Project Title Placing Fall-harvested Wyoming Big Sagebrush Plants to Catch Snow and Provide Seed for Creating Sagebrush Islands – Final Project Report

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Note: Mr. Kent McAdoo passed away unexpectedly in early January 2018. A search of his office and computers found his original study plan, geographic coordinates of the location of the initial three study plots, some photos, a few field notes, one abstract with summary data, and one PowerPoint presentation with similar information. I have not found any of the original data he collected, on any paper or electronic data form or database. For efforts initiated in 2016 and 2017, limited (i.e., incomplete) summary data values have been resurrected to the extent possible for each of the three treatments, but across all three sites.

Highlights

- We investigated the use of harvested, whole sagebrush plants, laden with ripe or ripening seed, as a sagebrush seeding technique (hereafter called cache seeding treatment) on recently burned areas. Plants were harvested in November and immediately staked to a fixed location. The three study sites established in November 2016 used completely fixed cache treatments (n=5 per site), with the cut sagebrush staked in place with chicken wire and rebar. No lateral movement in any direction was possible. At each study site, we seeded another five plots with commercially available sagebrush for the seed zone, to simulate the traditional broadcast seeing approach (hereafter broadcast sagebrush seeding treatment or BSB). An additional five plots were untreated controls. All treatments were assigned randomly to plots within sites.
- In 2017, we established three additional study sites. For each cache treatment, a single wire cable attached the cut sagebrush plants to a stake at the center of each plot. The sagebrush cache moved freely (laterally) with the wind across the treatment plot. The BSB and control plots were established the same as those in 2016.

- The first growing season (2017) followed an exceptionally wet winter. There were substantially more seedlings and greater seedling survival in the cache treatments, than for the BSB and control plots. The mean October count of 86 seedlings per 15-m^2 plot was two orders of magnitude greater than for the BSB and control treatments.
- In the second growing season (2018), almost all cache plots, across all sites (13 of 15), had at least one sagebrush seedling, with two plots having over 300 seedlings. Only one of the 30 BSB or control plots had any seedlings (n=2). The total number of seedlings in the spring of year two (n=1,496) exceeded the count in October 2017 (approximately 861), which suggests establishment of a seedbank beneath the sagebrush caches..
- Following a dry winter (2017-18), seedling counts on three additional (new) study sites were much less than in the first year of the plots established in November 2016. The sagebrush cache plots established in 2017 had 264 sagebrush seedlings in June 2018, with 258 of these located at one study site. We found no seedlings on any BSB or control plot, at any 2017 study site. Cut sagebrush on the cache plots swung freely with the wind and there were obvious scour marks. It is unclear whether the drier winter, the modified cache treatment, or a combination of the two resulted in fewer sagebrush seedlings.
- When sagebrush plants laden with seed are harvested at seed ripe (November in this study), staked to the ground so they cannot move, and above average precipitation occurs, the density of sagebrush plants one year later is will probably be much greater than with traditional BSB seeding or not seeding at all. With time, seedling survival appears to be influenced more by site specific conditions and events than initial seeding treatment.
- Most of the time, the establishment of mobile cache plots results in more sagebrush seedlings than either BSB or not seeding, but only marginally so. This approach should be avoided.
- In recently burned areas, the cache seeding technique has the potential to rapidly establish sagebrush islands. The full range of conditions (precipitation, snow cover, soils, current herbaceous vegetation composition) for which this seeding approach can be successful remains unknown, but warrants further study.

Project Description

The establishment of sagebrush on burned landscapes, particularly in the 20-30 cm (8-12 in) precipitation zone is difficult and can take decades or longer. The lack of sagebrush across large areas after large a wildfire can result in substantial population declines for wildlife that are sagebrush obligate or sagebrush facultative species. Sagebrush seed has a short lifespan and no mechanisms for long distance dispersal. Viable seed in the soil after a fire – if any – may die before climatic conditions that facilitate seed germination and seedling survival can occur (Hourihan et al. 2018).

Whole sagebrush plants harvested in November at seed ripe were placed in three recently burned areas in 2016, and three additional sites in 2017. In 2016, harvested sagebrush were staked to the ground so the plants could not move. In 2017, sagebrush plants were attached to a central stake and allowed to swing freely with the wind. In both years, at each site, broadcast seeded sagebrush plots (BSB) were hand seeded with commercially available sagebrush seed, and control plots remained unseeded. There were 15, 15-m^2 (161 ft^2) treatment plots (including controls) at each study site, with five for each treatment. For plots established in November

2016, seedling counts occurred annually from 2017 through 2019. For plots established in November 2017, seedling counts occurred annually from 2018 through 2020. Counts were made in late spring, typically in early to mid-June.

