RESEARCH ARTICLE

Evaluation of Locally-Adapted Native Seed Sources and Impacts of Livestock Grazing for Restoration of Historic Oil Pad Sites in South Texas

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ABSTRACT

Oil and gas activities, particularly road and drilling pad construction, impact large acreages of native rangelands across the country. Many landowners attempt to restore the pad sites of historic wells to native vegetation with varying results. To test the ability of a locally-adapted, native seed mix, made up of grasses, forbs, and legumes, we attempted to restore four former oil and gas wells to their historic grassland state. Adding to the complexity of the restoration process, these pads were located within large grazing units, making it unfeasible to exclude grazing. We evaluated the ability of the native seed mix to establish and persist, and the effects of grazing by cattle the on the restored sites for two years after planting. By seven months post seeding, we were able to establish restored species density of ≥ 0.9 seeded plants/m², comprising of an average of eight different species. Cattle grazing had little effect on the density of seeded species. Cattle grazing did have minor effects on species composition; however, these effects are not likely to create any long term effects on species composition. These results are promising to landowners attempting to perform native grassland restoration following oil and gas activities in South Texas, even when livestock exclusion is impractical.

Keywords: diversity, drill seeding, ecotypic, seed mix, South Texas natives program

Restoration Recap

- Historic oil and gas well pads have traditionally been very difficult to restore to native vegetation in South Texas; our results suggest this difficulty may have been due, in part, to a lack of locally-adapted seed for planting.
- We found that planting a diverse, locally-adapted, native seed mix can restore a native grassland community on historic oil and gas well pad sites even during drought and with continued grazing within a larger grazing unit.
- These results show the viability of reseeding historic oil and gas well pad sites with locally-adapted, native seeds, independent of continuous moderate grazing by livestock, to restore native grassland communities.

Oil and gas exploration and production activities have, and will continue to have, substantial impacts on United State rangelands. An estimated 1.1 million ha of rangelands in the western United States will be impacted by oil and gas activities over the next 20 years (Copeland et al. 2009). One of the primary contributors to the damage to native plant communities caused by oil and gas development is the construction of drilling pads and roads leading to these pads (Smith 2008). Construction of pad sites results in destruction of vegetation, habitat fragmentation, and invasive species introductions (Simmers and Galatowitsch 2010). Restoration of native plant communities to these sites following oil and gas activities is critical to maintain native grasslands in many areas.

The restoration of native plant communities to historic pad sites is typically difficult due to a number of factors. Removal of native top soil and addition of base materials during construction of pad sites often alters soil nutrients, resulting in decreased recruitment and growth of native species (MacFarlane 1999). Soils below pads are often left heavily compacted and may contain chemicals related

