Final Report:

Using Gypsum Red-Fines Waste Rock to Repair Damage to the Habitat of Gierisch Globemallow II. Monitoring and Restoring Experimental Cells

  

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EXECUTIVE SUMMARY

The second year (2017-2018) of this project monitored the 2016-2017 introduction of the endangered plant Gierisch Globemallow (GG, *Sphaeralcea gierischii*), quantified invasion of other plant species, and sowed two common plant species into gypsum red-fines (GRF), ripped (RIP) and control (CON) experimental treatment cells to develop improved methods for rehabilitating highly disturbed soils and vegetation in the Mojave Desert. This report includes some methods and data previously summarized (Pavlik, Cort and Uslaner 2017) for purposes of continuity. Results specific to the 2017-2018 effort include the following:

1) Monitoring of the experimental cells and plots was conducted In October 2017 and April 2018, after a relatively wet summer that preceded the former and a relatively dry winter that preceded the later.

2) Seedlings of GG within precision-sown plots were first recorded in October 2017. Germination was low and spread among sites and substrates. Out of the 7,400 seeds that had been sown in October 2016, a total of 24 seedlings appeared at this time, mostly in CON plots at Golden Downs and RIP plots at Lime Hill. These were mapped within plots for future reference.

3) During April 2018, a total of 21 plants were found, with mortality mostly occurring in CON plots at Golden Downs and RIP plots at Lime Hill. Seven new seedlings had been found at Golden Downs. Out of the 21 plants, 14 had produced inflorescences by this time and appeared to be established. Overall, these rates of germination appear low but consistent with previous reintroduction efforts (Pavlik and Cort 2016).

4) Of the 46 adult GG plants that were salvaged and transplanted back into GRF and RIP cells at Lime Hill, 18 (39%) grew and survived until April 2018. Of these, 14 (30% of the original salvage, 78% of the survivors) had produced inflorescences with open flowers by that time. There was a consistent tendency of transplants in RIP cells to have higher survivorship and a higher proportion that were reproductive. Salvage with initial watering of transplants during the first 3 months appears to be a reasonable mitigation method using either substrate treatment.

5) Invasion of GG plots by native and non-native plant species was documented. After summer 2017 a variety of native annual forbs were found in GRF and RIP cells at both sites. *Eriogonum deflexum* proved itself to be a particularly abundant and vigorous native invader on GRF and should be considered an excellent species for restoration purposes. The non-native *Salsola tragus* grew vigorously at this time, especially in GRF plots, but by April 2018 these plants had dispersed and very few could be found. These may have all come from the existing seed bank, so it will be interesting to see if this aggressive weed can re-establish on the hardened GRF substrate surfaces during summer 2018 and beyond.

6) Germination of *Atriplex canescens and Erioneuron pulchellum* seeds that were furrow-sown into experimental cells during October 2017 was low overall, regardless of site, substrate or accession. Low precipitation during the winter of 2017-2018 was probably responsible. More *Atriplex* was found at Lime Hill than Golden Downs and more *Erioneuron* was found at Golden Downs than Lime Hill. It is likely, however, that germination will continue in response to summer precipitation and in years with higher overall rainfall.

7) Finally, the great value of these experimental cells is to be had in the future, after the passage of several decades when the properties of these substrates and seed banks have been exposed to a full range of environmental conditions.

INTRODUCTION

Gierisch Globemallow (GG, *Sphaeralcea gierischii*) is federally listed as Endangered, restricted to gypsum outcrops of the Harrisburg Member of the Kaibab Formation in northern Mohave County, Arizona and adjacent Washington County, Utah (Atwood and Welsh 2002). There are currently 18 known populations on only 186 hectares (460 acres), almost entirely on BLM lands. Plants in Utah are limited to 2.5 acres of BLM land. Surveys by the BLM and USFWS estimate the total population size of this species to be between 7,000 and 12,000 individuals in Arizona; and between 5,000 and 8,000 individuals in Utah (Fed. Reg. 2012). Gypsum mining operations on BLM and ASLD lands have disturbed portions of its habitat and the largest population in Arizona occurs within an active mining operation (Western Mining and Minerals, Blackrock Gypsum Mine). Additional threats include habitat damage from off-road vehicles, recreational shooting, illegal dumping and cattle grazing. These threats increase annually as population growth and development in the St. George area expand (Fed. Reg. 2012). Diminishment of available habitat, especially in southern Utah, is the single greatest threat to the species.

Herein we address the lack of habitat issue by experimentally testing and subsequently developing a restoration/reclamation method to create new, high quality habitat in areas that have been previously disturbed. Building upon an effort begun in 1997 by Western Mining and Minerals and recently evaluated by Red Butte Garden (Pavlik and Cort 2015), we have initiated the creation of three "new" experimental populations of GG within historic range using a local, native soil amendment derived from mining waste rock. The amendment, known as "gypsum red-fines" (GRF) provides the right chemistry and water relations characteristics that not only make it suitable for GG but also make it suitable for arid land restoration in general. In such a rapidly growing region of the state, it will have numerous applications (e.g. repairing damage from road construction, housing development, OHV's) that could make a worthless bi-product of mining into a valuable commodity. In degraded agricultural ecosystems the addition of gypsum has been used to improve soil aggregate formation and stability, which in turn improve water infiltration, root penetration, air exchange, bacterial invasion and nutrient availability (Fisher 2011). It is especially effective in sodic soils common to the desert southwest (Walworth 2012). Gypsum has not been used to rehabilitate substrates in the United States but has recently been effective for establishing native vegetation in the arid regions of southeastern Spain (Ballesteros et al. 2014).

Rehabilitation and restoration efforts in a wide variety of ecosystems depend to a great extent on re-establishing soil-plant interactions on disturbed substrates (Pavlik 2011). This is especially challenging in drought-prone areas with little soil development (Dana and Mota 2006, Bainbridge 2007). The physical, chemical and biological features of arid land soil ultimately determine which plant species can invade, occupy and thrive in any disturbed area, so rehabilitation efforts cannot simply install nursery-grown plants. Soil rehabilitation is, therefore, an essential and often overlooked component of reviving disturbed ecosystems, especially the specialized habitats of rare and endangered species such as Gierisch Globemallow.

The 2016-2017 Experimental Installation

A large-scale experimental system was established in Fall 2016 for evaluating post-disturbance rehabilitation of arid land soils and vegetation near the Utah-Arizona border. This system is being used to study invasion by non-native and native plant species and subsequent vegetation development, the suitability of local native plants for restoration purposes (installed fall 2017) and methods for re-establishing cryptogamic crusts on disturbed substrates (analyzed in future studies).

One immediate goal was to use substrate ripping and top dressing with mining waste materials ("gypsum red-fines") to create habitat for the federally listed endangered plant Gierisch Globemallow (GG, *Sphaeralcea gierischii*). During the first growing season (October 2016 to April 2017) none of the 7,400 GG seeds sown within 22 plots at three sites had germinated and, therefore, there was no treatment effect. We have now witnessed a germination response to the 2017 summer-fall rains, as is more typical for the species (Pavlik and Cort 2016).

There was also no effect of substrate treatment on survivorship of adult GG plants that had been salvaged and transplanted into experimental cells. However, more than half of these transplants had survived until April 2017 and four produced inflorescences. A relatively high proportion of these plants survived until spring 2018, indicating that salvage and transplantation with watering during the first 3 months are reasonable conservation measures when development occurs within GG critical habitat.

Initial invasion of the experimental cells during the winter 2016-2017 was mostly by non-native species whose cover has higher on ripped surfaces rather than those capped with gypsum red-fines. This was probably a mechanical effect of the latter material that simply inhibited emergence from the pre-existing seedbank. But invasion during the summer of 2017 was mostly by native species, especially on the gypsum red-fines substrate.

Current Project

The current (2017-2018) project has built upon this experimental system by a) demographically monitoring precision-sown seeds of Gierisch Globemallow (GG, *Sphaeralcea gierischii*) within experimental plots, b) extending the monitoring of salvaged and transplanted GG plants, c) monitoring invasion of experimental plots and cells by native and non-native plants, d) sowing seeds of two dominant native plants (*Atriplex canescens and Erioneuron pulchellum*) into the cells to improve soil quality within restored GG habitat, and e) photo-monitoring biocrust plots (archived but not analyzed herein).

Specifically, we will be testing the following null hypotheses over the next 5 to 10 years:

H_o1: GG germination will not be higher within treatment plots relative to controls.
H_o2: GG germination will not be higher in gypsum-red fines plots relative to ripped.

H_o3: GG seedling survivorship/reproduction will not be higher within treatment plots relative to controls.
H_o4: GG seedling survivorship/reproduction will not be higher gypsum-red fines plots relative to ripped.
H_o5: Salvaged adult plants of GG transplanted into GRF and RIP plots will not have different survivorship/reproduction.
H_o6: Naturally invading plants of native and non-native species will not differ in composition or cover in GRF and RIP plots.
H_o7: Germination and establishment of *Atriplex canescens* and *Erioneuron pulchellum* will not be improved on gypsum-red fines plots relative to ripped.

In addition, we photo-monitored cryptogamic crust inoculations in treatment cells, but these will not be analyzed until sufficient time for establishment has passed.

