and low transplanting survival for both spring and fall dates; 56% germination, however, was obtained when fall-collected and fall-sown seeds were placed directly in the tubes. Our results are similar to Young (2001), who reported 50% germination without any pretreatment with seeds collected in the fall. During our study, false goldenaster germinated and grew slowly in the greenhouse and was not planted in the field.

Chrysothamnus viscidiflorus—Seeds of yellow rabbitbrush (*Chrysothamnus viscidiflorus*) are not dormant, but often have low viability (Young and Young 1986). This may help to explain why our yellow rabbitbrush did not germinate in Petri plates. To successfully use this species in restoration, it is possible that large numbers of seeds will need to be collected and germinated in order to obtain enough seedlings for outplanting.

Crepis atribarba—We successfully germinated slender hawksbeard (*Crepis atribarba*) in Petri plates, but none survived transplanting. Similarly, only three of four seeds planted directly in tubes became established, so it was not used in the outplanting portion of the study.

Crocidium multicaule—Common spring-gold (*Crocidium multicaule*) is an annual that must germinate every year in the field. Germination was attempted immediately following seed collection, but was not successful. We concluded that either the seeds were not viable or that they require physiological stratification to break dormancy. No attempt was made to germinate common spring-gold in tubes.

Elymus elymoides—Squirreltail (*Elymus elymoides*) showed variable germination by population, with some populations yielding high percentages, while other populations had little germination. Squirreltail had high germination in tubes and Petri plates for seeds collected at location UAD1, but relatively low germination in Petri plants for seeds collected at location D-1281. This result suggests that there may be population variation in germination success. Squirreltail germinates without seed pretreatment (Young and Young 1986).

Epilobium brachycarpum—Tall annual willowherb (*Epilobium brachycarpum*) seeds did not germinate in the Petri plates. While there is little published on the germination of willowherb, there is more on fireweed (Epilobium angustifolium). Skinner (2006) notes some populations of fireweed germinate better with stratification while others do not. More experimentation is needed to understand the germination requirements of willowherb.

Fritillaria pudica—Yellow fritillary (*Fritillaria pudica*) seeds did not germinate in the Petri plates. Seeds from this species require a long period (90 days) of cold, moist stratification to germinate, and are best prepared for propagation by sowing in flats and leaving them outside for the winter (Skinner 2007).

Hesperostipa comata—Needle and thread grass (*Hesperostipa comata*) seeds had only 6% germination in Petri plates and 27% germination when planted directly in tubes. Baskin and Baskin (2002) found that needle and thread grass seeds did not need pretreatment to germinate, and seeds will germinate at 27 °C (81 °F). However, Young and Young (1986) found that acid scarification increases germination success.

Lomatium macrocarpum—Bigseed biscuitroot (*Lomatium macrocarpum*) had very low to no germination without pretreatment in our study. Cold, moist stratification has been used to increase germination success in other Lomatium species (Parkinson and DeBolt 2005).

Lupinus sericeus—Silky lupine (*Lupinus sericeus*) showed variable germination by population. Silky lupine had significant germination success with seeds from the UAD3 location, but no germination with seeds from the UAD NE location. This variation suggests populations may differ in seed viability. Seeds should be collected from a number of sites to determine if there is an effect of population on seed viability. In addition, greater seed germination success may occur if seeds are scarified (Young and Young 1986).

Oenothera pallida—Evening primrose (*Oenothera pallida*) did not germinate in the Petri plates and germination was not attempted by planting seeds directly in tubes. Little is published on the germination of evening primrose, but other Oenothera species require cold, moist stratification for germination (Wick and others 2004).

Opuntia polycantha—Pricklypear pads nearly all survived transport from the field, 5 days of drying, and subsequent planting in tubes.

Phlox longifolia—Populations of longleaf phlox (*Phlox longifolia*) varied by collection site. Longleaf phlox germinated successfully from two of three populations and did not require pretreatment. This result contrasts with that of Ridout and Tripepi (2009) who found cold stratification was needed to elicit significant germination. Variation in seed viability may be due to population effects.