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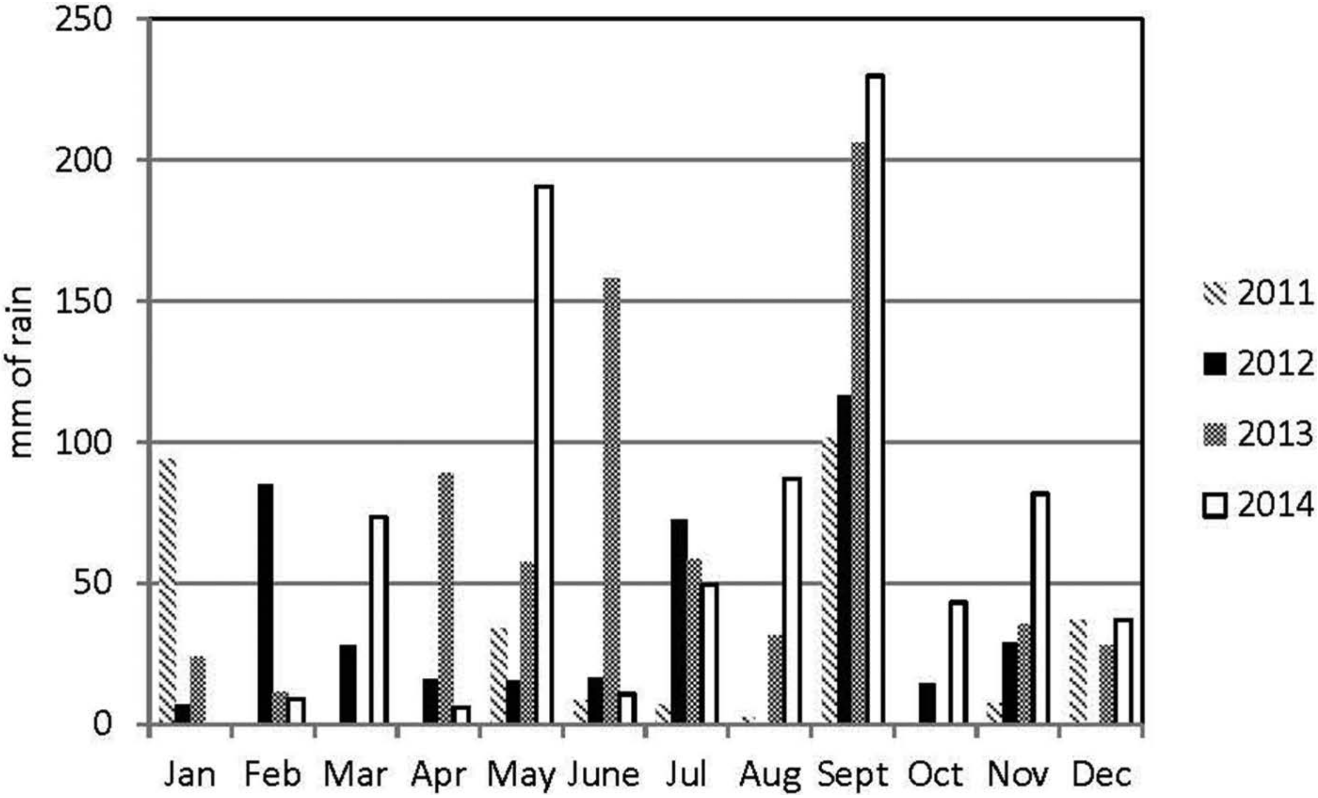

Figure 1. Monthly rainfall totals collected at the King Ranch in south Texas, USA, during the four years the project was conducted.

to the drilling process, making native plant restoration challenging (Eldridge et al. 2012).

Compounding the challenges of restoration on historic oil and gas production sites is a history of failed native seeding projects throughout South Texas, an area with a long and rich history of oil and gas production (Tinsley et al. 2006, Warner 2007). The majority of these past plantings likely failed due to a lack of locally-adapted, native seed sources (Smith et al. 2010). Previous research has shown that using local seed sources greatly increased the likelihood of success in native habitat restoration plantings (Lloyd-Reilley 2001, Espeland 2014). The purpose of our project was to test whether native plant restoration was possible on historic oil well pad sites in South Texas using locally-adapted, native seed sources developed specifically for the region through the "South Texas Natives" Project (Smith et al. 2010).

In addition to the inherent difficulties of restoring native plant communities on oil and gas pads because of edaphic and plant materials concerns, damage to restoration sites from livestock grazing is also a concern. Most oil and gas pads on rangelands in southern Texas are relatively small and are included within larger pastures or grazing units. Deferring, fencing, or otherwise limiting use of these pad sites for restoration is cost- and labor-prohibitive for most ranching enterprises. While deferral of livestock from restoration sites for a period of time after reseeding is a generally accepted management action, it is unknown how livestock grazing influences vegetation composition on small restored patches in otherwise expansive grazing units.

Increasing oil and gas development, along with historic difficulty of establishing native vegetation on pad sites, particularly in South Texas, have resulted in a large number of pads left in degraded states, or seeded with non-native species that are tolerant of grazing pressure and deteriorated soil conditions. Here, we hypothesized that a diverse mix of locally-adapted native seeds would become established and persist on historic pad sites despite continuous moderate grazing by livestock.

