Predicting First-Year Bare-Root Seedling Establishment With Soil and Community Dominance Factors

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Abstract—The usefulness of measuring community dominance factors and the soil parameters of geometric mean particle size and percent fines as predictors of first-year bare-root establishment of Wyoming big sagebrush seedlings was investigated. The study was conducted on six sandy soils in south-central Washington. Soil parameters that could affect the distribution of Sandberg's bluegrass and cheatgrass as dominants in seral plant communities were also examined. Plant health was inversely related to increasing geometric mean particle size and directly related to increasing percent fines. Percent fines were also directly related to cheatgrass cover on these sandy soils. The highest sagebrush survival occurred on the alien-dominated sites.

Introduction

Mitigation for impacts to mature sagebrush habitat on the Hanford Site was conducted during fall 1998 on the semiarid sagebrush steppe of south-central Washington. Restoration in this area usually relies in part on transplanting Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Beetle & Young) seedlings into post fire habitats where the shrub component is absent. Bare-root seedlings are inexpensive to produce and plant, and have been shown to establish as readily as container-grown stock under good conditions (Whisenant 1999). However, bare-root seedling establishment in poor or more variable conditions has not been as successful (Barnett and McGilvray 1997; McKell and Van Epps 1980; Lohmiller and Young 1972). In conjunction with the 1998 habitat mitigation effort, a field study was initiated to investigate environmental and vegetational elements of the landscape that might be associated with successful establishment of bare-root seedlings. This research was conducted in the Lower Cold Creek valley on the Fitzner/Eberhardt Arid Lands Ecology Reserve (ALE) adjacent to the Department of Energy's (DOE) Hanford nuclear reservation.

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Landscapes are sometimes described as a blend of resource patches that support a mosaic of plant communities associated with changes in slope, aspect, and soil type (Whisenant 1999). In the sagebrush steppe of south-central Washington, resource patches are often the result of soil water availability, which is one of the most significant edaphic features affecting the distribution of habitat types across this semiarid landscape (Daubenmire 1974; Franklin and Dyrness 1988; Hironaka 1979).

Soils with high water holding capacity allow plants to survive periods of drought (Larcher 1995). While temporary physiologically induced water deficits often occur mid day when it is hot and sunny, long-term deficits are mainly caused by decreasing soil water availability (Kramer 1983). As the water content within the root zone decreases, the remaining water becomes less available to plants (Bristow and others 1984; Larcher 1995). The degree to which this availability is limited is strongly dependent on the soil's texture, or particle size distribution (Larcher 1995). Coarse sandy soils exhibit a low affinity to water (which makes it easier for plants to obtain); however, they also have a low water holding capacity. This is evident as farmers are forced to irrigate at much higher (less negative) soil water potentials in sands than in silts or clays (Bristow and others 1984).

It is reasonable to expect that planted seedlings would be affected by environmental gradients. Because shrub transplanting can be expensive, careful site selection that considers these gradients is an important and reasonable approach to achieving a high level of success.

Shiozawa and Campbell (1991) have shown that soil texture in terms of a geometric mean particle diameter and a geometric standard deviation are associated with the soil hydraulic property of moisture retention. If a significant association exists between geometric mean particle diameter and first-year seedling establishment, then these modeled parameters could be useful in selecting appropriate sites for planting in sandy areas.

Community competition on a site may also be a factor to consider in the prediction of restoration success. One of the more prominent plant species across the study area is cheatgrass (*Bromus tectorum* L.). While this ubiquitous winter annual maintains a competitive edge across most of the study area, its distribution and abundance varies in response to environmental gradients (Rickard 1975). Across much of the lower elevations of Hanford and ALE, cheatgrass has replaced the small native bunchgrass, Sandberg's bluegrass (*Poa secunda* Presl.), as the dominant understory species (Daubenmire 1970; Rickard 1975), yet Sandberg's bluegrass is still found to dominate or co-dominate on this habitat type in many areas. Link and others (1990) determined that the dominance of one or the other of these species was not a direct result of phenological differences or plant water status, but suggested it might depend on some other abiotic or biotic factors.

The purpose of this study was to find a practical approach to the prediction of bare-root seedling establishment on sandy sites in varying competitive environments, and to investigate the soil parameters that might be affecting the distribution of Sandberg's bluegrass and cheatgrass as dominants in seral plant communities on the Wyoming big sagebrush/Sandberg's bluegrass habitat type. The specific objectives were to characterize the relationships that exist between: (1) modeled geometric mean particle sizes and corresponding percent fines (percentage of particle sizes less than 53 μm) to first-year survival and health of bare-root Wyoming big sagebrush seedlings; (2) modeled geometric mean particle sizes and percent fines to community composition; and (3) community composition to first-year bare-root seedling survival.