Plantago patagonica—Woolly plantain *(Plantago patagonica)* seeds germinated well in the Petri plates and in the tubes. Under our test conditions, we concluded that woolly plantain does not need pretreatment for increased germination.

Poa secunda—Sandberg bluegrass (*Poa secunda*) did not germinate in the Petri plates, even with seeds collected at different times and locations. However, 26% of seeds germinated when planted in tubes.

Pseudoroegneria spicata—Bluebunch wheatgrass (*Pseudoroegneria spicata*) germinated well in Petri plates and in tubes. Both Sandberg bluegrass and bluebunch wheatgrass seeds have not been found to need any pretreatment for germination (Young and Young 1986).

Purshia tridentata—Bitterbrush (*Purshia tridentata*) seeds germinated in the Petri plates and in the tubes, but the germination rate depended on location. These seeds were not pretreated, yet germinated relatively well. This is in contrast with the observation that bitterbrush seeds are quite dormant (Young and Young 1986).

Sporobolus cryptandrus—Sand dropseed (*Sporobolus cryptandrus*) did not germinate in Petri plates or in tubes. This species requires a pretreatment of 5 days of cold-moist stratification and then germination in light with potassium nitrate enrichment (Young and Young 1986).

Outplanting Survival

Outplanting survival was highly variable and strongly species dependent. By 28 June 2008, average survival of all outplanted seedlings was 81%. Survival of the four grass species was greater than 83%, while survival of perennials was averaged 79%. Pricklypear pads had 100% survival, while silky lupine had the lowest survival at 42%. Seven of 10 species had survival greater than 83%, with no significant differences observed between species (Figure 2A). The three species with the lowest survival (below 55%) were not significantly different from one another.

By 28 May 2009, the average survival of outplanted seedlings dropped to 67%. Three of the four grass species showed the same survival percentages, while squirreltail dropped to 51%. Survival of perennials averaged 67%. Pricklypear pads continued to have 100% survival, while silky lupine still had the lowest survival percentage, dropping to 14%. Survival of woolly plantain was not considered because it is an annual. Five species showed survival greater than 85%, all of which were not significantly different from one another (Figure 2B). Four species had survival between 43 and 52% and were not significantly different.

By 21 July 2010, the average survival of outplanted seedlings dropped to 50%. Survival ranged from 100% (pricklypear) to 5.6% (silky lupine). Grass seedling survival was 63%, while survival of perennials was 41%. By the third year of outplanting, only 3 species had survival greater than 80%; survival of these species was not significantly different (Figure 2C). Four species had survival between 40% and 59% and were not significantly different. Squirreltail, longleaf phlox, and silky lupine had the lowest survival.