METHODS 2016

Establishing Study Sites, Treatment Cells and Experimental Plots

With approval from Blackrock Gypsum. BLM-Arizona Strip and the U.S. Fish and Wildlife Service, Golden Downs, Lime Hill and Barney Top were chosen as study sites in September 2016. They occur between 2979' and 3191' elevation and are imbedded in Mojave Desert Scrub vegetation (Figure 1). Golden Downs has very little slope and is exposed towards the southwest. To the southeast about 1.53 km, is Lime Hill, a short knoll of limestone that has south- and north-facing slopes. Another 1.73 km south is Barney Top, which slopes gently to the north.

Between October 3 and 19, 2016, replicated treatment cells containing replicate seeding plots were established on all three sites (Figures 2-4). Golden Downs and Lime Hill were laid out as replicate 180' X 90' treatment areas composed of six contiguous cells each, the cells measuring approximately 90' X 30'. A Case D30 bulldozer (Budd Lee and Sons, St. George, Utah) was used to re-contour and smooth the surfaces of the two sites, redistributing loose or mounded substrate and ripping the entire surface of all cells to a depth of 6-8". Multiple loads of gypsum red-fines topdressing, totaling approximately 100-120 yd^3 per site were brought from the mine and dumped in three of the six cells ("GRF" cells, which had GRF and RIP treatments). This material was evenly spread with the D30, achieving a depth of 4-6" on top of the ripped surface. The other three cells ("RIP" cells) at each site were just ripped and left fairly rough and constituted a second rehabilitation treatment. At Barney Top, the old rehabilitation surface was ripped and 120 yd^3 of gypsum red-fines was spread over the entire area, such that only one large GRF cell and no RIP cells were created.

At Golden Downs and Lime Hill two rebar stakes were used to mark the 90' baselines along the southernmost edge of each experimental cell (oriented east to west). At Barney Top the baseline is along the eastern edge (oriented north to south). These baselines would

Figure 1. Study sites (Golden Downs, Lime Hill and Barney Top) near Black Rock Mine, Mohave County, Az.

Figure 2. Six completed treatment cells within Golden Downs, looking SW.

Figure 3. Completed GRF and RIP cells at Lime Hill. Bulldozer tracks were smoothed by raking at all sites.

Figure 4. Completed gypsum red-fines treatment at Barney Top, looking N.

subsequently be used to randomly position and eventually re-locate the seeded plots within each cell as well as control plots beyond the border of treatment areas where the vegetation and soil had not been previously disturbed.

Seed Lots of Sphaeralcea gierischii

Three seed accessions were used for the experimental and control plots at three study sites; S-449, S-548 and S-708. These seeds were collected from both the Black Rock and the Utah populations of *S. gierischii*, in 2011, 2014 and 2016, respectively. Laboratory testing determined that germination of these seeds could range between 7 and 32%.

Sowing the Experimental and Control Plots

Within each treatment cell, the locations of three $1m^2$ plots (either GRF or RIP) were determined (Figures 5-7) with pairs of random numbers corresponding to X-Y coordinates (X meters along the baseline from the eastern or northern rebar, Y meters perpendicular into the cell). A 1.2 X 1.3 m plywood sowing frame was laid down above and centered on that point and its two diagonal corners anchored with permanent rebar driven into the ground. The frames have a 10 X 10 grid of 3.5 cm diameter sowing holes into which a single seed of *Sphaeralcea gierischii* would be precisely sown (Figure 8). At total of nine CON plots were positioned, marked with rebar and sown using the frames at each of three sites.

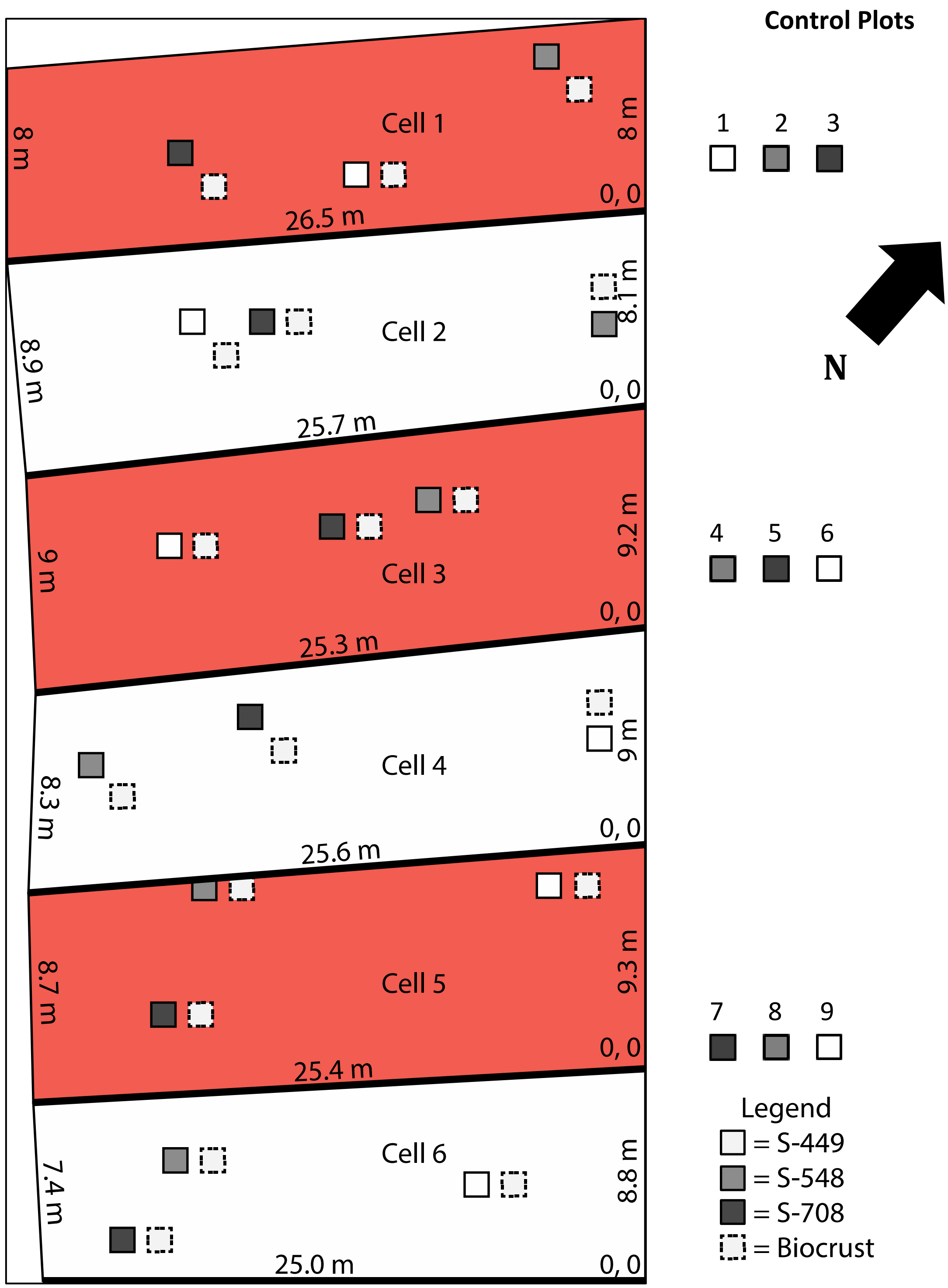


Figure 5. Golden Downs treatment layout with baseline measurements and experimental and control plot locations. Plots with GG seed accessions and plots inoculated with biocrust are shown within the treatment cells (red = GRF (+RIP), white = RIP). Control plots (CON) were established in undisturbed vegetation.

