Outplanting but not seeding establishes native desert perennials

Scott R Abella, Donovan J Craig, and Alexis A Suazo

ABSTRACT

Developing reliable techniques for revegetating disturbed arid lands is challenging. Few studies have directly compared effectiveness of the 2 main revegetation techniques—seeding and outplanting—and the relationship to various treatments intended to enhance plant establishment. We compared seeding and planting and evaluated granivory protection, irrigation, and shelter treatments with a range of native perennial species monitored for 3 y on a wildfire site in the Mojave Desert of southern Nevada. Contrasted with previous studies in the Mojave Desert, seeding failed to establish new plants, despite protecting seeds from small mammal granivory, irrigating, and using seeds known to be viable during a study period that included a mix of moist and dry years. Outplanting, however, resulted in third-year survival ≥ 22% for 4 of 10 species. The best-performing species and their survival included desert globemallow (*Sphaeralcea ambigua* A. Gray [Malvaceae]; 55%), Eastern Mojave buckwheat (*Eriogonum fasciculatum* Benth. [Polygonaceae]; 28%), white bursage (*Ambrosia dumosa* (A. Gray) Payne [Asteraceae]; 23%), and creosote bush (*Larrea tridentata* (DC.) Coville [Zygophyllaceae]; 23%). Adding either water or shelter approximately doubled survival. Surviving the first year appeared critical to success, as outplants healthy at year 1 remained alive at year 3. Although outplanting is often considered inferior for introducing propagules to larger areas in comparison with seeding, a finding that 86% of *Sphaeralcea* and 73% of *Eriogonum* survivors were flowering suggests that potential seed production by the outplants should not be dismissed. Results suggest that outplanting native perennials can revegetate desert disturbances, especially if early survival can be increased.

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KEY WORDS
container stock, disturbance, fire, Mojave, recovery, restoration, revegetation, species selection

NOMENCLATURE
Plants: USDA NRCS (2012)
Insects: ITIS (2012)

CONVERSIONS
1 ha = 2.47 ac
1 km = 0.6 mi
1 m = 3.3 ft
1 cm = 0.4 in
1l = 0.26 gal

Resource managers frequently seek to revegetate a variety of disturbances in arid lands to reduce soil erosion, enhance plant productivity, and improve wildlife habitat (Bainbridge 2007; Figure 1). Two major revegetation techniques include seeding and outplanting nursery-grown seedlings (Bean and others 2004). These methods have tradeoffs: seeding is considered capable of covering a greater area compared with outplanting, while outplanting bypasses the uncertainty of germination in field settings but requires nursery care of plants (Petersen and others 2004). Moreover, effectiveness can differ between these techniques, and some species perform well with only one technique or the other (Montalvo and others 2002). Despite the importance of choosing which technique to employ for revegetation, studies that directly compare effectiveness of seeding and outplanting for the same species are uncommon compared with studies that assess only one method. Furthermore, a sampling of seeding-planting comparative studies in the southwestern US, for example, shows mixed results. One study concluded that seeding was more effective than planting in a moist study area (Palmerlee and Young 2010), while three other studies, in moist and semiarid areas, concluded that outplanting was far more effective (Glenn and others 2001; Strathmann 2002; Bean and others 2004).

In addition to revegetation technique, treatments designed to improve plant establishment can affect revegetation success. For instance, consumption of seeds by granivores can impede seeding success. Consequently, protecting seeds (for example, by using fences to exclude granivores) may be a treatment associated with seeding (DeFalco and others 2009). Irrigation is an additional treatment that can promote germination for seeding and enhance survival of outplants (Bean and others 2004). Water can be provided through several methods, such as hand-watering or gel materials that slowly release water (Newton 2001). Another treatment affiliated with outplants is providing shelters, which are intended to ameliorate microclimates (by providing shade and conserving moisture) and to reduce herbivory (Bainbridge 1994a; Figure 2). Treatments have exhibited mixed efficacy for arid land revegetation (Abella and Newton 2009) and increased labor and cost, making it important to determine if the investment increases plant establishment.

The prevalence of anthropogenic disturbance and inherently slow natural revegetation has made developing effective revegetation techniques a priority in southwestern US deserts. For example, disturbance from solar energy development and wildfire have increased during the first decade of the 2000s (Steers and Allen 2010; Lovich and Ennen 2011). Invasion and fuel production by exotic annual grasses, such as red brome (*Bromus rubens* L. [Poaceae]), have facilitated fire spread in the Mojave Desert. A remarkable 3% of the entire desert burned in 2005 alone, and this desert has little history of fire and contains mature vegetation considered poorly adapted to fire (Brooks and Matchett 2006). Our study objectives were to 1) compare seeding and planting for establishing a range of native Mojave Desert perennial species; and 2) evaluate effectiveness of granivory protection, water, and shelter treatments for promoting plant establishment.