Methods

Study Site

We attempted to restore four historic oil pad sites using locally-adapted native seed sources on the King Ranch in south Texas, USA (27°34′00.00″ N, 98°3′56.48″ W). All of the pads were within 2,000 m of each other. Two of the pads were located on the western edge of Kleberg County, TX while the other two were on the eastern edge of neighboring Jim Wells County, TX. Each former pad site was on a different soil series, including Clareville loam, Gertrudis and Palobia fine sandy loams, and Racombes sandy clay loam (USDA Web Soil Survey 2014). Historically, all sites would have been dominated by native grasslands and savannahs comprised of mid-tall grass species including *Setaria vulpiseta* (plains bristlegrass), *Trichloris pluriflora* (multiflower false Rhodes grass), and *Digitaria californica* (Arizona cottontop [Soil Survey Staff 2014]). However, mechanical brush clearing and high stocking rates leading to overgrazing, lack of fire, and more favorable growth conditions for brush have all likely contributed to converting the area surrounding these pad sites to a mixed brush community dominated by *Prosopis glandulosa* var. *prostrata* (honey mesquite), *Acacia farnesiana* (sweet acacia), and *Zanthoxylum fagara* (lime pricklyash).

Climate of the study region is characterized as subtropical with dry, warm winters and humid, hot summers. Over the last 100 years, precipitation has occurred primarily in a bi-modal fashion with peaks in the late spring and fall with rainfall totals averaging 500–700 mm/year (Office of the State Climatologist 2016). Annual rainfall at the site was highly variable during the study, ranging from 293 mm during severe drought in 2011 to 817 mm in 2014 (Figure 1).

Seedbed Preparation

The four pads we restored were approximately 0.4 ha in size and were constructed between 1974 and 1988. These pads were constructed using a bulldozer to remove existing vegetation and add a 0.5–1-m layer of caliche (calcium carbonate mineral) base material on top of the existing top soil. Following construction, oil and gas wells were drilled and remained in active production for about 30 years. Additional well work-over, drilling, or stimulation activities likely occurred throughout the last 30 years since construction, as did maintenance of the cleared areas around the wells by mechanical or herbicide treatments. When production from these wells fell below a profitable level prior to 2011, the well bores were plugged according to state regulations, and all infrastructure was removed (Texas Railroad Commission 2000). Beginning in summer 2011, the caliche base layer was removed, and the remaining soil under the caliche base layer on the pads was ripped, using a bulldozer mounted ripper, then disked to alleviate compaction, per the lease agreement between the operator and landowner.

Following these efforts, soil samples were collected from the pad sites as well as the adjacent, unaltered habitat to examine characteristics of the soils at each pad site. Soil tests were analyzed by the Texas Plant and Soil Lab in Edinburg, TX. Soil tests revealed that pad MC 41 had excessively high amounts of sodium, and sites MC 41 and MC 113 tested very high for chloride levels. The high levels of sodium and chloride at MC 41 likely related to brine water discharges during drilling activities, a common occurrence in past oil and gas drilling in the region. We decided not to address the sodium and chloride issues identified because doing so would have been prohibitively expensive and because these conditions are fairly representative of many historic pad sites in the region.

The study site received 100 mm of rain in early September following the ripping and disking treatments. This firmed the seedbed and germinated a number of early successional weedy species, primarily *Solanum elaeagnifolium* (silverleaf nighshade) and *Cynodon dactylon* (Bermudagrass). In order to control these undesirable species, each pad was sprayed in late September 2011 with a mixture of glyphosate and 2,4 D amine herbicides at rates of 54 oz/ha and 15 oz/ha respectively. Following herbicide applications, each pad site was immediately planted in late September 2011.