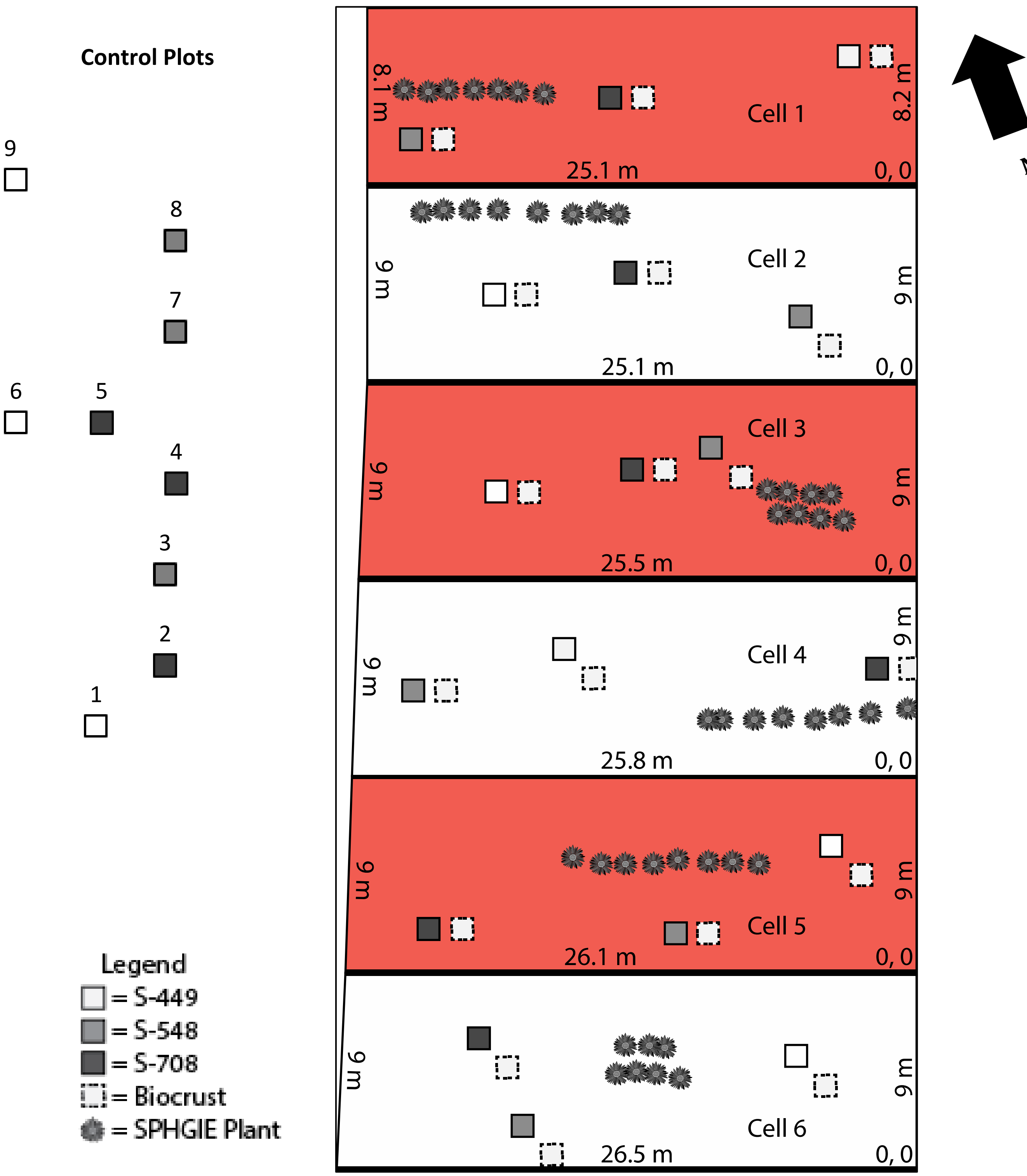


Figure 6. Lime Hill site outline with baseline measurements and experimental and control plot locations. Plots with GG seed accessions, salvaged and transplanted GG plants and plots inoculated with biocrust are shown within treatment cells (red = GRF (+RIP), white = RIP). Control plots (CON) were established in undisturbed vegetation.

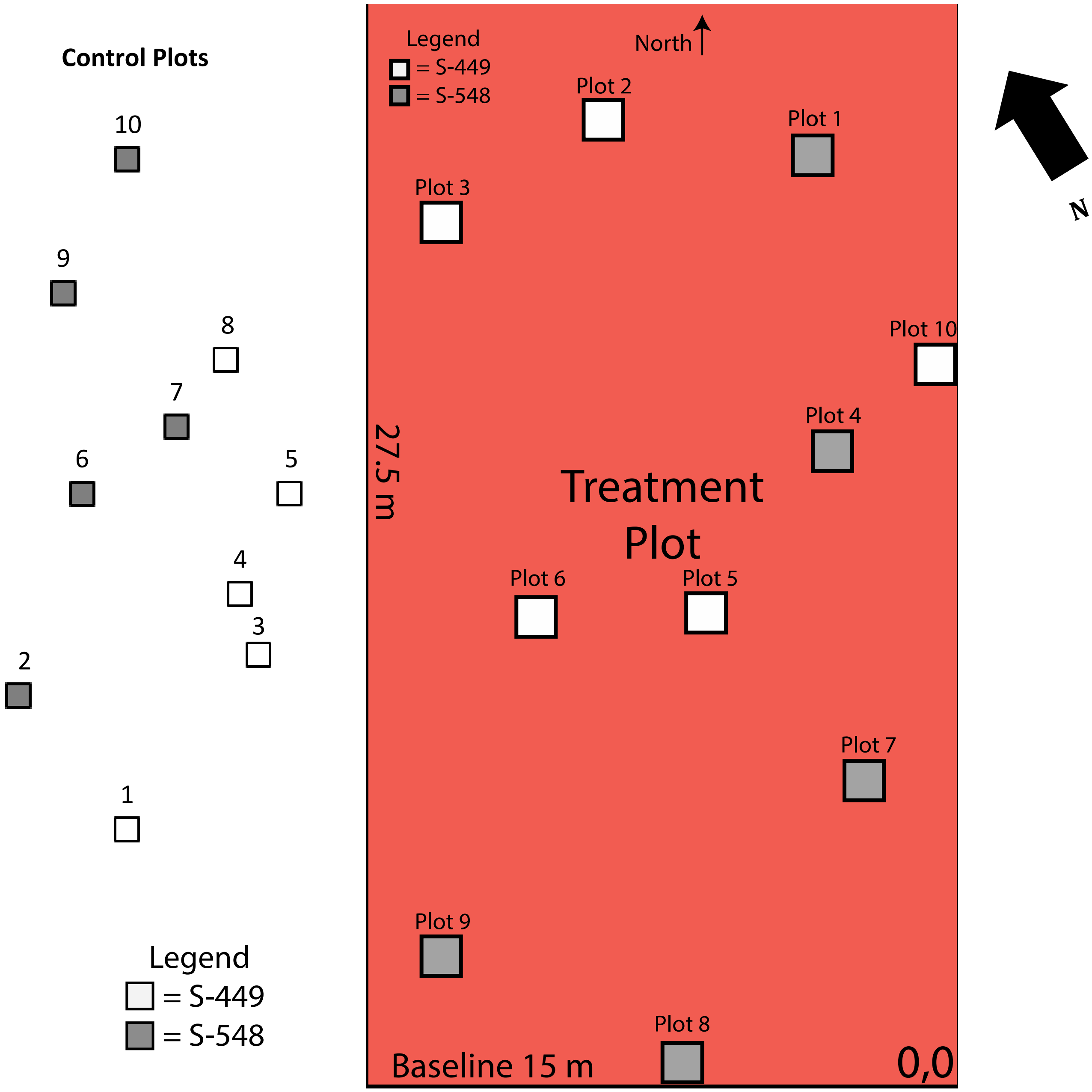


Figure 7. Barney Top site outline with measurements and experimental and control plot locations. Plots with GG seed accessions are shown within the treatment cell (red = GRF (+RIP). Actual location of control plots is beyond the northern edge of the cell, with #1 to the west and #9 to the east.

Figure 8. Staff and volunteers place and secure the removable plot frames to be sown with seeds of GG. Frames were used for monitoring on subsequent visits.

Salvage and Transplantation of Sphaeralcea gierischii

While surveying the Lime Hill site, we counted 46 adult *Sphaeralcea gierischii* plants of various sizes and conditions (ranging from poor to good, depending on leafiness). Before treatment cells were installed we salvaged these plants by carefully digging the canopy perimeter and carefully lifting on the shovel blade to maximize the capture of roots and clinging soil. Apparently, these plants did not have deep root systems because only a few had multiple large taproots that had to be severed. The smallest plants were then wrapped in wet paper towels and all root-soil balls bundled in a thick layer of burlap fabric. The root-soil bundles were watered thoroughly and placed under a makeshift shade tent for four days during cell installation, watering twice a day to keep the roots moist and alive.

On October 13th 2016, the 46 plants were redistributed across all 6 experimental cells at Lime Hill, mixing size and condition so that all cells contained a variety. The post-cell installation substrates were still light so that holes could be easily dug 0.2-0.3m deep. After each plant was placed in its hole, the root-soil ball and surrounding soil were thoroughly watered. A trough was created around each transplant to keep water from running off (Figure 9). Transplants were again watered on October 21, November 17 and December 24, 2016.

The location of each transplant was mapped using the same cell baseline as the seeded plots, and a tag number was assigned for future monitoring (tag numbers 901-946). Plant condition was ranked from "good" (nearly 100% leafy, green canopy) to "fair" (50% leafy canopy) and "poor" (<25% leafy) and observations will be documented in future monitoring seasons.

Monitoring

Weather

Collecting rain gauges (Stratus Premium Rain and Snow Gauge) were installed at each of the three sites, mounted on posts approximately 1 m above the ground and within adjacent, undisturbed vegetation. A small drop of machine oil was added to prevent evaporation when the gauges were checked and emptied on each monitoring date during the 2016-2017 period (November 17, December 26, February 25, March 28 and April 12). During one interval (December to February) cattle had knocked over two of the gauges (at Lime Hill and Barney Top), so those data are lacking.

In addition, a wireless weather station (AcuRite 01075RM 5-in-1 Weather Station, Chaney Instruments) was installed on the top of a tower at Blackrock Gypsum. The station recorded and transmitted data on daily air temperature (maximum, mean, minimum), daily precipitation, humidity, wind speed (mean, maximum gust) and dewpoint. The station (KAZLITTL3) can be monitored remotely via the internet (*https://www.wunderground.com/personal-weather-station/mypws*).

Sphaeralcea gierischii In Situ Germination and Establishment

All experimental and control plots seeded with *Sphaeralcea gierischii* were examined for the appearance of germinules and seedlings on five dates during the 2016-2017 period (November 17, December 26, February 25, March 28 and April 12). A removable plot frame was laid down (using the rebar as guides) so that the 100 precise sowing positions could be identified. In addition, we recorded the presence of cattle hoof prints in the spring. Any new plants would be marked on a datasheet according to their position in the frame so that demographic monitoring could be subsequently performed.

