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Is Pile Seeding Wyoming Big Sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) an Effective Alternative to Broadcast Seeding?

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Abstract

Sagebrush plays an important role in the ecological functions of sagebrush steppe plant communities and is a necessary component of habitat for a variety of wildlife including greater sage-grouse (*Centrocercus urophasianus*). At lower elevations, increased fire frequency associated with exotic annual grass invasion has heightened the need for effective sagebrush restoration strategies, but existing techniques have been largely ineffective. Our objective was to evaluate "pile seeding" (placing mature seed heads on the ground) of Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) as an alternative to broadcast seeding. We used a randomized block design ($n=5$) replicated in 2 yr at two contrasting ecological sites in southeastern Oregon. Treatments applied to 100×1.5 m plots included 1) pile seeding (four mature seed heads $\cdot$ pile$^{-1}\times10$ piles $\cdot$ plot^{-1}), 2) broadcast seeding (0.5 kg pure live seed [PLS] $\cdot$ ha^{-1}), and 3) natural recovery (i.e., nonseeded). Planting occurred in fall 2008 and 2009, and plots were monitored for seedling establishment for three or two growing seasons postplanting. Seedling density was estimated at the plot scale within a 50-cm radius of each seed head pile ("island scale"). In the year following planting, sagebrush seedling density at the plot scale was up to 60-fold higher ($P \leq 0.05$) in pile-seeded plots compared to natural recovery and broadcast plots. Seedling mortality was high (up to 98% reduction in density) for pile-seeded plots between the first and second growing seasons postplanting and differences between broadcast and pile-seeded plots dissipated by 2–3 yr postplanting. Although pile-seeding had higher initial density than broadcast seeding, neither technique had sufficient multiyear survival to suggest restoration efficacy at the plot scale. Seedling density at the island scale suggests that pile-seeding may be useful for establishing sagebrush islands, depending on year conditions. Research is needed to determine strategies capable of increasing long-term sagebrush seedling survival.

Key Words: competition, restoration, sagebrush restoration, seedling, survival

INTRODUCTION

Sagebrush plays an integral role in the ecology of sagebrush plant communities, fostering nutrient cycling and altering microhabitats to increase plant diversity and habitat structure (West 1983; Jackson and Caldwell 1993a, 1993b; Davies et al. 2009; Boyd and Davies 2012a). Additionally, empirical evidence (Boyd and Davies 2010, 2012a) suggests that prefire presence of sagebrush can increase postfire establishment of seeded perennial grasses. Sagebrush also provides habitat resources for a wide diversity of wildlife species (Crawford et al. 2004; Shipley et al. 2006; Aldridge et al. 2008; Davies et al. 2011). Recent concerns over declining greater sage-grouse (*Centrocercus urophasianus*) numbers and listing of this sagebrush obligate species as "warranted but precluded" from listing by the US Fish and Wildlife Service under provisions of the Endangered Species Act, have underscored the importance of both maintenance and restoration of sagebrush habitats.

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Sagebrush resources are particularly at risk in Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis* [Beetle & A. Young] S.L. Welsh) habitat. In these plant communities, exotic annual grasses such as cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* [L.] Nevski) have invaded and are disrupting ecological processes across large portions of the western United States (Melgoza et al. 1990; Whisenant 1990; D'Antonio and Vitousek 1992; Stringham et al. 2003; Davies 2011). Increased fire frequency associated with the subsequent accumulation of fine fuels is accelerating the loss of fire-intolerant native perennial plant species including Wyoming big sagebrush (Davies et al. 2011).