Figure 1. Mature Mojave Desert vegetation is increasingly threatened by wildfires fueled in part by exotic annual grasses, such as in this view of Red Rock Canyon National Conservation Area in southern Nevada. Photo by Robert J Abella

METHODS

Study Area

We conducted the study in the eastern Mojave Desert in Clark County, southern Nevada, southwestern US. The experimental site (lat 35°52′08″N, long 115°27′31″W; 25 km southwest of the City of Las Vegas) was on USDI Bureau of Land Management acreage within the 2005 Goodsprings Fire. This fire was ignited by a 22 June lightning strike and burned 13,585 ha of desert shrubland with native fuels augmented by exotic annuals such as *Bromus rubens*. At an elevation of 1250 m, the site was on a generally flat plain containing burned woody skeletons indicative of a mixed-shrubland community dominated by *Ambrosia dumosa* (A. Gray) Payne (Asteraceae), *Larrea tridentata* (DC.) Coville (Zygophyllaceae), and blackbrush (*Coleogyne ramosissima* Torr. [Rosaceae]). When we initiated the study 3 y after the fire, the burned area was typical of initial post-fire environments in the Mojave Desert: the mature, late-successional shrub community was lost, annual plants remained sparse, and colonization by early successional perennials such as *Sphaeralcea ambigua* A. Gray (Malvaceae) was sporadic (Steers and Allen 2010) (Figure 2). Soils were mapped as loamy, mixed, superactive, thermic, shallow Typic Petrocalcids of the Irongold series (Lato 2006).

Seed Characteristics and Species

Seeds for the seeding and outplanting experiments were collected locally in Clark County and included a range of native

TABLE 1

Species used for seeding and outplanting on the Goodsprings Fire in the Mojave Desert, southern Nevada.

Seed mix/species	Common name	Germination[z] (%)	Seeding density[y] (Seeds/m²)	Seeding density[y] (PLS/m²)	Seed mass (mg/seed)	Outplanted
FORB						
Baileya multiradiata Harv. & A. Gray ex A. Gray (Asteraceae)	Desert marigold	70	500	425	0.5 ± 0.1[x]	Yes
Penstemon bicolor (Brandegee) Clokey & D.D. Keck ssp. *roseus* Clokey & D.D. Keck (Scrophulariaceae)	Pinto beardtongue	0	500	425	0.5 ± 0.1	Yes
Sphaeralcea ambigua A. Gray (Malvaceae)	Desert globemallow	30	1000	420	1.0 ± 0.1	Yes
GRASS						
Aristida purpurea Nutt. (Poaceae)	Purple threeawn	100	500	425	0.7 ± 0.1	Yes
Muhlenbergia porteri Scribn. ex Beal (Poaceae)	Bush muhly	—	—	—	—	Yes
Sporobolus airoides (Torr.) Torr. (Poaceae)	Alkali sacaton	—	—	—	—	Yes
EARLY SUCCESSIONAL SHRUB						
Bebbia juncea (Benth.) Greene (Asteraceae)	Sweetbush	30	500	200	0.9 ± 0.1	No
Encelia farinosa A. Gray ex Torr. (Asteraceae)	Brittlebush	5	500	210	1.0 ± 0.1	Yes
Hymenoclea salsola Torr. & A. Gray (Asteraceae)	Burrobrush	20	500	338	3.9 ± 0.4	No
EARLY-LATE SUCCESSIONAL SHRUB						
Ambrosia dumosa (A. Gray) Payne (Asteraceae)	White bursage	4	500	257	4.7 ± 0.7	Yes
Eriogonum fasciculatum Benth. (Polygonaceae)	Eastern Mojave buckwheat	9	1300	234	1.0 ± 0.1	Yes
Larrea tridentata (DC.) Coville (Zygophyllaceae)	Creosote bush	39	500	210	4.7 ± 0.4	Yes

[z] Laboratory germination test.

[y] Total density of seed and pure live seed (PLS) seeded on plots.