Sphaeralcea gierischii Transplants at Lime Hill

The 46 adult plants of *Sphaeralcea gierischii* that were salvaged and transplanted into experimental cells at Lime Hill were examined for new growth (usually leaves) on five dates during the 2016-2017 period (November 17, December 26, February 25, March 28 and April 12). Plants that did not produce new leaves by April 12 were pronounced dead.

Native and Non-native Invaders

Experimental and control plots were also examined for the presence and cover of native and non-native plant species that had invaded the cells after construction had removed all previous vegetation. These most often included native annuals in the genera *Camissonia, Eriogonum, Mentzelia, Nama, Phaceli*a and *Stephanomeria* and non-native annuals such as *Erodium cicutarium, Salsola tragus* and *Bromus rubens* (Figure 20). During field estimations of cover, "r" was used for very low cover (and translated into 0.1 % for analysis purposes), increasing through 1, 3 and 5% values.

Figure 9. *S. gierischii* plants transplanted into a RIP cell at Lime Hill, October 2016.

METHODS 2017-2018

Weather

After May 2017 the automated weather station began to fail (due to battering from severe winds in its exposed location) and data from the rain gauges was too incomplete to use (due to cattle constantly knocking the gauges over). As a result, precipitation data were obtained from the NOAA station in St. George station ID GHCND:USC00427516 (https://gis.ncdc.noaa.gov/maps/ncei/summaries/monthly) and analyzed for the entire study period (October 2016 to April 2018). Monthly amounts were totaled for two fall-winter phenoperiods (Oct-Apr) and for the 2017 summer phenoperiod (May-Sept) to correspond with winter and summer growing seasons, respectively.

Monitoring 2016 Plots of Sphaeralcea gierischii

All experimental and control plots seeded with *Sphaeralcea gierischii* at Golden Downs and Lime Hill were examined for the appearance of germinules, seedlings and established plants on seven dates during the 2016-2018 period (17 November and 26 December 2016, 25 February, 28 March, 12 April and 25 October 2017, and 12 April 2018). A removable plot frame was laid down (using the rebar as guides) so that the 100 precise sowing positions could be identified. In addition, we recorded the presence of cattle hoof prints during spring. Any new plants would be marked on a datasheet according to their position in the frame so that demographic monitoring could be subsequently performed. Barney Top was also monitored, but without replicate GRF and RIP plots, it was not included in this analysis.

Monitoring 2016 Sphaeralcea gierischii *Transplants at Lime Hill*

The 46 adult plants of *Sphaeralcea gierischii* that were salvaged and transplanted into experimental cells at Lime Hill were examined for new growth (usually leaves) on seven dates during the 2016-2018 period (17 November and 26 December 2016, 25 February, 28 March, 12 April and 25 October 2017, and 12 April 2018). Plants that did not produce new leaves were pronounced dead.

Invasion of Experimental Cells by Native and Non-native Plants

Experimental and control plots were examined for the presence and cover of native and non-native plant species that had invaded the cells after construction had removed all previous vegetation. These most often included native annuals in the genera *Camissonia, Eriogonum, Mentzelia, Nama, Pectis, Phaceli*a and *Stephanomeria* and non-native annuals such as *Erodium cicutarium, Salsola tragus* and *Bromus rubens*. During field estimations of cover, "r" was used for very low cover (and translated into 0.1 % for analytical purposes), increasing through 1, 3 and 5% values.

In addition, the number and canopy volume of every *Salsola tragus* individual that was rooted in each cell were recorded.

Sowing Seeds of Atriplex canescens and Erioneuron pulchellum

We locally collected two seed (actually fruits) accessions each of *Atriplex canescens and Erioneuron pulchellum*, both from native populations just north of Barney Top. Two were collected in October 2016 and another two in October 2017 (designated "ATCA 2016", "ATCA 2017", "ERPU 2016", "ERPU 2017"). These were stored in paper bags at room temperature and germination tested in the lab in 2017. ATCA 2016 germination ranged from 5-19% and ERPU 2016 ranged from 24-38%. Replicate lots of 100 seeds of each accession were weighed (these included fruit walls, chaff, etc.) and sealed in paper envelopes the night before sowing.

At Golden Downs and Lime Hill, three lots of ATCA 2016, three lots of ATCA 2017, three lots of ERPU 2016 and three lots of ERPU 2017 were sown into each experimental cell (three GRF and three RIP). Thus, 18 lots of each accession were required for each site. Furrow-sowing, rather than precision sowing (as was done with GG), was done by cutting a 2 cm deep furrow in the substrate surface with a large nail and evenly distributing a single pre-weighed seed lot throughout the furrow. Furrow placement was 1 m left or 2 m above each of the three GG demographic plots in a cell (Figures 10, 11), with each seed lot in a separate furrow. A metal irrigation staple was driven into the substrate at each end of the furrow to serve as a permanent marker.

Figure 10. Sowing pre-weighed lots of *Atriplex canescens* and *Erioneuron pulchellum* seeds in furrows (orange lines) around a *Sphaeralcea gierischii* demographic plot. Placement of furrows was either left OR above the plot, but the order of seed lots (top furrow to bottom) was always the same.

Figure 11. Furrow-sowing pre-weighed lots of 100 ATCA and ERPU seeds each, October 2017. Furrows are 1 m in length and positioned near the GG demographic plots within treatment cells.

<u>RESULTS AND DISCUSSION</u>

Weather 2016-2017

A wide range of air temperatures were recorded during the 2016-2017 growing season, with highs exceeding 80^{o} F in the fall and spring and lows below 32^{o} F in winter (Figure 12). Total precipitation for the same period was 8.1”, which was close to the 71-year annual average for St. George (8.0”) and slightly more than the 42- year annual average for Beaver Dam (7.1”). However, monsoonal storms to come during May to October 2017 need to be recorded in the tally for Blackrock. Temporal distribution of the rainfall was fairly even (Figure 13), with smaller events (<0.6”) common across the winter but a single strong event (> 1.2”) in mid-March.

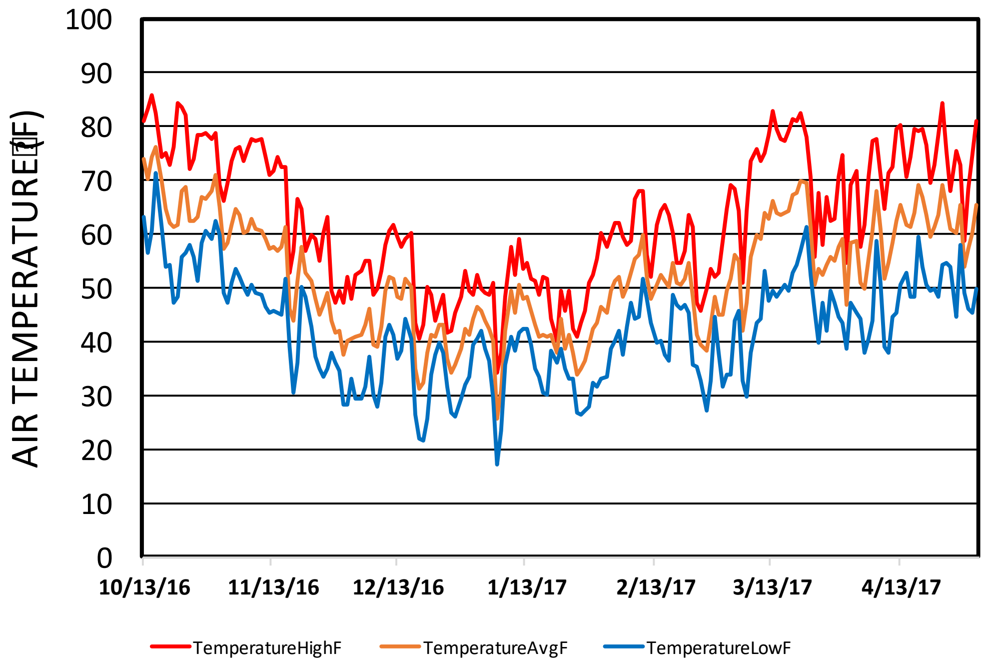


Figure 12. Daily air temperature (high, average, low) measured continuously over the study period by a wireless weather station at the Blackrock Gypsum mine.

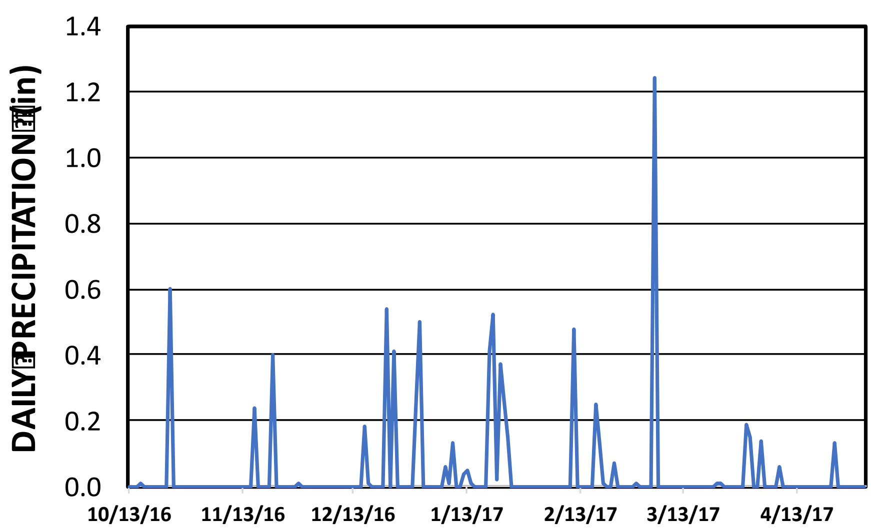


Figure 13. Daily Precipitation measured continuously during the study period by a wireless weather station at the Blackrock Gypsum mine.