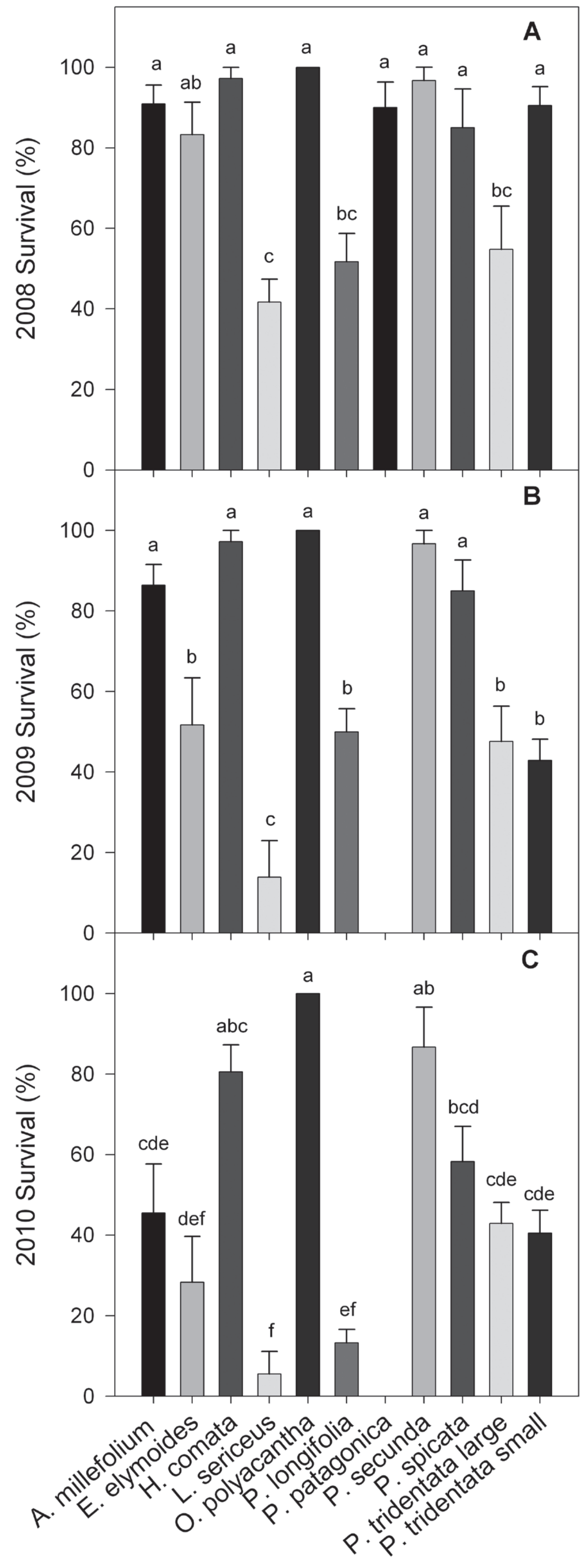

Figure 2. Mean seedling and *O. polycantha* (pricklypear) survival at the UMCD restoration site as measured on 28 June 2008 (A), 28 May 2009 (B), and 21 July 2010 (C). Different letters indicate significant differences at a = 0.05; error bars represent one standard error of the mean.

In general, our survival results were similar to Davies and others (1999), who found variability in survival of transplanted plugs on a species-poor grassland in Britain. They observed high survival 3 months after transplanting, but survival dropped to between 20% and 40% after 3 years. Cabin and others (2002) also saw outplanting survival drop to 56% after 18 months in Hawaii; survival was highly varied by species, ranging from 23% to 91%. We observed a drop in overall survival from 81% to 50% after 28 months, with individual species ranging from 6% to 100% survival. Regression analyses showed that survival rate decreases were significant for 7 of the 10 species planted. According to the trends observed in our regression analyses most of the species in this study may continue to show reductions in survival while pricklypear, Sandberg bluegrass, and bitterbrush may have stabilized (Figure 3). Continued monitoring is needed to accurately determine long-term survival and success of this restoration effort. It appears that the three species that have stabilized could be used, with some confidence, for long-term survival, for other restoration sites under similar conditions.

The conditions of our test may limit the generality of our results. It is possible that survival was higher in our study than a typical water-limited, competitive environment. In the summers of 2008 and 2009, we observed high amounts of soil water, a likely contributor to high survival. In 2008, soils were wet to a depth of only 5 cm (2 in); in 2009, soils were wet to a depth of 7 cm (2.8 in). This gives us the indication that seedling roots were planted in ideal soil moisture establishment conditions. We hypothesize that the recent removal of the asphalt and the lack of significant vegetation likely contributed to relatively high soil moisture conditions. It is also possible that the pre-existing parking lot became porous over the decades, thus allowing large amounts of soil water to accumulate in the underlying soil, making the study plots wetter than natural conditions.

Gravel cover ranged from 11% to 88% across the study plots and was a significant covariate for two of the species in the study area. From the cumulative survival data collected on 21 July 2010, a significant correlation was observed between percentage of gravel cover and survival percentage for squirreltail (P = 0.0322) and yarrow (P = 0.0246). The increase in gravel cover had a positive survival effect on squirreltail, while the effect was negative for yarrow (Figure 4).