Methods

Six 20-m x 30-m study plots were positioned on ALE along a sandy drainage of the Lower Cold Creek valley. The sites were in a post-burn seral condition with the shrub component lacking due to fire. The sites had not burned in at least 10 years. Three sites (A1, A2, A3) were selected to represent alien communities dominated by cheatgrass, while three other sites (N1, N2, N3) were selected to represent native communities dominated by Sandberg's bluegrass. Elevation at the study sites is about 134 m (440 ft). The potential native vegetation is Wyoming big sagebrush/Sandberg's bluegrass. Normal effective precipitation (October through May) is 126 mm (4.9 inches), with summer precipitation averaging 33 mm (1.3 inches) at the Hanford Meteorological Station (HMS) located about 22.5 km (14 mi) NNW of the study areas (Hoitink and others 1999). The soils were mapped into the Burbank series, which is made up of coarse-textured sands and loamy sands underlain by gravel (Hajek 1966).

Soil Measurements

Soils were sampled systematically at each site. Five cores were extracted at two depths (0.3 m and 1.0 m respectively) from each site. Samples from each core (30 cores, 60 samples) were sent to Soiltest Farm Consultants in Moses Lake, Washington, where nutrient content, soluble salts, organic matter, pH, and cation exchange capacities (CEC) were determined. Sand, silt and clay fractions were determined using hydrometer and wet sieve methods (Gee and Bauder 1986) on the 0.3-m soil samples. Prior to hydrometer measurements, soil samples were soaked in sodium-hexametaphosphate solution and placed on a shaker table overnight for particle dispersion. Soil drying methods and soil water calculations were conducted following Gardner (1986).

The parameters of geometric mean particle diameter and the associated standard deviation were estimated based on the two-parameter Sirazi and Boersma (SB) model described by Shiozawa and Campbell (1991):

$$d_g = \exp(5.756 - 3.454m_t - 7.712m_y) \qquad (1)$$

and,

$$\sigma_g = \exp\left\{\left[33.14 - 27.84m_t - 29.31m_y - \left(\ln d_g\right)^2\right]^{1/2}\right\} \qquad (2)$$

where: d_g is the geometric mean particle diameter, σ_g is the geometric standard deviation (both in μm), and the silt and clay fractions are represented by m_t and m_y respectively.

Community Measurements

Percent cover, species composition (based on relative cover), and frequency were determined during May 1999, following the coverage class method described by Daubenmire (1959), using a modified 0.2-m x 0.5-m sampling frame. Fifty samples were obtained from each site by splitting the 20-m x 30-m planting areas into two 10-m x 30-m halves. Five 10-m lines were then randomly positioned along the interior long axis and the flip of a coin determined if the lines would be positioned to the left or right of the tape. The sampling frame was then systematically positioned every meter along each of the five lines and ocular estimates of percent cover, percent species composition, and percent frequency for each species were determined.

Seedling Measurements

During November 1998, each 20-m x 30-m planting area was divided into 120 sections. Bare-root seedlings were randomly assigned (60 at each site) within each planting area. Seedling roots were dipped into a solution of water and fine-grade Terra-Sorb™ hydrogel (acrylamide coploymer) before planting. The following summer, during late July 1999, plant survival and health were qualitatively ranked according to the plant's overall appearance and phenological development (Caldwell and others 1973; Daubenmire 1975), and the following guidelines:

0 Dead, no live leaves left on the plant.
1 Plant displays low vigor (for example, no apparent new growth, no bud or reproductive stem elongation, and so forth) and at least 61 percent of the foliage is missing, chlorotic, or otherwise unhealthy in appearance.
2 Plant displays good vigor (for example, new growth and relatively green turgid leaves) and only displays between 11 and 60 percent of the unhealthy characteristics listed above.
3 Plant displays very good vigor (for example, ephemeral leaves growing on reproductive shoots) and displays no more than 10 percent of the unhealthy characteristics listed above.

All seedlings were identified (alive or dead), and measures of seedling height and two widths were recorded. Data for second-year survival, health, and growth, were not obtained because the test sites were destroyed by a large range fire that occurred in June 2000.

Analysis

Logistic regression and analysis of deviance were used to analyze the relationship between environmental and community characters and the multinomial ordinal response of the bare-root seedlings. The SAS Genmod procedure (SAS Institute, Cary, North Carolina) was used to perform the calculations.