The rain gauges demonstrated that there was a weak but consistent gradient across the sites, with Golden Downs receiving the most accumulations and Barney Top the least (Figure 14).

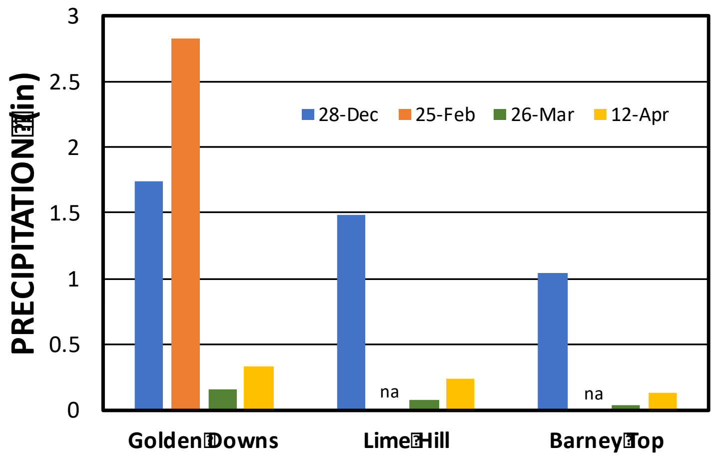


Figure 14. Periodic precipitation measured with collection rain gauges during the winter 2016-2017. Missing data (na) due to gauges knocked over by cattle.

Weather 2017-2018

Analysis of precipitation data from St. George during the entire study period showed that the winter of 2017-2018 had nearly half the precipitation of the previous winter (Figure 15). Regional drought was wide spread and the floral display in April 2018 was meager. Summer precipitation in 2017, however, was nearly equal to that during winter 2016-2017 and was probably responsible for the October 2017 floral display that included many native annuals (see below).

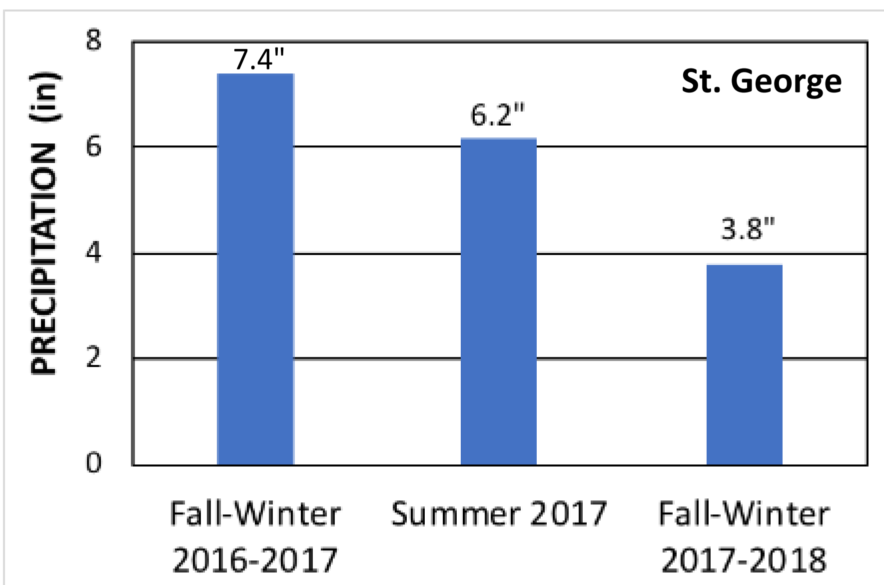


Figure 15. Precipitation during three phenoperiods, 2016-2018. Data from the St. George weather station (https://gis.ncdc.noaa.gov/maps/ncei/summaries/monthly).

Sphaeralcea gierischii In Situ Germination and Establishment 2016-2017

No germination of *Sphaeralcea gierischii* (GG) was observed in any of the experimental or control plots during the October 2016 to April 2017 study period. Germination of the same seed lots in the laboratory was low to moderate (7-32%, Pavlik and Cort 2017), but we do expect they remain viable in the plot seed banks and could still respond to the monsoonal rains of summer 2017.

During a previous study (Pavlik and Cort 2016) over a three-year period (2012-2015), we found that fall germination rates of GG were higher than winter rates. Even during a year with above-average precipitation (2012-2013), seedlings were not observed until fall (one year after sowing). This suggests summer rainfall may be required for germination and establishment. We also found that total *in situ* germination was very low over the entire study period, just over 2% of all seeds sown at that time (23,000 seeds). Given that performance and the fact we sowed only 7,400 seeds in these plots, we can expect a maximum number of 148 germinules to appear over several years.

Sphaeralcea gierischii In Situ Germination and Establishment 2017-2018

Seedlings of *Sphaeralcea gierischii* (GG) within precision-sown plots were first observed in October 2017 (Table 1). Germination had been higher in CON plots at Golden Downs, but not at Lime Hill. By April 2018 more plants were found in plots at Golden Downs (although the controls had died) and 75-80% of these had flowered despite the dry conditions. Fewer plants were found at Lime Hill, but 50-100% of the survivors were in flower.

Table 1. Number of live *Sphaeralcea gierischii* (GG) seedlings in all precision-sown plots at Golden Downs and Lime Hill, 2017-2018. Numbers in parentheses are the live plants which flowered during spring 2018.

Golden Downs			
	Apr-17	Oct-17	Apr-18
GRF	0	3	5 (4)
RIP	0	7	8 (6)
CON	0	14	1 (0)
Lime Hill			
	Apr-17	Oct-17	Apr-18
GRF	0	3	4 (2)
RIP	0	5	2 (2)
CON	0	0	1 (0)

Of the 46 adult *Sphaeralcea gierischii* (GG) plants salvaged and transplanted into GRF and RIP cells, 18 (39%) grew new green canopies and survived until April 2018. Of these, 14 (30% of the original salvage, 78% of the survivors) had produced inflorescences with open flowers by that time. There was no apparent correlation with the original condition of the transplants, but there was a consistent tendency of transplants in RIP cells to have higher survivorship and a higher proportion that were reproductive (Figures 16 and 17).

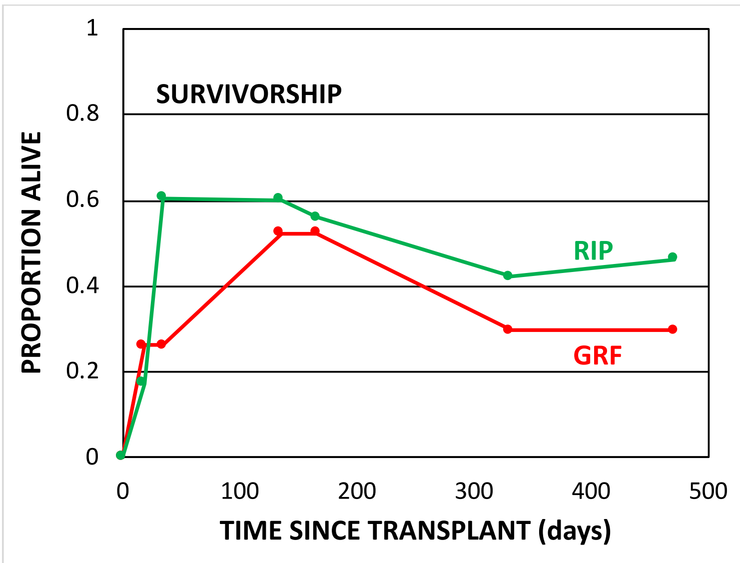


Figure 16. Proportion of GG transplants apparently alive (i.e. with new green canopy) within GRF and RIP cells at Lime Hill, October 2016 to April 2018.

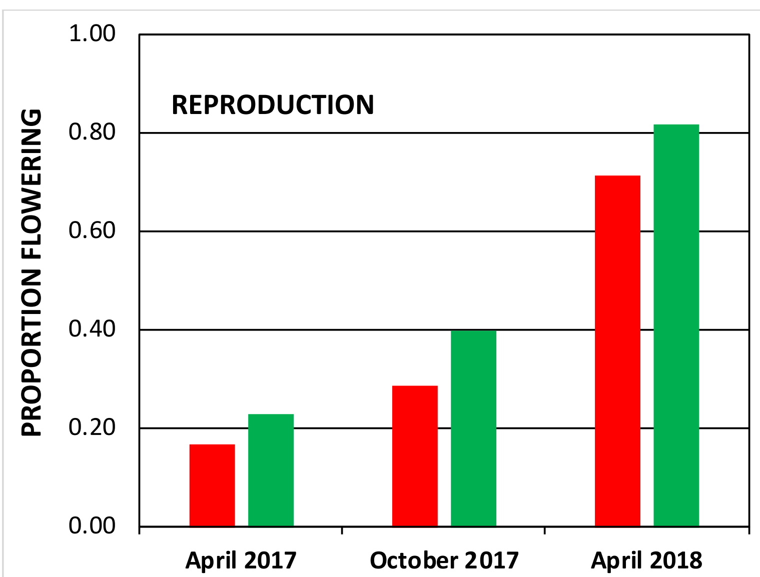


Figure 17. Proportion of live plants bearing inflorescences within GRF (red) and RIP (green) cells at Lime Hill, April 2017 to April 2018.