Seeding Methods

The seed mix for this project was made up of 20 locally-adapted, native species (Table 1) including grasses, forbs, and legumes. Areas were seeded at the rate of 40 pure live seeds per 0.09 m^2, suggested by the Natural Resources Conservation Service guidelines for seed mixes used for range seedings on critical area planting sites (Kleberg County Electronic Field Office Technical Guide, efotg.sc.egov.usda.gov/treemenuFS.aspx). The seed for the project was purchased from DK Douglas King Seeds (San Antonio, TX). The mixture of species was developed based on a number of factors identified by previous research done by "South Texas Natives" (Falk et al. 2014). First, we attempted to ensure the mix could meet the need to quickly establish vegetation cover. To meet this need, we included the early successional native grass species *Bouteloua repens* (slender grama) and *Chloris subdolichostachya* (shortspike windmill grass) at 30% composition by amount of pure live seed in the mix. The remainder of the mix was comprised of mid- and late-successional grass species. Species composition of the mix was based on the NRCS ecological site descriptions of the area, adjacent plant communities, and results from previous local plantings. Overall, the seed mix was made up of 94% perennial grasses and 6% annual and perennial forbs and legumes. The forb and legume components were added to enhance the typically persistent forb and legume seed bank that recovers from disturbance quickly in the region (Table 1; Gonzalez and Latigo 1981).

Seeding was conducted using a Truax Flex II® native seed drill (Truax Company Inc., New Hope, NM). This drill was used because of its ability to handle the different seed sizes included in the planting mixture. Chaffy seed was separated from the slick seed in the drill seed boxes to achieve a more uniform seed distribution (Table 1). Due to poor seed quality of some chaffy species, we were required to put out large bulk quantities of this seed. Unfortunately, the drill configuration was not capable of handling the bulk quantity of seed flowing through the drop tubes so they had to be removed from the planting units, allowing the seed to drop freely directly onto the soil surface. After distributing the seed, a second pass was made with the drill to increase seed to soil contact. As a result, the planting technique used was essentially broadcast seeding, followed by cultipacking using two passes with a native seed drill.

Table 1. List of species and varieties seeded on each restored pad site at the King Ranch in south Texas, USA, including the percent of the seed mix and which seed box was used to complete the seeding.

Variety	Species	% of mix (by PLS)	Seed drill box
Dilley Germplasm Slender grama	*Bouteloua repens*	15.0%	Chaffy
Mariah Germplasm hooded windmillgrass	*Chloris cucullata*	8.0%	Chaffy
Welder Germplasm shortspike windmill grass	*Chloris subdolichostachya*	15.0%	Chaffy
Maverick Germplasm pink pappusgrass	*Pappophorum bicolor*	10.0%	Chaffy
Catarina Blend bristlegrass	*Setaria* spp.	10.0%	Slick
Atascosa Germplasm Texas grama	*Bouteloua rigidiseta*	1.5%	Chaffy
Chaparral Germplasm hairy grama	*Bouteloua hirsuta*	2.5%	Chaffy
LaSalle Germplasm Arizona cottontop	*Digitaria californica*	5.0%	Slick
Webb Germplasm whiplash pappusgrass	*Pappophorum vaginatum*	5.0%	Chaffy
Van Horn green sprangletop	*Leptochloa dubia*	2.5%	Slick
South Texas Germplasm sideoats grama	*Bouteloua curtipendula*	6.0%	Chaffy
Oso Germplasm hall's panicum	*Panicum hallii*	3.0%	Slick
Hidalgo Germplasm multiflower false Rhodes grass	*Trichloris pluriflora*	5.0%	Chaffy
Carrizo Blend little bluestem	*Schizachyrium scoparium*	3.5%	Chaffy
Falfurrias Germplasm big sacaton	*Sporobolus wrightii*	2.0%	Slick
Venado Germplasm awnless bushsunflower	*Simsia calva*	1.0%	Slick
Rio Grande Germplasm prairie acacia	*Acacia angustissima* var. *texensis*	1.0%	Slick
Divot blend tallow weeds	*Plantago* spp.	2.0%	Slick
Zapata Germplasm Rio Grande clammyweed	*Polanisia dodecandra*	1.0%	Slick
Hoverson Germplasm deer pea vetch	*Vicia ludoviciana* var. *texana*	1.0%	Slick

Livestock Exclusion

The restored pads were located in a 2,500-ha pasture that is continuously grazed by a varying number of cow-calf pairs with stocking rates ranging from one animal unit per 12–16 ha depending on year and rainfall. This stocking rate was used to achieve light to moderate grazing pressure. In order to evaluate effects of cattle grazing on restoration of desired vegetation, three 28-m^2 grazing exclosures were installed on each pad three days after planting. The exclosures were randomly located and constructed using 2.5-m metal posts and cattle panels that were 2.5 m tall with 10 × 10-cm mesh. Deferral from grazing is generally recommended in native grassland seedings; however, we wanted to evaluate the effects of grazing in addition to the evaluation of the locally-adapted seed mix because of the impracticality of fencing each site entirely.