Results and Discussion

Effective precipitation recorded at the HMS for the 1998–1999 (October through May) growing season totaled 99 mm (3.9 inches), which is about 78 percent of normal (Hoitink and others 1999, 2000). Summer precipitation received during the two months prior to seedling health and survival measurements totaled 10 mm (0.38 inches).

Soil and Seedling Measurements

Although there were several notable differences between the soil properties of the alien study plots and the native study plots (table 1), native plot N2 was more similar to the three alien plots in terms of soil properties than to the other two native plots. The alien plots exhibited higher percent fines and lower geometric mean particle sizes, than the native plots. In addition, alien plots had higher magnesium contents and higher CEC than the native plots (table 1). All sampled soils were considered alkaline, exhibiting pH values from 7.9 to 8.6 and increasing at depth to a maximum pH of 9.2. Soluble salts were also low across all plots (0.2 dSm^{-1}), indicating no hinderance to plant growth (Cline and others 1977).

Modeled geometric mean particle size was related to plant health ($X^2 = 13.41$, $p = 0.0003$, $df = 1$). Plant survival was inversely related to increasing geometric mean particle size (fig. 1). Mean particle sizes ranged from 97.1 to 213.3 μm. Modeled means across all sites were classified as fine sands based on the USDA classification system.

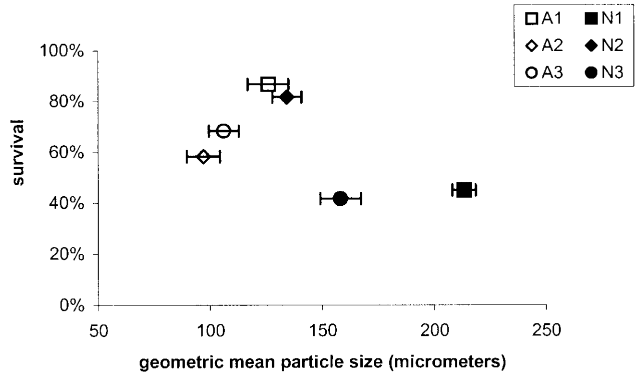

Figure 1—Percent survival of Wyoming big sagebrush seedlings relative to modeled geometric mean particle diameters for the six study sites. Bars represent ± one modeled standard deviation (n = 5 soil cores from each planting site).

Percent fines were also shown to be related to plant health ($X^2 = 12.22$, $p = 0.0005$, $df = 1$) with plant survival directly associated with increasing percent fines (fig. 2). Percent fines ranged from 5 to 27 percent. Seedling survival ranged from 42 to 87 percent (figs. 1, 2, 3).

Soil and Community Measurements

Percent fines were directly related to cheatgrass cover indicating that this component of soil texture was a good predictor of community dominance in the samples measured for this study ($X^2 = 245.83$, $p < 0.0001$, $df = 1$). Lower cheatgrass cover was observed on soils exhibiting less than 15 percent fines (tables 1 and 2). Nevertheless, native site N2 was found on soils similar to the soils found on the alien-dominated sites (table 1), indicating that community dominants on that site were affected by factors other than soil texture and available water.

Table 1—Summary of selected physical and chemical properties measured on the six study sites. Data are presented as means with ± one standard deviation (n = 5 soil cores from each site).

	Alien-dominated plots			Native-dominated plots		
	A1	A2	A3	N1	N2	N3
Texture						
Percent sand	82.8 ± 1.7	70.6 ± 3.7	71.6 ± 1.0	94.3 ± 1.0	79.6 ± 5.0	89.8 ± 3.5
Percent fines	17.2 ± 1.7	29.4 ± 3.7	28.4 ± 1.0	5.7 ± 1.0	20.4 ± 5.0	10.2 ± 3.5
Mean particle size (μm)	126 ± 9.1	97 ± 7.4	106 ± 6.6	213 ± 5.2	134 ± 6.5	158 ± 9.0
Nutrients						
Calcium (ppm)	964 ± 62.3	1136 ± 121	1136 ± 32.9	856 ± 388	1180 ± 130	764 ± 108
Magnesium (ppm)	174 ± 18.4	177 ± 38.8	186 ± 22	84.7 ± 24.2	201 ± 13.8	96.8 ± 28.4
Soluble salts (dSm^{-1})						
0.3 m depth	0.20 ± 2E-09	0.26 ± 0.089	0.20 ± 2E-09	0.20 ± 2E-09	0.20 ± 2E-09	0.20 ± 2E-09
0.9 m depth	0.46 ± 0.358	0.22 ± 0.045	0.20 ± 2E-09	0.22 ± 0.045	0.30 ± 0.228	0.22 ± 2E-09
Cation exchange capacity						
meq/100 g	6.5 ± 0.5	6.9 ± 0.5	7.0 ± 0.4	3.5 ± 0.5	7.2 ± 1.1	4.2 ± 0.3
pH 0.3 m depth	8.0 ± 0.1	8.4 ± 0.2	8.0 ± 0.2	8.2 ± 0.2	8.1 ± 0.2	8.4 ± 0.1
0.9 m depth	8.6 ± 0.5	9.2 ± 0.1	8.7 ± 0.4	8.7 ± 0.1	9.0 ± 0.1	8.9 ± 0.1