[x] Values are mean ± standard error of the mean (based on 20 seeds/species).

perennial forb, grass, and shrub species that regional land managers are interested in working with in revegetation projects (Table 1). We divided shrubs into 2 categories: 1) early successional species that are initial colonizers of disturbance; and 2) early-late successional species that can either be initial colonizers and components of mature communities or late-successional species (Abella 2010). In addition to the pure live seed information supplied by the seed collectors, we conducted our own germination tests to confirm that some seeds were ready to germinate (Table 1). Using 120 seeds/species placed on moistened paper towels in Petri plates at room temperature in a laboratory lighted from outside windows, we monitored for radicle protrusion for 6 wk.

Seeding Experiment

The seeding experiment was a 3-factor, randomized complete block factorial design including 5 levels of seeding (4 mixtures of species and a non-seeded control), 2 levels of granivory protection (caged or not), and 2 levels of irrigation (present or none), with each of the 20 treatment combinations appearing in each of 4 blocks. Each block was 20 m × 25 m and contained 20 plots that measured 2 m × 2 m in size (with a ≥ 4-m buffer between plots); each plot received the appropriate treatment. Blocks were laid out 100 m from one another. Plots were seeded by hand-broadcast and patted down by hand to ensure seed:soil contact on 29 January 2008 according to the seed mixtures in Table 1. Cages (mesh wire with 1-cm diameter openings), 1 × 1 m (length × width) and 0.25 m tall, were affixed to the centers of appropriate plots to exclude small mammals and birds for the granivory protection treatment (Figure 2A). Flush on top of the ground and emanating perpendicularly to the cage, 15 cm of wire was fastened around each cage to deter burrowing into cages (which was observed on only one plot). The irrigation treatment consisted of applying 4 l/m² (0.4 cm of water)

Figure 2. Views of this revegetation experiment in the Mojave Desert, southern Nevada, showing seeded plot with a granivory exclusion cage (A; foreground), installation of outplants and shelters (B), initial hand-watering of outplants (C), and site immediately after outplanting (D). Photos by Scott R Abella

of tap water using a watering can by hand immediately after seed application and 2 l/m^2 (0.2 cm of water) as a single application each month for the first 4 mo after seeding.

Outplanting Experiment

Plants were grown for a year in 4-l (15 cm in diameter and 20 cm tall) plastic pots filled with 2:1 sand:organic potting soil in local greenhouses. We kept plants in the containers, rather than creating bareroot stock, because our field site was accessible (so added weight of containers was not a concern) and we wished to retain the full root mass and potting soil during outplanting (Bainbridge 2007). The outplanting experiment was a randomized complete block design containing species (10 native perennial species), irrigation (present or absent), and shelter (present or absent) factorially applied as 40 combinations each appearing once in each of the 10 blocks. This resulted in 40 total outplants per species and 400 overall. This experiment occurred 100 m east of the seeding experiment. Blocks (replicates) were 80 m long transects containing treatments assigned at random distances (in 1 m increments). Transects were separated from one another by 3 m. Plants were 1 y old when outplanted on 12 February 2008. After digging holes with shovels, we carefully ensured that the full root mass and soil from pots were transferred into the ground. We immediately provided each outplant with 1 l of water. Shelters (10 cm diameter × 60 cm tall green plastic cylinders; Tubex®, South Wales, United Kingdom) were installed over appropriate plants and fastened to the ground with bamboo sticks (Figure 2B). The irrigation

Figure 3. Tube containing a DriWater™ gel pack, providing slow-release water, installed to the left of the *Sphaeralcea ambigua* outplant in the foreground of the photo. Photo by Scott R Abella

treatment consisted of installing DriWater™ gel packs (DriWater Inc, Santa Rosa, California) in plastic tubes open in the soil adjacent to the root mass following manufacturer-recommended procedures (Figure 3). DriWater was recharged after 3, 5, 7, 15, and 20 mo.

Data Collection and Climate

Seeded plots were inventoried for seeded species 45, 90, 125, 220, and 365 d after seeding, with a final inventory 3 y after seeding (18 May 2011). On the same schedule, survival, height (to the nearest 5 cm), and flowering status were recorded for outplants.

Precipitation data were obtained from a weather station 2 km from the site (Regional Flood Control District, Clark County, Nevada; http://www.ccrfcd.org/raingauges.htm) with 10 y of records. The 10-y average was 114 mm/y. During the study, annual precipitation and percentage of the 10-y average was 116 mm (102%) in 2008, 72 mm (63%) in 2009, 200 mm (175%) in 2010, and 40 mm (70%) in 2011 through May (Figure 4). We obtained the Palmer Drought Severity Index for southern Nevada (Division 4) from the National Climatic Data Center (http://ncdc.noaa.gov). Extended dry conditions characterized by negative index values prevailed during the first part of the study period before conditions became moist during the latter part of the study (Figure 4).