Much of the effort to rehabilitate these rangelands, both pre- and postfire, has centered on planting of perennial grass species, both as a matter of convention and because of the critical role of perennial grasses in controlling annual grass invasion (Davies 2008; Hardegree et al. 2012). Efforts to restore sagebrush using broadcast seeding techniques have met with only limited success, particularly at low elevations, and failure rates in excess of 70% have been reported (Lysne and Pellant 2004). High failure rates can be compounded by low seed availability and the limited lifespan of sagebrush seed. The viability of sagebrush seed in soil seed pools is limited to 2 yr (Wijayratne and Pyke 2012). This short life span is problematic following fire, given that environmental conditions necessary for germination and establishment of sagebrush (e.g., precipitation timing and amount) must occur within a short time period. When timely recovery does not occur, the limited dispersal distance of sagebrush seed severely constrains sagebrush reestablishment in the interior portions of burns (Ziegenhagen and Miller 2009).

New approaches for sagebrush establishment are clearly needed. One method that has shown potential for increased success rates is establishment via transplanting juvenile sagebrush plants (e.g., McAdoo et al. 2013). Although relatively successful, this method is hampered by significant financial and logistical outlays and may only be useful in establishing islands of sagebrush within larger disturbed areas (Longland and Bateman 2002; Davies et al. 2013; McAdoo et al. 2013). Another option would be to use "pile seeding," in which harvested mature sagebrush seed heads are arranged in small piles to maximize seed concentration. This technique is being evaluated in southeastern Oregon by the Bureau of Land Management and the localized concentration of seeds and plant material is thought to provide a favorable microclimate for seedling establishment. Our objectives were to 1) evaluate postfire pile seeding of Wyoming big sagebrush relative to natural recovery and broadcast seeding as a tool for increasing sagebrush density at the plant community scale, and 2) evaluate the potential of pile seeding for establishing small sagebrush islands.

MATERIALS AND METHODS

Experimental Design

This study used a randomized block design, with five blocks and three planting treatments and was replicated at two different ecological sites in 2 yr. At each site we located five experimental blocks to represent local variability in topography and vegetation composition, and within each block we established six adjacent 100×1.5 m plots. Plots within block were randomly split by year and then randomly assigned within year to one of three planting treatments: 1) natural recovery (i.e., no sagebrush planting), 2) broadcast seeding, or 3) pile seeding. All seeding was done in November of 2008 and 2009.

Study Areas

Ecological sites utilized in this study included: 1) a Clayey 10–12 PZ ("clay") site, and 2) a Sandy Loam 8 – 10 PZ ("sandy") site (Natural Resources Conservation Service [NRCS] 1997). Both sites were located near Frenchglen, Oregon (lat 42°49′N, long 118°53′W) and had been previously burned by wildfire; the sandy site in 1999 and the clay site in 2006. Data on prefire vegetation composition were not available but burned woody bases indicate prefire presence of shrubs. Fires at both study sites appeared to burn completely, removing all but one prefire shrub from the study plots. Ecological site descriptions suggest the clay site is capable of supporting Wyoming big sagebrush and bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh) A. Löve] whereas the sandy site can produce Wyoming big sagebrush, needle and thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), Thurber's needlegrass, (*Achnatherum thurberianum* [Piper] Barkworth), and Indian ricegrass (*Achnatherum hymenoides* [Roem. & Schult.] Barkworth). These plant communities are common across ecological provinces in southeastern Oregon and throughout the western United States (Anderson et al. 1998; Holechek et al. 2000). Soils at the clay site were well drained with a very cobbly clay loam surface underlain by very gravelly clay changing to fractured basalt at 33 cm depth. At the sandy site, soils were well drained with a loamy sand surface layer underlain by sandy loam (NRCS 1997). Elevation of the clay site was 1 463 m and 1 402 m for the sandy site. Both sites had $\leq 3\%$ slope and the clay site had a slight westerly aspect. The majority of the precipitation in this area falls as snow during the winter months and average frost-free period is 50–100 d (Eastern Oregon Agricultural Research Center data file, unpublished data; NRCS 1997).