Transplants in RIP cells appeared to grow a new canopy earlier than transplants in GRF cells, but this difference had disappeared by April 2017. Overall, these plants will continue to be severely challenged by impending summer conditions (and without watering), possibly leading to new or differential patterns of establishment on these two substrates.

Native and Non-native Invaders Spring 2017

The experimental and control plots were invaded by native and non-native plant species, either from seeds already present in the pre-installation seed bank or from seeds that dispersed into the cells during the study period. There was an obvious difference between GRF and RIP cells that became apparent by March 2017 – GRP cells had few invaders with very low cover while RIP cells had more invaders with relatively high cover (Figure 18). Some GRF cells had absolutely no plant cover during this first growing season. It is likely, however, that this difference was due to the "smothering" effect of the GRF cap rather than the chemical or physical properties of the substrate itself. Unlike GRF cells, the RIP cells had pre-existing seed banks that were fully exposed (uncapped), allowing more germination and establishment of invaders in response to winter rainfall.

Figure 18. Invasion of treatment cells during the winter of 2016-2017. (left) Looking north across Golden Downs, showing RIP cell 4 in foreground and relatively high cover by *Eriodium cicutarium.* (right) Looking east across GRF cell 3 at Golden Downs, showing no invasion within or between plots.

Invasion of both GRF and RIP plots at this time was most commonly by the non-native annuals *Erodium cicutarium* and *Salsola tragus* and a native annual, *Eriogonum deflexum*. On average, RIP and CON plots had higher species richness (SR), especially of non-natives, than GRF plots at both Golden Downs and Lime Hill (Table 2). RIP plots at Golden Downs also had the natives *Camissonia parryi* and *Nama demissum*, but rarely.

Table 2. Mean species richness (SR) and standard deviation (SD) of native and non-native plant species in GRF, RIP and CON plots (n=3) at Golden Downs and Lime Hill, April 2017.

Golden Downs	**native SR**			**non-native SR**		
	GRF	RIP	CON	GRF	RIP	CON
mean	0.44	0.89	2.33	0.56	2.56	0.89
SD	0.20	0.38	1.12	0.20	0.20	0.78
Lime Hill	**native SR**			**non-native SR**		
	GRF	RIP	CON	GRF	RIP	CON
mean	0.44	0.56	0.50	0.56	1.67	1.33
SD	0.20	0.51	0.71	0.20	0.58	0.71

Absolute cover by non-natives in RIP plots was higher than in GRF plots at both sites, especially by *Erodium cicutarium* (Table 3). The exposed gypsum and limestone at Lime Hill may have been less conducive to annual invasion and growth, as cover in plots was half that of Golden Downs. However, the proportion of cover that was native was higher in GRF plots than RIP plots at both sites by a factor of two to three (Table 4).

Table 3. Mean absolute cover (%) and standard deviation (SD) of native perennials, forbs and grasses and non-native plant species in GRF, RIP and CON plots (n = 3) at Golden Downs and Lime Hill, April 2017.

Golden Downs	Native Perennials		Native Annual Forbs						Native Grasses		Non-Natives		
GRF			*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*			*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0	0	0	0.34	0	0	0	0			0	0	0.06
SD			0	0.02	0	0	0	0			0	0	0.02
RIP	0	0	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*			*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean			0.01	0.24	0	0.02	0	0.89			0.48	2.46	0.58
SD			0.02	0.37	0	0.02	0	0.38			0.17	1.07	0.18
CON	0	0	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*			*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean			0.79	0.24	0.01	0.38	0.02	0.01			0.03	0.14	0.01
SD			0.96	0.43	0.03	0.47	0.04	0.03			0.05	0.32	0.03
Lime Hill													
GRF			*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*			*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0	0	0	0.14	0	0	0	0			0	0	0.07
SD			0	0.16	0	0	0	0			0	0	0.04
RIP	0	0	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*			*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean			0.00	0.90	0.00	0.00	0.00	0.00			0.00	0.91	0.59
SD			0.00	1.25	0.00	0.00	0.00	0.00			0.00	0.80	0.17
CON	0	0	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*			*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean			0.00	0.03	0.00	0.18	0.00	0.00			0.03	1.67	0.14
SD			0.00	0.05	0.00	0.40	0.00	0.00			0.05	1.03	0.35

Table 4. Total mean absolute cover (%) by life form in GRF, RIP and CON plots (n = 3) at Golden Downs and Lime Hill, April 2017.

site	plot	Native Perennials	Native Annual Forbs	Native Grasses	Non-Natives (all)	total absolute cover (%)	Native cover (%)
Golden Downs	GRF	0.00	0.34	0.00	0.06	0.40	85.0
	RIP	0.00	1.16	0.00	3.52	4.68	24.9
	CON	0.00	1.46	0.00	0.19	1.64	88.5
Lime Hill	GRF	0.00	0.14	0.00	0.07	0.21	68.3
	RIP	0.00	0.90	0.00	1.50	2.40	37.4
	CON	0.00	0.22	0.00	1.83	2.05	10.6

Native and Non-native Invaders Fall 2017

Summer rainfall had only a minor effect on mean plant species richness within plots at both sites (compare Tables 2 and 5), but it greatly increased plant cover (Tables 7 and 8). At Golden Downs, high cover was contributed by the native *Eriogonum deflexum*, especially in cells 1 and 3 (see Appendix Figures A1 and A3) with the GRF substrate. RIP plots also had the native grass *Erioneuron pulchellum* and the non-natives *Bromus rubens* and *Salsola tragus*. The pattern was similar at Lime Hill, with native annual herbs contributing the most cover. Again, the proportion of total cover that was native was higher in GRF than RIP plots, continuing the trend established during the spring.

Table 6. Mean species richness (SR) and standard deviation (SD) of native and non-native plant species in GRF, RIP and CON plots (n=3) at Golden Downs and Lime Hill, October 2017

Golden Downs	**native SR**			**non-native SR**		
	GRF	RIP	CON	GRF	RIP	CON
mean	0.44	1.33	1.56	0.33	1.11	0.11
SD	0.20	1.00	0.73	0.34	1.07	0.33
Lime Hill	**native SR**			**non-native SR**		
	GRF	RIP	CON	GRF	RIP	CON
mean	0.33	0.67	0.89	0.11	0.89	0.11
SD	0.00	0.67	0.93	0.19	0.70	0.33

Table 7. Mean absolute cover (%) and standard deviation (SD) of native perennials, forbs and grasses and non-native plant species in GRF, RIP and CON plots (n = 3) at Golden Downs and Lime Hill, October 2017.

Golden Downs	Native Perennials			Native Annual Forbs							Native Grasses		Non-Natives		
GRF		*Gutierrezia sarothrae*	*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0	0.0	0.0	0.0	0.0	4.66	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03
SD		0.0	0.0	0.0	0.0	7.51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04
RIP		*Gutierrezia sarothrae*	*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0	0.0	0.07	0.0	0.0	3.57	0.0	0.0	0.0	0.0	0.0	0.33	0.12	0.72	2.45
SD		0.0	0.12	0.0	0.0	4.78	0.0	0.0	0.0	0.0	0.0	0.34	0.21	0.82	3.67
CON		*Gutierrezia sarothrae*	*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0	0.67	0.00	0.0	0.11	3.02	0.00	0.13	0.0	0.0	0.0	2.28	0.01	0.01	0.33
SD		1.66	0.00	0.0	0.33	5.55	0.00	0.33	0.0	0.0	0.0	4.38	0.03	0.03	1.00
Lime Hill															
GRF			*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0	0	0.00	0.0	0.00	0.13	0.00	0.00	0.00	0.00	0.0	0.0	0.00	0.00	0.01
SD			0.00	0.0	0.00	0.17	0.00	0.00	0.00	0.00	0.0	0.0	0.00	0.00	0.02
RIP			*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0	0	0.17	0.44	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.0	0.02	0.13	0.23
SD			0.17	0.77	0.00	0.34	0.00	0.00	0.00	0.00	0.01	0.0	0.02	0.17	0.38
CON			*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0	0	0.00	0.67	0.00	0.23	0.01	0.02	0.00	0.00	0.11	0.0	0.56	0.00	0.00
SD			0.00	1.66	0.00	0.66	0.03	0.04	0.00	0.00	0.33	0.0	1.67	0.00	0.00

Table 8. Total mean absolute cover (%) by life form in GRF, RIP and CON plots (n = 3) at Golden Downs and Lime Hill, October 2017.

site	plot	Native Perennials	Native Annual Forbs	Native Grasses	Non-Natives (all)	total absolute cover (%)	Native cover (%)
Golden Downs	GRF	0.00	4.66	0.00	0.03	4.70	99.3
	RIP	0.07	3.60	0.33	3.29	7.29	54.8
	CON	0.67	3.30	2.28	0.36	6.60	94.6
Lime Hill	GRF	0.00	0.13	0.00	0.01	0.14	92.9
	RIP	0.17	0.78	0.00	0.39	1.33	71.0
	CON	0.00	0.93	0.11	0.56	1.60	65.3

Russian thistle (*Salsola tragus*) had also become established by this time, with cells supporting large individuals on both substrates and at both sites. Density was significantly higher and plants were significantly larger on GRF substrates, especially at Golden Downs (Figure 19). It is possible that storage of summer rainfall was higher on the GRF due to the gypsum content.