Data Analysis

The seeding experiment failed to result in seedling establishment, so no statistical analysis was done. In the outplanting experiment, the proportion of plants alive at year 3 was analyzed using the following analysis of variance (ANOVA) model: arcsin (square root) proportion alive = species + water + shelter (+ all two-way interactions). Because some components of the model had zero variance (simply because some species had no survival), and this violated the homoscedasticity assumption, we computed *P*-values for ANOVA and significance of pairwise contrasts between means through permutation (1000 permutations). Analyses were conducted using R software (http://www.r-project.org/).

RESULTS

Seeding

No seedlings of seeded species were observed on seeded plots during the duration of the study.

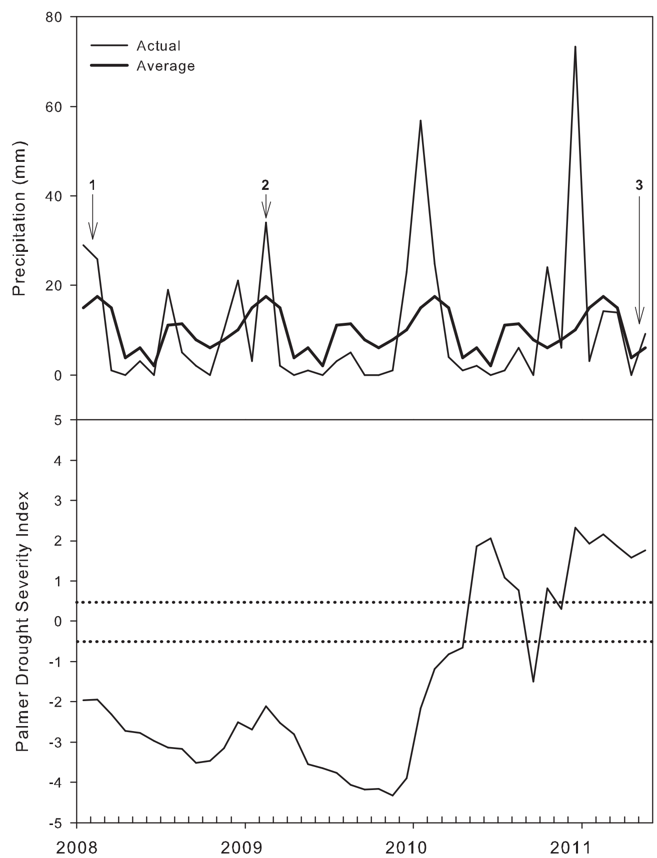

Figure 4. Precipitation recorded during the study compared with the 10-y average of available records (top). Arrows with numbers represent key study events: 1, completion of seeding and planting treatments; 2, data collection at year 1 following intermediary measurements; 3, final data collection 3 y after seeding and planting. Palmer Drought Severity Index recorded during the study (bottom). Index categories are as follows: wet: 0.5–2, slightly; 2–3, moderately; 3–4, very. Drought: –0.5 to –1, incipient; –1 to –2, mild; –2 to –3, moderate; –3 to –4, severe.

Outplanting

Outplant survival at year 1 averaged across treatments ranged from 2.5% for *Aristida purpurea, Penstemon bicolor* ssp. *roseus*, and *Sporobolus airoides,* to 65% for *Sphaeralcea ambigua*. Survival patterns were similar at year 3, ranging from 0% to 55%, indicating that few plants died from year 1 to 3 (Figure 5). No significant interactions ($P > 0.05$) for third-year survival were observed between species and treatments or between treatments, although the shelter + water combination tended to approximately double survival compared with either treatment applied alone (Figure 5 inset). Species ($F = 21.8$, $P = 0.001$), shelter ($F = 10.6$, $P = 0.008$), and water ($F = 10.7$, $P = 0.012$) were significant main effects. In general, species could be assigned to one of 3 groups (Figure 5). First, *Sphaeralcea* was the best-performing species with more than twice as many plants surviving as the other 9 species. Second, *Eriogonum fasciculatum*, *Ambrosia dumosa*, and *Larrea tridentata* formed a species group exhibiting similar survival at 23% to 28%. The third group contained the remaining species, all of which exhibited minimal (≤ 2.5%) survival.