Planting Treatments

We used a Versa-Drill seed drill (Kasco Mfg. Co. Inc., Shelbyville, IN) with drop-tubes disconnected to seed the broadcast treatment at a rate of 0.5 kg pure live seed (PLS) $\cdot$ ha^{-1}. A cultipacker attached behind the drill was used to help ensure adequate seed to soil contact. Due to the small size of sagebrush seeds, we mixed seeds with rice hulls for better flow through the seeder. For the pile seeding treatment we collected fully developed seed heads from Wyoming big sagebrush plants in unburned habitat within 10 km of the study sites. For each plot we placed four seed heads in each of 10 equally spaced piles along a transect that bisected the long axis of each plot. A landscaping nail was driven into the ground in the center of each pile to facilitate pile relocation. To approximate the number of seeds within piles, each planting year we stripped all seed and chafe from 10 seed heads, and for each seed head weighed seeds and chafe, and counted seeds in a 20% (by weight) subsample. The resulting number was multiplied by 20 (20% of a seed head sampled from piles containing four seed heads) to estimate the number of seeds within piles. We then used an estimated 5.5×10^6 sagebrush seeds $\cdot$ kg^{-1} (Tilley et al. 2008) to estimate the weight of seed applied per hectare using the pile seeding method. The average number of seeds within piles was 11 802.4 seeds $\cdot$ pile^{-1} $\pm$ 3 453.2 SE for the 2008 planting, and 12 554.0 seeds $\cdot$ pile^{-1} $\pm$ 2 036.6 SE for the 2009 planting. This equates to a seeding rate of approximately 1.45 kg $\cdot$ ha^{-1}, or, about three times the broadcast seeding rate.

Data Collection

Precipitation data were collected from the P Ranch Refuge, Oregon (Western Regional Climate Center 2013) and summarized by crop year (October 1–September 30). Sagebrush density was counted in June (2010) or July (2009 and 2011). Number and location of preexisting juvenile and mature sagebrush plants were noted for pretreatment density estimation and these individuals were excluded from all subsequent density counts (i.e., only seedlings that emerged during the course of our study were used in data analysis). To count density of seeded sagebrush we counted all plants occurring within a 100-m-long, 1-m-wide belt transect that bisected the long axis of each plot. We used this same transect to count the number of preexisting juvenile and mature sagebrush plants during the first year following seeding. Size differences allowed us to distinguish the seeded cohort from preexisting juvenile sagebrush plants. Within the belt transect, we noted the number of sagebrush seedlings occurring within a 50-cm radius of the nails used to mark the center point of seed piles. Pretreatment herbaceous and shrub canopy cover for existing vegetation was recorded for 10 40×50 cm quadrats spaced equally along the center long