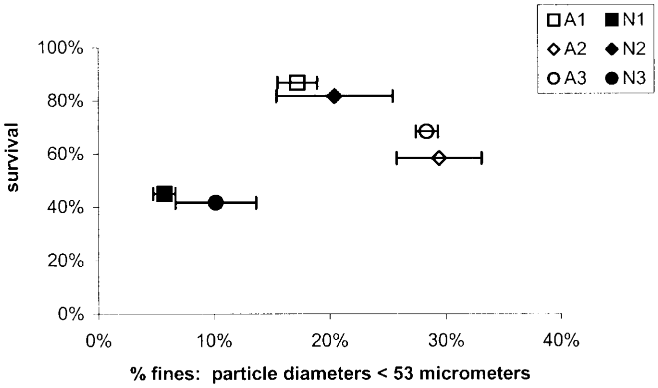

Figure 2—Percent survival of Wyoming big sagebrush seedlings relative to the percent fines across the six study sites. Bars represent ± one standard deviation (n = 5 soil cores from each planting site).

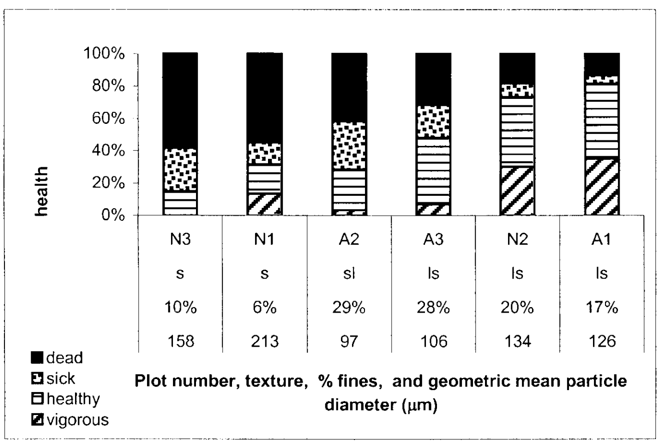

Figure 3— Health rankings in relation to alien [A] or native [N] dominated communities, texture, percent fines, and geometric mean particle diameters across the six study sites. Data are ordered by increasing survival (n = 60 bare-root Wyoming big sagebrush seedlings planted at each site). Textures were determined based on the USDA classification scheme (s = sand, sl = sandy loam, and ls = loamy sand).

Community and Seedling Measurements

Community factors of percent cover appear to be good predictors of bare-root seedling survival on these sandy sites ($X^2 = 7.12$, $p = 0.0076$, $df = 1$). Overall, the highest sagebrush survival occurred on the alien dominated sites with percent survival ranging between 58 and 87 percent (figs. 1, 2, and 3). This may be due to the increased percent fines and corresponding increased water-holding and cation-exchange capacities. On native sites N1 and N3, sagebrush survival was 42 and 45 percent respectively, while native site N2 exhibited an 82 percent survival (figs. 1, 2, and 3). Clear distinctions were evident with respect to percent cover and frequency between the native and alien plots (table 2). Sandberg's bluegrass cover on the native sites was between 30 and 39 percent and fell between 0.3 and 11.6 percent on the alien dominated sites. Likewise, cheatgrass cover on the native sites was between 16 and 22 percent and reached between 53 and 68 percent on the alien dominated sites. All sites exhibited low species diversity (table 2) which is consistent with the Wyoming big sagebrush/Sandberg's bluegrass habitat type (Daubenmire 1970).