The 4 species that attained appreciable survival grew rapidly, with plant heights at year 3 averaging 51 ± 14 cm (±SD) for *Sphaeralcea ambigua*, 49 ± 17 for *Eriogonum fasciculatum*, 42 ± 23 for *Larrea tridentata*, and 26 ± 15 cm for *Ambrosia dumosa* (Figure 6). Moreover, 86% of live *Sphaeralcea*, 73% of *Eriogonum*, 33% of *Larrea*, and 22% of *Ambrosia* were flowering at the year 3 inventory.

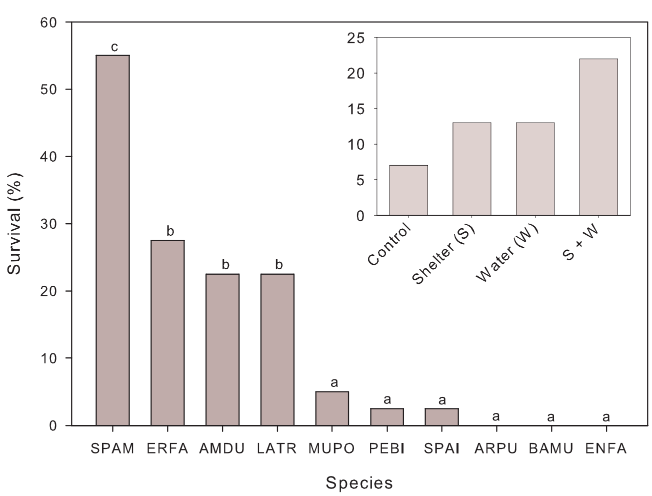

Figure 5. Survival 3 y after outplanting for 10 perennial species native to the Mojave Desert, southern Nevada. Species without shared letters differ significantly at $P < 0.05$ and are abbreviated as: AMDU = *Ambrosia dumosa*, ARPU = *Aristida purpurea*, BAMU = *Baileya multiradiata*, ENFA = *Encelia farinosa*, ERFA = *Eriogonum fasciculatum*, LATR = *Larrea tridentata*, MUPO = *Muhlenbergia porteri*, PEBI = *Penstemon bicolor* ssp. *roseus*, SPAI = *Sporobolus airoides*, and SPAM = *Sphaeralcea ambigua.* Shelter and water were significant main effect treatments, and the inset shows influences of the full arrangement of treatments on survival (%) for descriptive purposes.

DISCUSSION

Monitoring for 3 y after seeding showed that seeding failed despite 1) protecting seeds from predation by small mammals; 2) seeding at rates of ≥ 200 pure live seeds/m^2 for each species; 3) conducting germination tests to ensure that some seeds were viable; 4) irrigating plots; and 5) receiving above-average precipitation in 2 post-seeding years. Although it cannot be ruled out that seeds immediately germinated and died, we did not detect any seedling emergence by 45 d after seeding or in 45-d monitoring intervals during the initial 220 d after seeding. Invertebrates could access seeded plots, but if or how invertebrate seed predators might have affected the seeding is unclear. Harvester ants (*Messor pergandei* Mayr [Hymenoptera: Formicidae]), for example, can consume and also disperse large quantities of seeds in the Mojave Desert (DeFalco and others 2009). Future research could evaluate outcomes of protecting seeds from both mammal and invertebrate granivores (Predavec 1997). We do not believe that competition with other plants influenced the outcome of seeding. The highly competitive exotic *Bromus rubens* was still reduced at the time of seeding (3 y after the fire), which is typical for this species in the short term after fire especially when precipitation is not above average (Steers and Allen 2010). Thus, competition with *Bromus* was unlikely to have affected the seeding outcome. Although seeds could produce plants over longer time periods than the 3-y post-seeding monitoring period we employed, this would be a function of seedbank longevity (the specifics of which are not well known for most desert perennials). Moreover, it could be argued that given reasonably good rainfall years after seeding, some established plants should result within ≤ 3 y to be effective for post-fire revegetation (Grantz and others 1998). Results suggest that tracking seed fate after seeding and (or) demographic studies of natural seed rain may be useful in future research to better mechanistically understand seeding successes and failures (Chambers 2000).