Vegetation Sampling

Vegetation that established following restoration was sampled in the spring and fall for three years: 2012, 2013, and 2014. Two different sampling techniques were employed outside of the grazing exclosures to evaluate the vegetation response. The first technique, which was only conducted outside of the grazing exclosures, was a walking step-point method in which the recorder walked three, 100-pace transects equaling approximately 300 m, recording the species intersecting the toe of their boot at each step. This method is used to estimate the percent basal cover of each species (Evans and Love 1957). The second sampling technique, which was conducted both inside and outside of grazing exclosures, was to count plant density and estimate plant species richness in 0.5 m^2 frames (USDA NCRS 2014). Areas outside of the exclosures were sampled with 25 randomly-located frames at each of the four pad sites. Within each pad site we also sampled four randomly-located frames within each of the three grazing exclosures for a total of 12 per pad site. This method was also used to estimate plant density and species richness within the smaller grazing exclosures.

Data Analysis

Species richness and seeded plant density data were collected inside and outside each exclosure in 12 and 25 randomly-placed 0.25-m^2 quadrats, respectively, on each of six sampling dates. Although sampling date is an effect of interest to better understand plant establishment dynamics, random re-location of quadrats for each sampling period means that sampling date was not a repeated measures effect; thus, data were analyzed following Kempthorne (1952) with a factorial combination of location (inside or outside each exclosure) and sampling date. A significant interaction between location and sampling date was followed by a simple effect test (Kirk 2013) of location for each sampling date at each pad. Species richness and seeded plant density data are "count" data and thus residuals in an analysis of variance are not expected to be normally distributed or homoscedastic. A nonparametric analysis was used based on normal scores (Conover 1999) to obtain a more reliable test of location-by-sampling date interaction (Mansouri and Chang 1995); in particular, normal scores were calculated for each observation and an F test

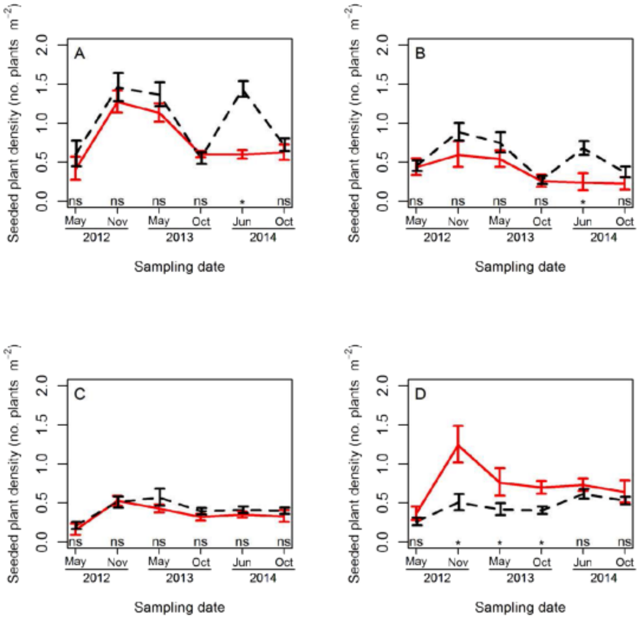

Figure 2. Mean seeded plant density inside and outside of grazing exclosures on all four pads, King Ranch, Texas, USA. Each pad is indicated by a separate letter. Seeded plant density inside enclosures is indicated with a solid line and outside is a dashed line. Dates with significant differences are indicated with a *.