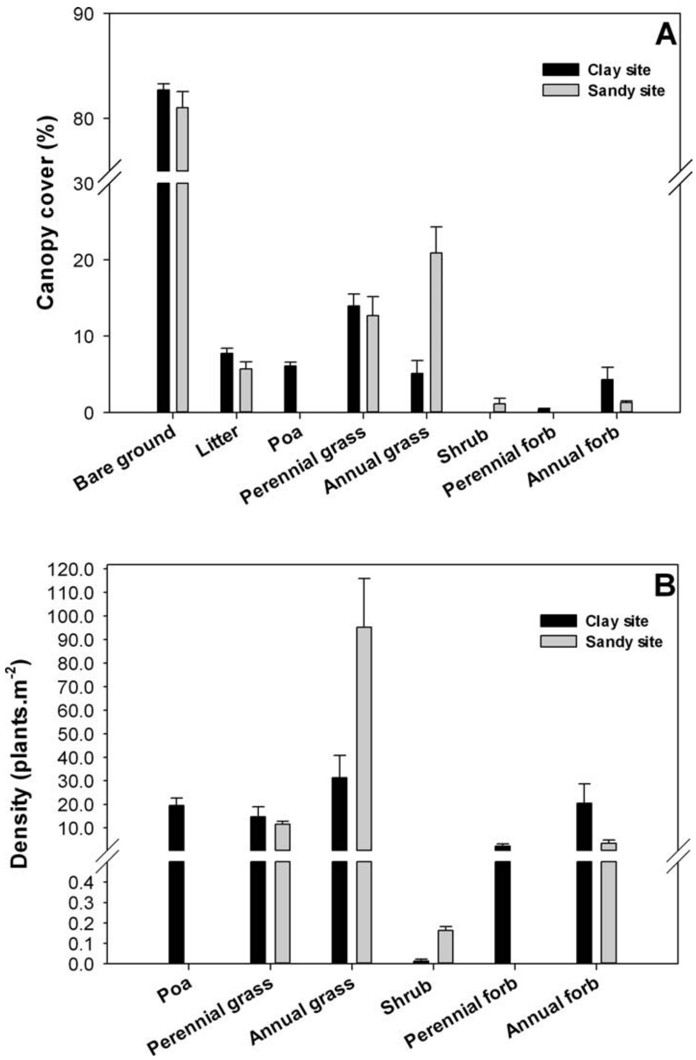

Figure 1. Graphs depicting canopy cover values for, **A**, bare ground, litter, and vegetation functional groups and, **B**, density of vegetation functional groups for study sites in southeastern Oregon. Bars reflect site means with associated standard errors.

axis of each block; density of herbaceous species was also counted within these quadrats. Cover and density values for preexisting vegetation were averaged within block and then across all blocks within site. Data were summarized by functional group: shrubs, large perennial bunchgrasses (excluding Sandberg bluegrass [*Poa secunda* J. Presl]), annual grasses, perennial forbs, and annual forbs.

Rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.]) was the dominant shrub at both sites. Common perennial bunchgrasses included needle and thread (sandy site) and squirreltail (*Elymus elymoides* [Raf.] Swezey, clay site, Fig. 1). Sandberg bluegrass was an abundant perennial grass at the clay site but did not occur at the sandy site. Cheatgrass was the only annual grass recorded and was more prevalent at the sandy site. Perennial forbs were a minor portion of species composition. Willowherb (*Epilobium palustre* L.), rough eyelashweed (*Blepharipappus scaber* Hook.), and annual pepperweed (*Lepidium* spp.) were abundant annual forbs at both sites.

Data Analysis

All statistical procedures were conducted using SAS v. 9.2 (SAS Institute, Cary, NC). Data were examined for skewness and kurtosis and if normality or homogeneity of variance assumptions were violated, data were weighted by the inverse of the treatment variance for analysis (Neter et al. 1990). The effects of seeding treatment and site on sagebrush seedling density at the plant community scale were determined by planting year and within year of data collection using mixed-model analysis of variance (ANOVA; Proc Mixed; Littell et al. 1996) with repeated years ($n=3$ for 2008 planting, $n=2$ for 2009 planting). When significant year by treat effects were found, data were analyzed with mixed-model ANOVA within year to assess treatment differences. To avoid confounding the effects of time since planting and year of data collection, we evaluated data for plots planted in 2008 and 2009 in separate models. Block and the block by treatment interaction were considered random effects in the model. Covariance structure for all models was determined using the Akaike's information criterion (Littell et al. 1996). To evaluate the efficacy of pile seeding for establishing sagebrush islands, we averaged annual density of sagebrush seedlings within a 50-cm radius of each pile in a plot and expressed this value as seedlings $\cdot$ m^{-2}. We then used mixed-model ANOVA as above to determine differences in pile seedling density between sites. When significant ($\alpha=0.05$) main or interactive effects were detected, we used the LSMEANS procedure to determine treatment, year, or site differences ($\alpha=0.05$). All means are reported with their associated standard errors.