This seeding failure contrasts with 7 previously published Mojave Desert seeding studies that recorded some plant establishment even in studies for which precipitation was below average (Hall and Anderson 1999; Abella and Newton 2009). For example, 2 of our seeded species, *Ambrosia dumosa* and *Eriogonum fasciculatum*, became established in all 3 previous studies in which they were seeded (Hall and Anderson 1999; Abella and Newton 2009). Seeding failures may have occurred but not been reported, representing a publication bias of selective nonreporting of results (Møller and Jennions 2001). If so, this highlights the importance of reporting successful and unsuccessful revegetation efforts to provide a balanced perspective for supporting land management decision-making. The previously published Mojave Desert seeding studies occurred in the 1970s to the mid-1990s; none have occurred in contemporary climates that might offer different conditions to seeding projects,

Figure 6. Views of outplants 3 y after planting, showing flowering *Larrea tridentata* emerging from a shelter (A), *Sphaeralcea ambigua* (left foreground) treated with DriWater™ (B; top right of plant), and *Eriogonum fasciculatum* with DriWater™ (C).

including changing amounts and seasonality of precipitation (Hereford and others 2006). Additionally, the previous Mojave Desert seeding studies occurred in environments other than burns. If burns are more difficult to revegetate than other disturbances is unknown; however, burns were successfully revegetated by seeding native species in the Sonoran (Abella and others 2009) and Great Basin Deserts (Humphrey and Schupp 2002).

In contrast to seeding, outplanting established some species. This finding concurs with previous research indicating that outplanting can establish desert perennials, but as we also found, success can be species-specific (Glenn and others 2001). *Sphaeralcea ambigua*, not previously examined in any Mojave Desert outplanting study, was our best-performing species. This species is an early successional forb that often naturally colonizes post-burn environments (Abella 2010) and appears to be a good candidate revegetation species for augmenting natural colonization. Traits, such as water use (Smith and others 1997), that may have promoted *Sphaeralcea* success are not well known and warrant further study. *Eriogonum fasciculatum*, *Larrea tridentata*, and *Ambrosia dumosa* also performed well, similar to previous research (Abella and Newton 2009). Of the species that exhibited little or no establishment, *Aristida purpurea*, *Baileya multiradiata,* and *Penstemon bicolor* ssp. *roseus* were not previously evaluated for outplanting in the Mojave Desert. *Sporobolus airoides* had ≥ 50% survival in one study but ≤ 2% in another, similar to *Encelia farinosa* (Abella and Newton 2009).

Increasing first-year survival appears critical to increasing outplanting effectiveness, and several factors could be assessed to accomplish this (Johnson and Okula 2006). For example, the container type used to grow plants in the nursery can affect their survival in the field (Landis and others 2010). We used plastic containers of the same size (4 l) and dimension that Bean and others (2004) found outperformed smaller containers and 4-l paper pots in a Sonoran Desert outplanting. Container type can influence many characteristics of outplants (for example, root length and volume), which can be species-specific, and has logistical tradeoffs for greenhouse care, transport of plants, and outplanting efficiency (Bainbridge 1994b). Similarly, many other factors related to nursery production, such as age of plants or irrigation regime, can influence outplant performance (Schmal and others 2011). In the field, additional care such as providing more initial water might be worth the added cost if it increases survival. Other factors, such as type of shelter, can also affect field survival and growth (Bainbridge 2007). Future research could evaluate whether manipulating any of these factors increases survival of our poorly performing species. Another approach should seek to identify additional species like *Sphaeralcea ambigua* that perform well using the simplest and cheapest techniques.

Our results are consistent with the few published papers that compared planting and seeding effectiveness in arid and semiarid environments in the Southwest. Two previous studies, at a Sonoran Desert site averaging 190 mm/y of precipitation (Bean and others 2004) and at a Colorado Plateau site in Arizona averaging 160 mm/y (Glenn and others 2001), concluded that outplanting was more effective in establishing a range of native perennial species than was seeding. Glenn and others (2001) further noted that plant cover on seeded areas did not differ significantly from unseeded areas. Irrigation was provided to seeded areas in both studies, as in our study, but it did not affect plant establishment.

Although this study found that outplanting established native perennial plants whereas seeding did not, a potential criticism of outplanting is that it cannot revegetate large areas. Our finding that up to 86% of surviving outplants among species flowered and produced seeds, however, suggests potential for outplants to facilitate recruitment through their own seed production. This might help outplanting revegetate larger areas, as other authors have suggested (for example, Strathmann 2002; Reever Morghan and others 2005). Identifying ways to promote outplant-facilitated recruitment and strategic spatial arrangements of outplants warrants further research. Because nearly all outplants that were healthy at year 1 were still alive at year 3, we recommend identifying ways to increase early outplanting survival as a critical step to enhancing effectiveness of this method for desert revegetation.

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