Conclusions

Our study found that geometric mean particle size, percent fines, and community-dominance factors could be good indicators of potential bare-root seedling survival. With respect to soil texture, measuring geometric mean particle size was cumbersome and time consuming. The percent fines in a soil were much easier to measure, and can predict seedling establishment success just as well. Based on this data from the Lower Cold Creek valley, overall establishment success is more likely in soils containing greater than 15 percent fines. We recommend that percent fines, rather than geometric mean particle size, be used as an indicator of environments that would promote the successful establishment of bare-root seedlings on sandy locations. Furthermore, percent fines were found to be good predictors of community dominance, and community dominance factors were considered good predictors of seedling establishment. Often site selection guidelines restrict mitigation areas to high quality native sites. However, when quality native sites are not available, or if successful establishment of sagebrush is the only goal, the data provided in this study suggest that cheatgrass stands on sandy sites can be indicative factors that promote successful establishment of bare-root Wyoming big sagebrush seedlings.

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Table 2—Community measurements across the six study sites (n = 50, 0.2-m x 0.5-m plots from each 20-m x 30-m study site).

	Alien dominated plots			Native dominated plots		
Taxa	**A1**	**A2**	**A3**	**N1**	**N2**	**N3**
Shrubs	Percent cover * Percent species composition * Percent frequency					
Artemisia tridentata	–[1]	–	–	–	+[2]	+
Chrysothamnus nauseosus	–	–	–	–	–	+
Half shrubs						
Phlox logifolia	+	–	–	–	+	+
Antennaria dimorpha	–	–	–	–	+	–
Native perennial grasses						
Poa secunda	8.4 * 11.3 * 46	11.6 * 13.4 * 84	0.3 * 0.4 * 2	30.0 * 52.0 * 96	34.4 * 56.6 * 98	39.1 * 61.6 * 98
Pseudoroegneria spicatum	–	–	–	–	+	–
Sitanion hysterix	–	–	–	–	0.8 * 1.2 * 2	–
Stipa comata	+	–	–	+	–	–
Stipa thurberiana	–	–	–	–	0.8 * 1.2 * 2	–
Introduced annual grasses						
Bromus tectorum	53.0 * 71.7 * 100	67.6 * 76.7 * 100	62.6 * 83.0 * 100	16.0 * 27.7 * 82	21.9 * 36.0 * 96	18.9 * 29.7 * 96
Native perennial forbs						
Balsamorhiza careyana	–	+	–	–	+	+
Chaenactis douglasii	–	–	–	–	–	0.1 * 0.2 * 4
Crepis atrabarba	–	+	–	–	+	–
Erigeron poliospermus	–	–	–	–	+	+
Lomatium macrocarpum	–	–	–	–	+	–
Machaeranthera canescens	–	–	–	–	+	–
Native annual forbs						
Agoseris heterophylla	–	0.1 * 0.1 * 2.0	–	–	0.8 * 1.2 * 2	–
Ambrosia acanthicarpa	0.3 * 0.3 * 10	–	–	–	–	0.3 * 0.3 * 10
Amsinckia tessellata	0.1 * 0.1 * 2	–	+	0.1 * 0.1 * 2	–	–
Epilobium paniculatum	0.1 * 0.1 * 2	0.4 * 0.4 * 14	0.1 * 0.1 * 4	–	–	–
Microsteris gracilis	–	–	–	0.1 * 0.1 * 2	–	0.1 * 0.2 * 4
Introduced annual forbs						
Draba verna	0.8 * 1.1 * 32	3.9 * 4.4 * 86	4.3 * 5.7 * 62	8.4 * 14.6 * 96	1.1 * 1.8 * 44	3.6 * 5.6 * 54
Holosteum umbellatum	7.8 * 10.5 * 82	4.0 * 4.5 * 72	6.4 * 8.5 * 58	1.8 * 3.0 * 15	–	0.7 * 1.0 * 26
Salsola kali	1.9 * 2.5 * 54	0.5 * 0.6 * 20	0.7 * 0.9 * 26	1.2 * 2.0 * 46	1.2 * 3.5 * 48	0.3 * 0.5 * 12
Sisymbrium altissimum	1.3 * 1.8 * 22	0.1 * 0.1 * 2	0.2 * 0.3 * 8	0.2 * 0.3 * 6	–	–
Tragopogon dubius	0.6 * 0.7 * 12	0.1 * 0.1 * 4	0.9 * 1.2 * 6	0.2 * 0.3 * 6	–	+
Total native taxa and % cover	6 * 8.9%	6 * 12.1%	3 * 0.4%	4 * 30.2%	13 * 36.8%	10 * 39.6%
Total alien taxa and % cover	6 * 65.4%	6 * 76.2%	6 * 75.1%	6 * 27.8%	3 * 24.2%	5 * 23.5%

[1]– = not present on site.
[2]+ = present but not sampled.

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