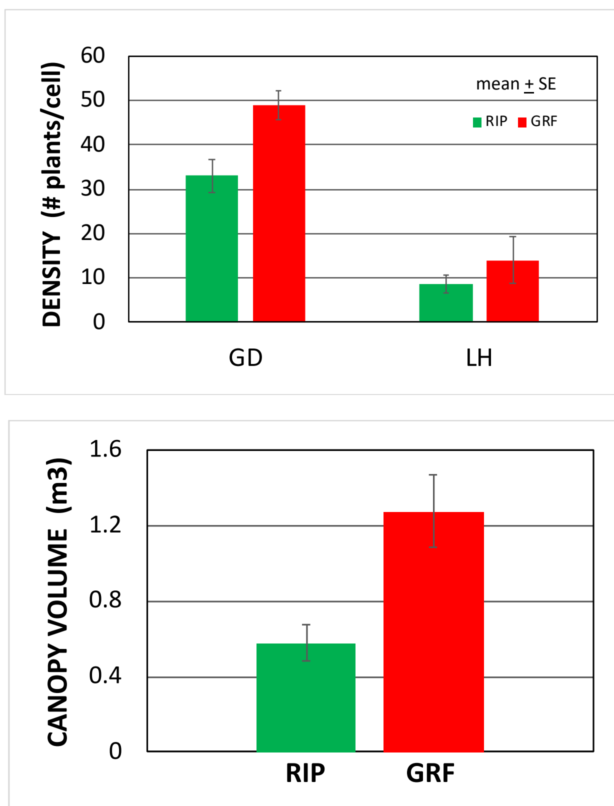


Figure 19. Density and canopy volume of *Salsola tragus* individuals (mean ± SE) within experimental cells at Golden Downs and Lime Hill, October 2017.

Figure 20. Native invaders established during the summer and fall of 2017 on both substrates and at both sites. Top to bottom, left to right: *Eriogonum deflexum, Lepidium montanum* var. *jonesii, Camissonia parryi, Allonia incarnata, Pectis papposa* and *Erioneuron pulchellum*.

Native and Non-native Invaders Spring 2018

Low precipitation during the winter of 2017-2018 probably inhibited the establishment and growth of new invaders, as species richness (Table 9) and cover (Tables 10 and 11) had not changed significantly since the fall. *Eriogonum deflexum* and *Erioneuron pulchellum* were still the natives contributing the most cover on both substrates at both sites. Cover by the non-native *Erodium cicutarium* was much lower in spring 2018 compared to spring 2017 and there was essentially no cover by *Salsola tragus* at this time (last year's adults had almost completely dispersed). The proportion of total cover in GRF plots that was native was still higher than in RIP plots at Golden Downs, but this was not true at Lime Hill (Table 11).

Table 9. Mean species richness (SR) and standard deviation (SD) of native and non-native plant species in GRF, RIP and CON plots (n=3) at Golden Downs and Lime Hill, April 2018.

Golden Downs		**native SR**			**non-native SR**	
	GRF	RIP	CON	GRF	RIP	CON
mean	0.78	1.56	1.89	0.89	1.34	1.67
SD	0.69	0.84	0.60	0.19	0.58	0.71
Lime Hill		**native SR**			**non-native SR**	
	GRF	RIP	CON	GRF	RIP	CON
mean	0.33	0.67	0.89	0.11	0.89	0.11
SD	0.00	0.67	0.93	0.19	0.70	0.33

Table 10. Mean absolute cover (%) and standard deviation (SD) of native perennials, forbs and grasses and non-native plant species in GRF, RIP and CON plots (n = 3) at Golden Downs and Lime Hill, April 2018.

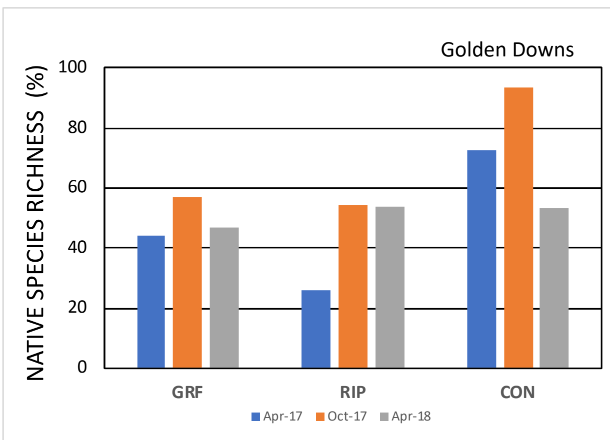
Golden Downs	Native Perennials			Native Annual Forbs							Native Grasses		Non-Natives		
GRF	*Chrysothamnus nauseosus*	*Gutierrezia sarothrae*	*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0.0	0.0	0.0	0.0	0.0	3.79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.08
SD	0.0	0.0	0.0	0.0	0.0	6.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.06	0.02
RIP	*Chrysothamnus nauseosus*	*Gutierrezia sarothrae*	*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0.01	0.0	0.07	0.0	0.0	1.45	0.0	0.0	0.0	0.02	0.0	0.29	0.02	0.25	0.04
SD	0.02	0.0	0.12	0.0	0.0	1.70	0.0	0.0	0.0	0.02	0.0	0.22	0.04	0.37	0.03
CON	*Chrysothamnus nauseosus*	*Gutierrezia sarothrae*	*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean	0.00	1.00	0.00	0.11	0.0	1.81	0.00	0.13	0.0	0.00	0.0	2.51	0.04	2.59	0.03
SD	0.00	2.65	0.00	0.28	0.0	3.47	0.00	0.33	0.0	0.00	0.0	4.84	0.05	4.91	0.05
Lime Hill															
GRF			*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean			0.0	0.0	0.0	0.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.08
SD			0.0	0.0	0.0	0.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.08
RIP			*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean			0.44	0.0	0.11	0.78	0.11	0.00	0.00	0.00	0.01	0.0	0.02	0.00	0.02
SD			0.51	0.0	0.20	1.07	0.19	0.00	0.00	0.00	0.02	0.0	0.02	0.00	0.02
CON			*Lepidium montanum*	*Allonia* incarnata	*Camissonia parryi*	*Eriogonum deflexum*	*Mentzelia sp.*	*Nama demissum*	*Phacelia sp.*	*Stephanomeria exigua*	*Bouteloua* gracilis	*Erioneuron pulchella*	*Bromus rubens*	*Erodium cicutarium*	*Salsola tragus*
mean			0.11	0.12	0.03	0.24	0.06	0.00	0.00	0.00	0.01	0.11	0.85	0.16	0.14
SD			0.41	0.33	0.07	0.66	0.17	0.00	0.00	0.00	0.03	0.41	2.09	0.40	0.35

Table 11. Total mean absolute cover (%) by life form in GRF, RIP and CON plots (n = 3) at Golden Downs and Lime Hill, April 2018.

site	plot	Native Perennials	Native Annual Forbs	Native Grasses	Non-Natives (all)	total absolute cover (%)	Native cover (%)
Golden Downs	GRF	0.00	3.79	0.00	0.11	3.90	97.1
	RIP	0.08	1.49	0.29	0.31	2.16	85.9
	CON	1.00	2.08	2.51	2.67	8.26	67.7
Lime Hill	GRF	0.00	0.11	0.00	0.08	0.19	58.6
	RIP	0.44	1.00	0.01	0.04	1.49	97.3
	CON	0.11	0.46	0.12	1.15	1.84	37.5

Plot Invasion Trends Across Years

In general, native species richness at Golden Downs was similar in GRF and RIP plots, and about half that of adjacent control plots (Figure 21). At Lime Hill, however, native species richness in GRF plots was almost twice that of RIP plots and approaching that of Control plots.



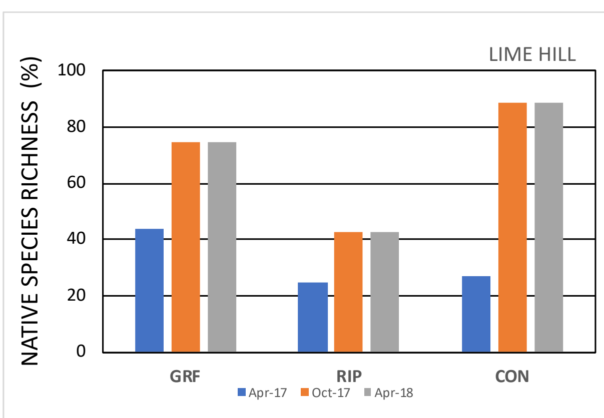
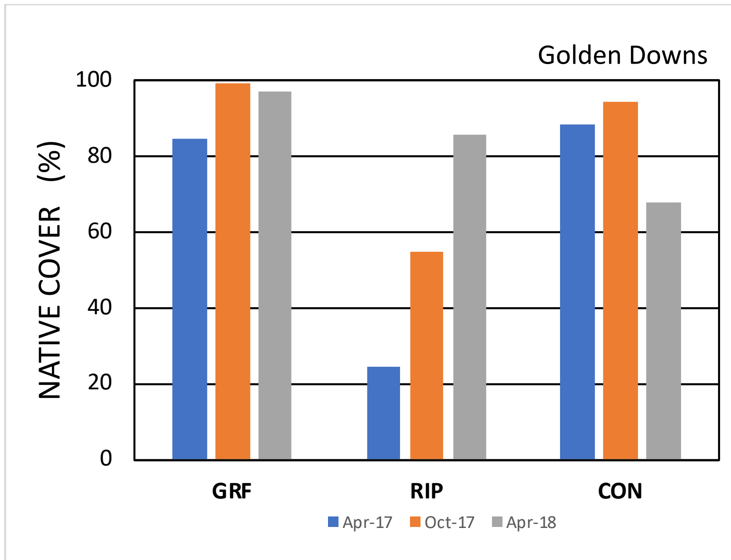


Figure 21. Comparison of the proportion of total species richness that was native in GRF, RIP and CON plots between April 2017 and April 2018 at Golden Downs (top) and Lime Hill (bottom).