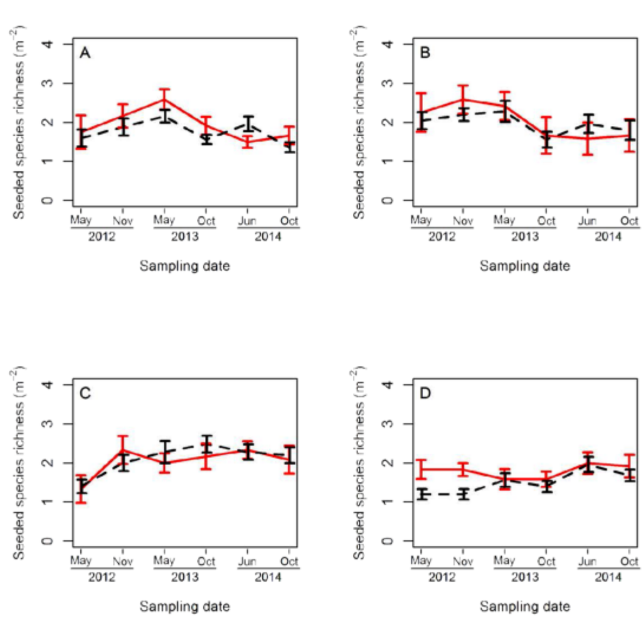

Figure 3. Mean seeded species richness inside and outside of grazing exclosures on all four well pads. Each pad is indicated by a separate letter. Species richness inside exclosures is indicated with a solid line and species richness outside of exclosures is a dashed line.

was computed to test hypotheses of treatment mean equality for location and date effects as well as the interaction between location and date. Observed means and standard errors are presented.

Results

Preceding seeding, severe drought conditions prevailed in the region. Following seeding, the sites received < 50 mm of rain during the remainder of the growing season. The following year, drought conditions persisted, with the pad sites receiving just 43 mm of rain. This amount is less than one-tenth of the average annual rainfall. Despite drought conditions and continued livestock grazing, seeded native vegetation successfully established on all four pad sites and met the minimum criteria defined by NRCS standards of 0.5 plants/0.25 m^2 by the first sampling date just seven months after seeding.

Differences in plant density inside enclosure versus outside of exclosure were only recorded in five of the possible 24 possible occurrences. At the first sampling date, mean plant density outside grazing exclosures was 0.45 seeded plants/m^2. This was not significantly different than the mean plant density within exclosures at this sampling date, which was 0.35 seeded plants/m^2. Plant density was different on all four pads and changed differently on all four pads with time. In three of the four pads seeded, plant density remained fairly static over time, while one pad saw drastic shifts. Overall, light to moderate grazing by livestock had only minor effects on native plant community establishment. Seeded plant density for both inside and outside of exclosures peaked at the second sampling date, one year after planting, with 0.93 seeded plants/m^2 and 0.97 plants/m^2, respectively. Seeded plant density decreased during the next two years except for a spike in June 2014 resulting from a 190 mm rainfall event in May preceding June sampling. Seeded plant density inside of grazing exclosures did not follow the same pattern as outside the grazing exclosures. Seeded plant density simply decreased through time and did not see the same spike as was seen outside exclosures (Figure 2).

Mean basal cover of seeded plant species outside grazing exclosures was 42% at the first sampling date. Percent seeded species cover continued to increase inside and outside grazing exclosures throughout the duration of the study. Despite a continual increase in plant density and percent cover of seeded species, we did observe cyclical decreases in both plant density and percent basal cover of seeded species each spring.

Species richness generally did not differ between grazed and ungrazed portions of pad sites (pad 1: $F_{1,210} = 1.69$, $p = 0.1948$; pad 2: $F_{1,210} = 0.01$, $p = 0.9949$; pad 3: $F_{1,210} = 0.19$, $p = 0.6668$; pad 4: $F_{1,210} = 7.02$, $p = 0.0087$). The mean number of species recorded outside grazing exclosures ranged from 1.5 to 2.1 species, while inside exclosures ranged from 1.8 to 2.0 species. Differences in the number of species recorded between grazed and ungrazed areas were likely explained by the growth of annual weeds in open space created by grazing (Figure 3), but no long-term effect of these annual weed pulses on the restored vegetation was apparent. Although species richness varied over time in three of the four study sites (pad 1: $F_{5,210} = 3.92$, $p = 0.0020$; pad 2: $F_{5,210} = 2.78$, $p = 0.0186$; pad 3: $F_{3,210} = 3.87$, $p = 0.0022$; pad 4: $F_{4,210} = 1.84$, $p = 0.1062$), these changes were independent of grazing at each site (pad 1: $F_{5,210} = 0.98$, $p = 0.4324$; pad 2: $F_{5,210} = 0.41$, $p = 0.8407$; pad 3: $F_{3,210} = 0.36$, $p = 0.8760$; pad 4: $F_{4,210} = 1.06$, $p = 0.3826$).