RESULTS

Crop year precipitation was 105%, 97%, and 165% of the long-term (1897–2011) average (293 mm) for 2009, 2010, and 2011, respectively. Sagebrush seedling density at the plant community scale did not vary by site for plots planted in 2008 ($P=0.855$) or 2009 ($P=0.433$). For plots planted in 2008, density varied by the interaction of year and treatment ($P=0.001$) and density values varied by treatment in 2009 ($P=0.006$) and 2011 ($P=0.003$) but not 2010 ($P=0.334$, Fig. 2A). In 2009, sagebrush density of pile-seeded plots was 13- and 5-fold higher ($P<0.05$) than natural recovery and broadcast-seeded plots, respectively. In 2011, sagebrush density of broadcast-seeded plots did not differ ($P>0.05$) from pile-seeding, but was 16-fold higher ($P<0.05$) than natural recovery plots. For plots planted in 2009, density varied by the interaction of year and treatment ($P<0.001$); within year, treatment density differed in both 2010 ($P=0.019$) and 2011 ($P=0.003$, Fig. 2B). In 2010, density of pile-seeded plots was 6- and 59-fold higher ($P<0.05$) than natural recovery and broadcast-seeded plots, respectively. In 2011, sagebrush was not found in broadcast-seeded plots, and pile-seeded plots did not differ from natural recovery plots ($P>0.05$).

Sagebrush density within a 50-cm radius of piles (i.e., the "island" scale) in the pile-seeded treatment did not vary by site for plots seeded in 2008 ($P=0.787$) or 2009 ($P=0.912$). For plots seeded in 2008, density ranged from 5.2 plants $\cdot$ m^{-2} $\pm$ 1.34 SE in 2009 to 0.27 plants $\cdot$ m^{-2} $\pm$ 0.14 SE in 2011 (Fig. 3). For plots seeded in 2009, density ranged from

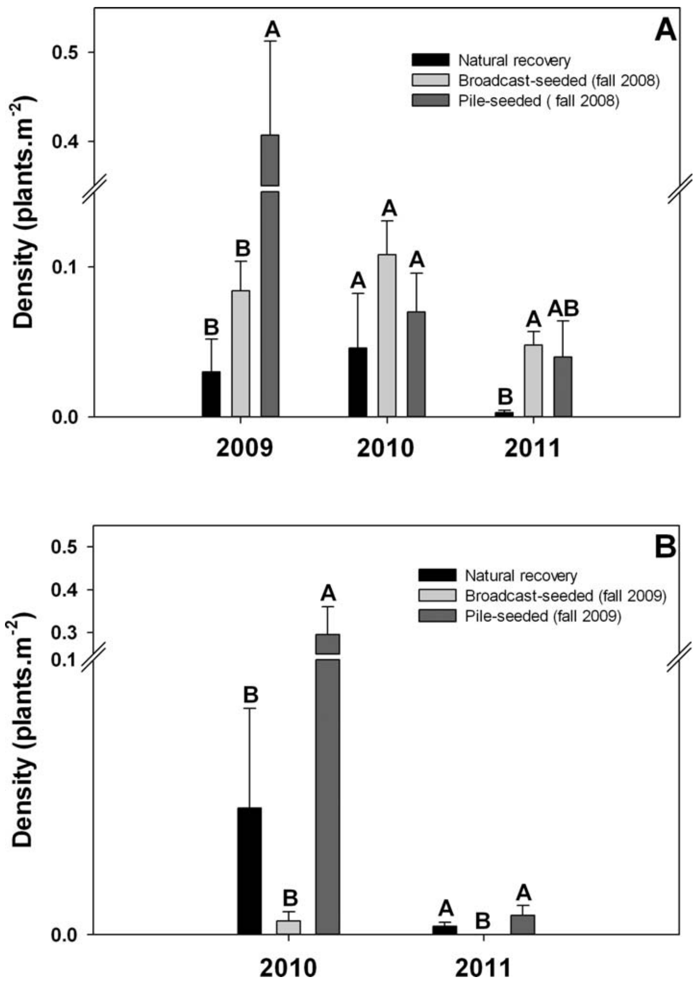

Figure 2. Density of sagebrush seedlings for natural recovery (i.e., nonseeded) and seeded plots in southeastern Oregon as a function of seeding treatment. Values represent averages across sites. **A,** Top graph depicts values for plots planted in 2008 and, **B,** bottom graph for plots planted in 2009. Bars represent treatment means with associated standard errors. Within a graph and year, bars without a common letter are different at $\alpha = 0.05$.