Initially, the proportion of total cover that was native was higher in GRF plots than RIP plots at both sites, but this difference was diminished by the dry winter of 2017-2018 (Figure 22).



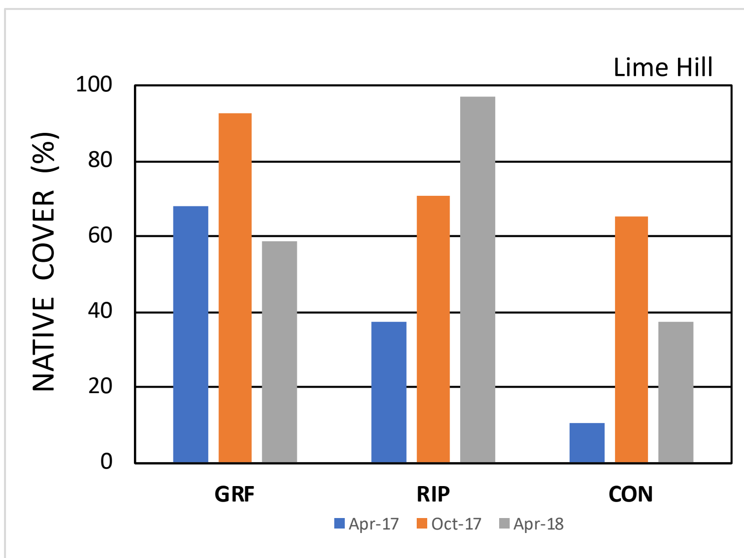


Figure 22. Comparison of the proportion of total cover that was native in GRF, RIP and CON plots between April 2017 and April 2018 at Golden Downs (top) and Lime Hill (bottom).

Sown Seeds of Atriplex canescens and Erioneuron pulchellum

Germination of these two common species was low overall, regardless of site, substrate or accession (Table 12.). Again, low precipitation during the winter of 2017-2018 is probably responsible. More *Atriplex* was found at Lime Hill than

Golden Downs and more *Erioneuron* was found at Golden Downs than Lime Hill. It is likely, however, that germination will continue in response to summer precipitation and in years with higher overall rainfall.

Table 12. Total number of seedlings of two accessions each of *Atriplex canescens* and *Erioneuron pulchellum* sown in October 2017 on two experimental substrates, April 2018.

Site	Substrate	ATCA 2016	ERPU 2016	ATCA 2017	ERPU 2017
Golden Downs	GRF	4	0	0	0
	RIP	0	8	1	17
Lime Hill	GRF	12	1	1	0
	RIP	6	0	6	0

CONCLUSIONS

A large-scale experimental system has been established for evaluating post-disturbance rehabilitation of arid land soils and vegetation near the Utah-Arizona border. This system can be used to study invasion by non-native and native plant species and subsequent vegetation development, the suitability of local native plants for restoration purposes (e.g. *Atriplex canescens and Erioneuron pulchellum*) and methods for re-establishing cryptogamic crusts on disturbed substrates (already installed and being photo-monitored on a yearly basis).

One immediate goal was to use substrate ripping and top dressing with mining waste materials ("gypsum red-fines") to create habitat for the federally listed endangered plant Gierisch Globemallow (GG, *Sphaeralcea gierischii*). During the summer 2017 and winter 2017-2018 seeds germinated at typically low rates, but some plants had become established well enough to have produced inflorescences by April 2018. These were observed at three sites and on all substrates, so as of yet there has been no treatment effect. We do expect a germination response continue, especially in response to ample summer-fall rains, as is more typical for the species (Pavlik and Cort 2016, Pavlik, Uslaner and Chapman 2017).

There was also no effect of substrate treatment on survivorship of adult GG plants that had been salvaged and transplanted into experimental cells. However, nearly 40% these transplants had survived until April 2018 and 78% of these produced inflorescences (despite no irrigation since December 2016 and a very dry winter 2017-2918). Given the successful production of GG seed under these conditions, salvage and transplantation with irrigation during the first three months are reasonable conservation measures when development occurs within GG critical habitat.

Initial invasion of the experimental cells after the winter of 2016-2017 was mostly by non-native species whose cover has higher on ripped surfaces (especially *Erodium cicutarium*) rather than those capped with gypsum red-fines. This is probably a mechanical effect of the latter material that simply inhibited emergence from the pre-existing seedbank. It is interesting to note that *Erodium* cover in RIP plots declined from 2.5% in April 2017 to 0.25% in April 2018 at Golden Downs, and from 0.9% to 0% at Lime Hill, perhaps due to low rainfall during winter 2017-2018.

It is possible that *Salsola tragus* also emerged from the existing seedbank in response to rainfall during summer 2017. These individuals were denser and larger on the GRF substrate compared to RIP, which may be an indication that moisture retention was greater on the former. Virtually all of these plants had dispersed from experimental cells by April 2018 (see Appendix photos). Monitoring after summer 2018 will determine if *Salsola* is able to re-invade and establish on the relatively smooth GRF substrate surface as readily as it will the rough RIP surface. Examination of vegetation developed on the 20-year-old Gypsum City restoration sites that used GRF as a top-dressing had virtually 0% absolute cover by *Salsola*, which may indicate declining ability of this noxious weed to invade (Pavlik and Cort 2015). However, long-term monitoring (5-20 years) will determine if the gypsum red-fines material is less prone to weed invasion because of its physio-chemical properties.

A variety of native forbs and grasses began to invade the experimental cells after summer 2017. These included geographically widespread species (e.g. *Allonia incarnata and Erioneuron pulchellum*) and even a narrow endemic (*Camissonia parryi*, found on the gypsiferous Moenkopi Formation of the Virgin River Mojave). There was a preference for the Golden Downs site, with slightly more native cover on the RIP substrate. But *Eriogonum deflexum* proved itself to be a particularly abundant and vigorous invader on GRF at Golden Downs (see Appendix) and should be considered an excellent species for restoration purposes.

Two other species, *Atriplex canescens and Erioneuron pulchellum* were tested for their restoration potential. Germination had begun over the winter of 2017-2018 at relatively low rates and is expected to continue in response to summer precipitation and in years with higher overall rainfall.

Finally, the great value of these experimental cells is to be had in the future, after the passage of several decades when the properties of these substrates and seed banks have been exposed to a full range of environmental conditions. We expect that the high variability in plant species richness and cover will begin to diminish and that the developing vegetation will reveal the utility of using gypsum red-fines material for purposes of rehabilitating disturbed sites in the greater St. George region.

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APPENDIX

Rephotographs of experimental treatment cells at Golden Downs and Lime Hill, October 2017 and April 2018.

Figure A1. Golden Downs GRF Cell 1 in October 2017 (left) and April 2018 (right). Note dominance by the native annual *Eriogonum deflexum* and the near absence of non-natives.

Figure A2. Golden Downs RIP Cell 2 in October 2017 (left) and April 2018 (right).

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Figure A3. Golden Downs GRF Cell 3 in October 2017 (left) and April 2018 (right). Note the absence of large individuals of *Salsola tragus* in April 2018 after dispersal

Figure A4. Golden Downs RIP Cell 4 in October 2017 (left) and April 2018 (right). Note the presence of *Lepidium montanum* var. *jonesii* in the foreground.

Figure A5. Golden Downs GRF Cell 5 in October 2017 (left) and April 2018 (right). Note the absence of large individuals of *Salsola tragus* in April 2018 after dispersal.

Figure A6. Golden Downs RIP Cell 6 in October 2017 (left) and April 2018 (right). Note the absence of large individuals of *Salsola tragus* in April 2018 after dispersal.

Figure A7. Lime Hill GRF Cell 1 in October 2017 (left) and April 2018 (right). Note the absence of large individuals of *Salsola tragus* in April 2018 after dispersal.

Figure A8. Lime Hill RIP Cell 2 in October 2017 (left) and April 2018 (right). The native annual *Camissonia parryi* (light green with yellow flowers) became established in October.

Figure A9. Lime Hill GRF Cell 3 in October 2017 (left) and April 2018 (right). Note the absence of large individuals of *Salsola tragus* in April 2018 after dispersal.

Figure A10. Lime Hill RIP Cell 4 in October 2017 (left) and April 2018 (right). Note the presence of transplanted *Sphaeralcea gierischii* in the foreground.

Figure A11. Lime Hill GRF Cell 5 in October 2017 (left) and April 2018 (right). Note the absence of large individuals of *Salsola tragus* in April 2018 after dispersal.

Figure A12. Lime Hill RIP Cell 6 in October 2017 (left) and April 2018 (right).