The effect of gravel cover indicates that edaphic factors are significant for squirreltail and yarrow establishment. Variation in sand and gravel has been recognized as a significant factor in species establishment (Chambers 2000; Elmarsdottir and others 2003). Suzuki and others (2003) found higher survival with plants in finer soils and suggests this was associated with the greater water-holding capacity of a those soils compared to gravel. It is possible that greater water-holding capacity of the non-gravel surfaces improved success of yarrow, although we did not observe a strong gravel effect on soil moisture. Because there is a strong relationship between soil texture and soil moisture, it is possible that soils dried more in the gravel-covered areas later in the summer after we took our observations. It is also possible that factors other than water-holding capacity affected survival of the two species.

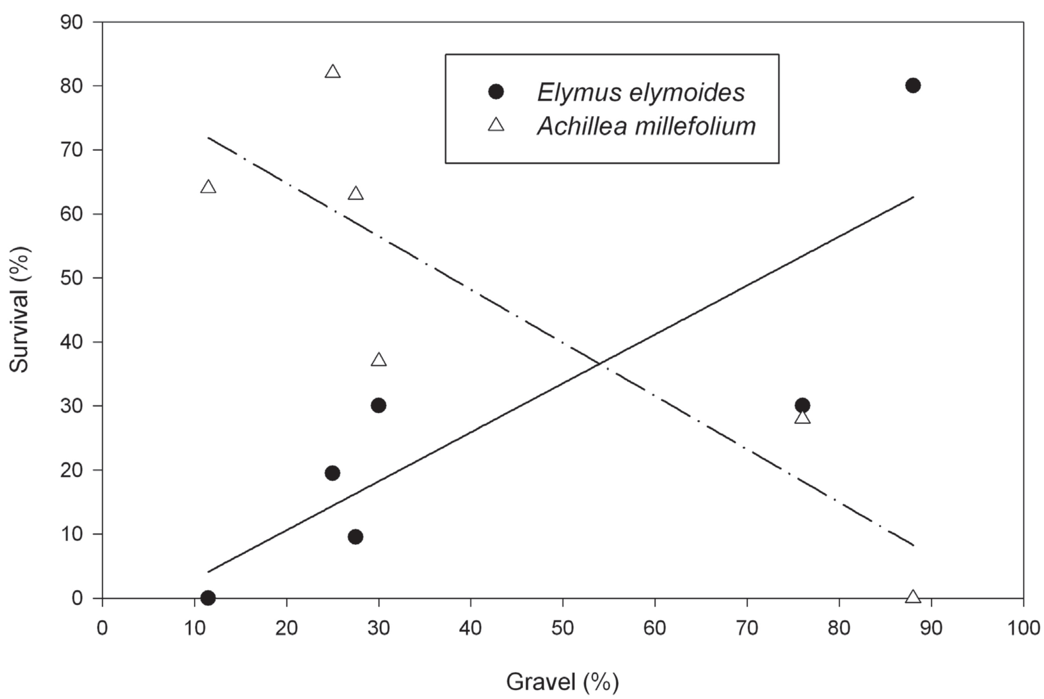

Figure 3. Linear and non-linear regression analyses describe changes in seedling survival over the 28 month study period.