Discussion

Our work quantified that persistent native grass stands, representative of historic vegetation communities of the region, can be established on historic oil and gas well pad sites in South Texas despite drought, soil limitations, and livestock grazing. These results are different than those of many other past projects in almost every aspect. First, research done on the Roosevelt Oil Field in Utah found that climate, geology, and compaction were primary limiting factors to revegetation success (Babb 2014). The first part of this is contrary to what we found in that climate during this restoration project was dry, and we were still able to successfully establish vegetation. Our results are also encouraging because several researchers have shown that drying following an initial germination event can cause extensive mortality that can be near 100 percent (Fehmi et al. 2014). Our planting received ≤ 50 mm of rain during the 4 months after we seeded, and moisture conditions remained poor for nearly nine months after the seeding. Despite poor soil moisture conditions, we were able to establish a stand, and it persisted through the drought.

Other than climate, limitations in soil structure and chemistry have also been identified as key factors that have historically limited establishment. The simple construction of pad sites has been shown to change soil physical condition and bulk structure. Along with a change in structure, organic matter and the resulting microbial community are often degraded or completely lost following these activities (Avirmed et al. 2015). These changes in structure and biotic characteristic of soils may slow plant establishment and community development unless these poor soil characteristics are corrected (Viall et al. 2014). Although we did not conduct any additional soil treatments to typical restoration practices in the region, low organic matter and soil structure did not limit seeded plant establishment. A possible explanation for this could be the fact that early successional species made up a large portion of the seed mix. These species are generally adapted to harsher soil conditions and not dependent on biotic communities of soils for establishment and growth.

Grazing by livestock is widely suggested to be detrimental to seeded plant establishment in early stages of seedling growth. This is primarily because new seedlings are sensitive to herbivory as they contain low levels of energy reserves and do not have the root structure to be able to anchor the plants and prevent them from being uprooted. Aside from being sensitive to herbivory, new seedlings are often targeted by grazers because of their tender new foliage (Archer and Pyke 1991). It is because of these factors that NRCS has recommended grazing be deferred for one to two growing seasons following seeding (USDA NRCS 2015). For our project, it did not make sense to defer grazing in the area as the seeded area was such a small portion of the entire grazing unit, and large grazing exclosures encompassing the entire pad would not have been cost effective. Despite the rationale suggesting deferment of reseeded areas, ours were continually grazed for the duration of the study, and plants established successfully from seed.

Native plant reseeding projects have been conducted in South Texas since the mid-1900s. The vast majority of these plantings have been unsuccessful due to a number of factors including a lack of adapted native plant material. A central and emerging truth in successful restoration projects is the need for plant material adapted to provisional seed zones (Bower et al. 2014), e.g., ecotypic seed. The "South Texas Natives" project creates high quality, ecotypic plant material adapted to South Texas (Smith et al. 2010). Use of these kinds of seeds for this restoration project was one fundamental difference between this and the many similar projects reviewed.

Our results are very promising for landowners as well as oil and gas companies interested in restoring native grassland habitats to former pad sites. We found that despite a plethora of cited negative factors that should have limited reseeding success, we were able to successfully restore native plant communities. While grazing by cattle was had a minim impact on restored species richness, continued use of small restoration seeding sites by properly stocked cattle was not detrimental to successful native vegetation restoration. We found that use of high quality, ecotypic, native seeds has great potential for addressing common restoration limitations.

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