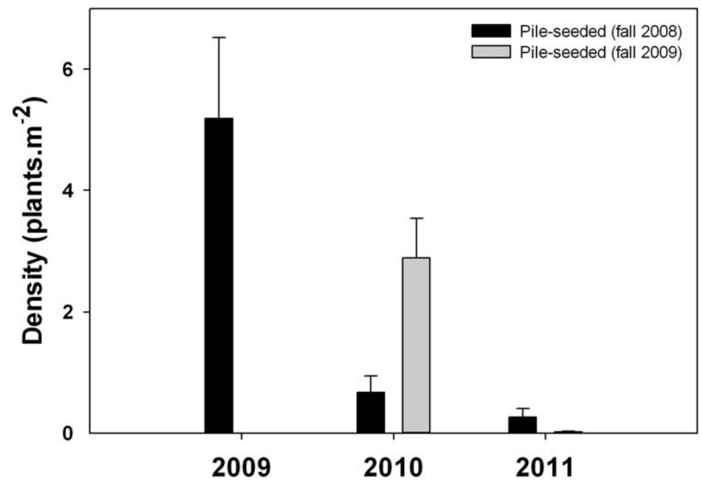

Figure 3. Density of sagebrush seedlings for pile-seeded plots in southeastern Oregon. Values reflect density within a 50-cm radius of the center of piles and are averaged across sites within year of planting.

3.68 plants $\cdot$ m^{-2} $\pm$ 0.83 SE in 2010 to 0.03 plants $\cdot$ m^{-2} $\pm$ 0.01 SE in 2011.

DISCUSSION

At the plant community scale, we found pile seeding to be an effective technique for promoting initial establishment (first year) of sagebrush seedlings as compared to broadcast seeding or natural recovery (Fig. 2) but multiyear survival of seedlings was poor across treatments. Data for nonseeded plots suggests that up to half or more of the initial seedlings (1 yr postplanting) in the broadcast treatment and less than 15% of the initial seedlings in the pile-seeded treatment were from natural recovery (Fig. 2). The estimated number of seeds associated with pile seeding was approximately three times higher per unit area as compared to broadcast seeding. Thus, we might have expected higher initial seedling density with pile seeding based solely on the number of seeds planted. However, pile-seeded plots had approximately five times and 60 times the number of sagebrush seedlings in the first growing season following planting in 2008 or 2009, respectively (Fig. 2). This suggests that factors associated with pile seeding other than estimated seeding rate were contributing to increased initial sagebrush establishment in this treatment. We suspect that piling seed heads may have created a favorable microclimate for germination and/or initial development of sagebrush seedlings as compared to the broadcast seeding. Others have reported that application of surface mulch at time of seeding can increase seedling establishment, perhaps in association with reduced diurnal temperature variability and increased and prolonged water availability (Schuman et al. 1980, 1998).

One of the clear messages from our work was that seedling survival is a critical demographic stage for Wyoming big sagebrush restoration. Although the literature indicates that establishment of Wyoming big sagebrush from seed is often, if not generally, problematic, little is known regarding which specific demographic stages are most limiting. Some empirical evidence suggests that germination is not likely to be a limiting factor for sagebrush (Harniss and McDonough 1976). This research is consistent with field observations in the current study indicating prodigious numbers of seedlings in the first late-spring period (i.e., early May) following planting, and much reduced seedling abundance by the time of first data collection (June or July). This trend of decreasing density over time was also observed in natural recovery plots.