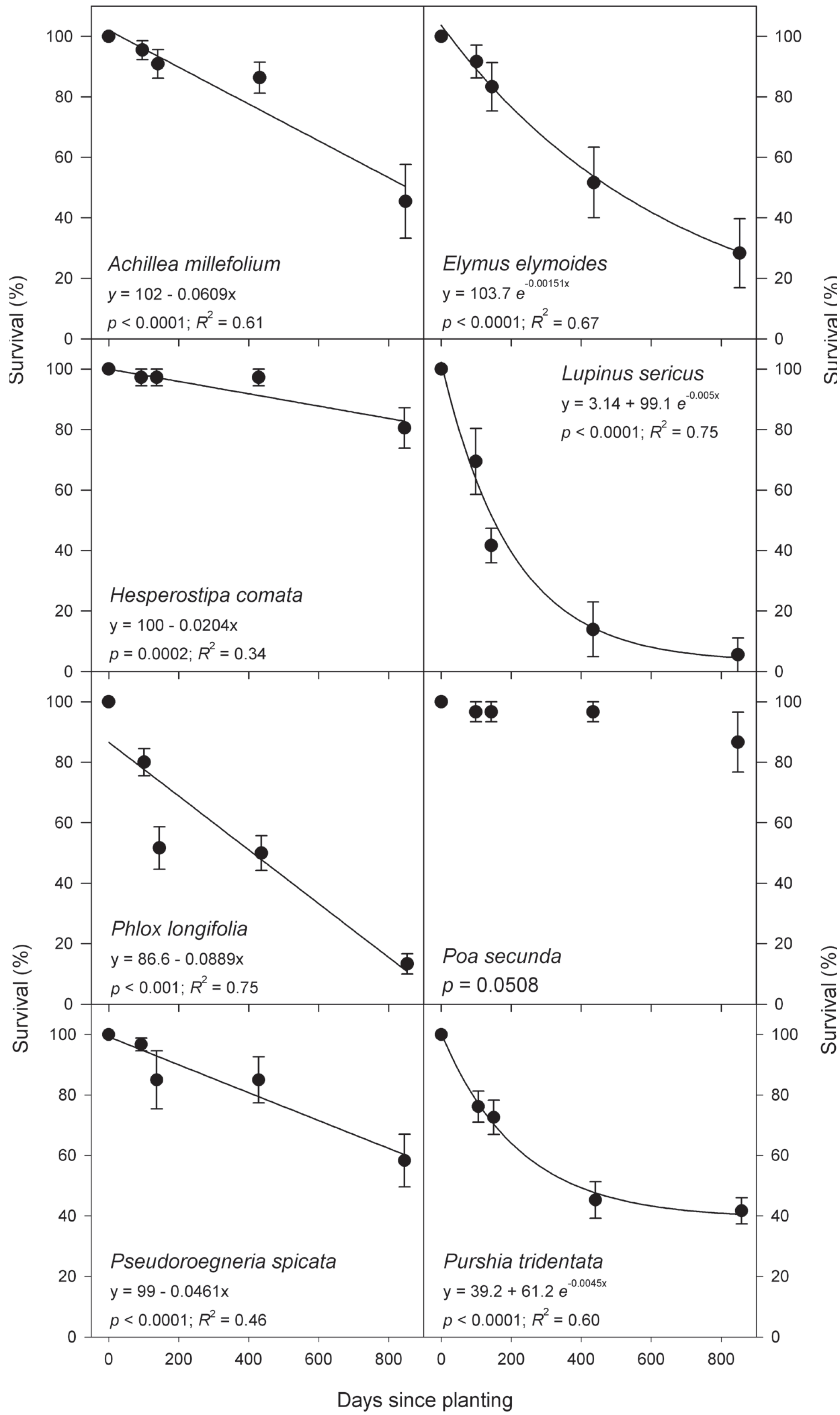

Figure 4. *Elymus elymoides* (squirreltail) (solid circles, black line) exhibited a positive survival relationship with percent gravel cover (y = -4.16 + 0.758x; R^2 = 0.66), while *Achillea millefolium* (yarrow) (empty triangles, dashed line) exhibited a negative survival relationship with percent gravel cover (y = 81.1 - 0.831x; R^2= 0.70).

Conclusions

The purpose of this work was to investigate and begin the process of ecological restoration at the UMCD. Many areas in need of restoration have a sand and gravel base that may limit the types of species that can successfully establish. Our trial restoration project helped us determine how some species respond to planting into sands and gravels. Overall survival was 50% during the course of the experiment. Most of the species in this study may continue to show reductions in survival, while pricklypear, Sandberg bluegrass, and bitterbrush survival may have stabilized. Further investigation is needed to determine how other species found on the UMCD can be germinated and which ones will successfully establish on bare soils. This knowledge will increase the likelihood of restoration success using local native flora for all future projects.

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