Overall, our data suggest that interannual survival may severely limit long-term establishment of pile-seeded sagebrush seedlings. Given that our sites were within established herbaceous plant communities, interspecific competition from existing perennial and annual species could have reduced interannual survival of sagebrush seedlings and slowed sagebrush recovery (Williams et al. 2002; Boyd and Svejcar 2011). However, our choice to seed into an existing herbaceous plant community is similar to conditions encountered in postfire sagebrush restoration (i.e., sagebrush is greatly reduced or eliminated but herbaceous vegetation is present). Alternatively, clustered sagebrush seedlings associated with pile seeding could increase intraspecific competition and reduce survival (Owens and Norton 1989), but the role of intraspecific competition in influencing survival of sagebrush seedlings is not well understood. Clustering of sagebrush seedlings could also mimic natural seed dispersal patterns of sagebrush (Young and Evans 1989) and other authors have noted improved growth rates of clustered vs. nonclustered seedlings in single-species growth trials (Madsen et al. 2012). Under conditions of moderately limited resources, conspecific growth has been shown to promote facilitation, as opposed to intraspecific competition (Fajardo and McIntire 2011). Low soil water content, or asynchronous timing of seedling development relative to seasonal precipitation patterns could also increase mortality of sagebrush seedlings (Stahl et al. 1998; Maier et al. 2001; Ziegenhagen and Miller 2009).

Low interannual survival of pile-seeded seedlings in the current study and low seedling density with broadcast seeding or natural recovery suggests that none of these options are ideal for establishing Wyoming big sagebrush at the plant community scale. We calculated plant community scale density values to facilitate comparison between pile and broadcast seeding, but these values are somewhat misleading for pile-seeded plots in that the actual piles of seed heads occupied only a small portion of the overall plot. Calculating density for pile-seeded plots within a 50-cm radius of the center point of the pile (i.e., the "island" or the area actually seeded) indicated that pile seeding may be useful as a technique for establishing sagebrush islands (Longland and Bateman 2002), dependent on yearly conditions. At 3 yr postplanting, the 2008 pile seeding retained 0.04 plants $\cdot$ $m^{-2} \pm 0.02$ SE (Fig. 3). This is certainly well below the density of a fully stocked Wyoming big sagebrush community (approximately 0.5 plants $\cdot$ m^{-2} to 1.0 plants $\cdot$ m^{-2}; Anderson and Inouye 2001; Davies and Bates 2010) but densities of this magnitude could be useful in establishing plants to provide a seed source to accelerate recovery of sagebrush (Ziegenhagen and Miller 2009).

Lack of differences in seedling establishment between sites used in this study was somewhat intriguing given abiotic differences between the two ecological sites. In dry years, we predicted that seedling germination and establishment at the sandy site would be hampered by a lack of water-holding capacity associated with coarse-textured soils (Eiswerth et al. 2009; Boyd and Davies 2012b). The fact that precipitation was roughly at or above normal in all 3 yr of this study may have acted to promote adequate soil water availability across sites and minimized site differences in seedling establishment.

MANAGEMENT IMPLICATIONS

Our low success with direct seeding techniques, combined with similar published results, suggests that with current technologies direct seeding is a low-probability method for reestablishing Wyoming big sagebrush at the community scale. Other techniques, namely transplanting juvenile sagebrush, may be more labor intensive but offer a higher probability of success in harsh environments typical of the Wyoming big sagebrush alliance (e.g., Davies et al. 2013; McAdoo et al. 2013). That said, the high density of seedlings we found in the year following planting suggests that pile seeding may offer advantages to natural recovery or other direct seeding methods such as broadcast seeding, and pile seeding may be effective at smaller scales associated with island seeding. Our seedings took place within the context of preexisting herbaceous plant communities (i.e., no attempt was made to control non-sagebrush vegetation) and low interannual survival of seedlings (see Fig. 2), regardless of planting technique, is consistent with previous research suggesting potential management benefit from control of competing herbaceous vegetation prior to sagebrush seeding (e.g., McAdoo et al. 2013). Success with the pile seeding technique will depend in part on timing of seed head collection. Seed heads must be mature, but should be collected prior to seed shatter to avoid loss of seeds. Additional research to determine the specific environmental drivers of survival of emergent seedlings could help isolate factors to be addressed in future development of sagebrush restoration techniques.

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