In all years, seedling counts were several or more orders of magnitude greater in the sagebrush cache treatment plots. Eighty-seven percent of the cache treatment plots established 2016 had at least one sagebrush seedling two years later. The study sites established in 2016 coincided with an exceptionally wet winter, region wide. For plots established in November 2017, seedling counts on cache treatment plots were much less than for plots established in November 2016. The winter of 2017-18 was much drier, but seedling numbers may have been substantially less due the change for how the sagebrush caches were established. Sagebrush caches established in 2017 swung freely in the plot, while those established in 2016 were immobile. Only about 2% of the BSB or control plots had a sagebrush seedling.

Introduction

Sagebrush is an important mid- to late-successional shrub species that provides important to essential wildlife habitat for a suite of wildlife species (McAdoo et al. 1989; Crawford et al. 2004; Shipley et al. 2006; Davies et al. 2011), and influences numerous ecosystem process and properties. Wyoming sagebrush (*Artemisia tridentata* ssp *wyomingensis* and black sagebrush (*Artemisia nova*) inhabit some of the most arid regions in the western states, being the predominant shrub species in the 20 to 30-cm (8 to 12-in) precipitation zone.

The large-scale establishment of sagebrush plants is episodic, with long periods possible between establishment events (Hourihan et al. 2018). Also, almost all establishment occurs within 1-m (3.3 ft) several feet of the mother plant (Wagstaff and Welch 1990; Young and Evans 1989) and seed viability is very short. These demographic constraints coincide with a dramatic increase in the acreage of sagebrush landscapes burned by wildfire in the past 30 years. Furthermore, many areas now have a shortened fire return interval, compared to the pre-settlement era.

The recovery of sagebrush across large burned areas is typically poor, even when post-fire broadcast seeding occurs. Many challenges must be overcome and include: low and erratic precipitation, difficulty obtaining adequate supplies of seed, obtaining the correct sagebrush subspecies or ecotype adapted to the sites where seeding must occur, the short shelf-life of seed and limited cold storage facilities (Shaw et al. 2005), and inadequate seeding technology. The recent work by Hourihan et al. (2018) strongly suggests that certain climatic conditions (more moisture) associated with the positive phase of the Pacific Decadal Oscillation benefit sagebrush establishment.

Planting sagebrush seedlings can successfully establish young plants. This creates sagebrush islands that provide limited habitat and also supply seed for the immediate surrounding area (Davies et al. 2013; McAdoo et al 2013). Rearing, transporting, and planting seedlings, however, is expensive and does not ensure the plants established are those best adapted to the site. Rangeland mangers' need alternative seeding approaches that ensure the use of local seed, that it can be placed in the area needed at an appropriate time, and that the seed has the greatest viability possible. These factors suggest seeding success may improve with the use of seed from the immediate area to be seeded, and with harvest and seeding occurring the seed ripe.

This study was novel in that it harvested seed from mature sagebrush adjacent to recently burned areas, and seeded plots in the burned area, less than one -quarter mile of their origin. We immediately placed the harvested sagebrush plants in piles (caches) and secured them to the ground surface via two methods, with the specific method differing by year of establishment (details in methods section). The sagebrush caches acted as seed sources, nurse plants to seedlings that emerged, and as "snow fences" to catch and hold greater amounts of snow, intended to benefit seed germination and any seedlings that emerge.

Objectives/Hypotheses

- The placement of sagebrush plants harvested in the fall at seed ripe will result in more initial seedlings the following spring and subsequent years, compared with broadcast seeding and no seeding at all.

Methods

Plots established in 2016. In the fall of 2016, we established three study sites in North-central Nevada: one each at Squaw Valley, Izzenhood, and Maggie Creek (Figure 1). All were in the 20 to30-cm precipitation zone. Fire had recently burned all sites, with sagebrush absent in the Squaw Valley and Izzenhood sites, and nearly absent at Maggie Creek. At Squaw Valley and Izzenhood, cheatgrass was well-established prior to the recent fires, and deep-rooted perennial herbaceous species were rare. At Maggie Creek, cheatgrass was common, but deep-rooted perennial herbaceous species had a much greater density than at the other two sites. The Squaw Valley site was a Droughty Loam 8-10 ecological site (024XY020NV – Humboldt MLRA); while the Izzenhood and Maggie Creek sites were Loamy 8-10 (024XY005NV - Humboldt MLRA) and Loamy 10-12 (025XY014NV – Owyhee High Plateau MLRA) ecological sites, respectively (NRCS 1987a, NRCS 1987b).

At each site, we established fifteen, 15-m^2 circular treatment plots in a grid design with approximately 20-m between each plot. Each plot was assigned one of three treatments: 1) sagebrush cache piles with plants harvested in November (seed ripe) and piled in their treatment plot the same day, and staked in place; 2) commercially and seed zone adapted Wyoming big sagebrush broadcast seeded (BSB) to simulated traditional broadcast seeding; and 3) unseeded controls. In each cache treatment plot, the sagebrush was secured in place with an overlay of chicken wire staked to the ground with rebar stakes (Figures 2 and 3). Cache plots were denoted by placing two rebar stakes at the center point, and the BSB and control plots had one center stake.

Following the death of PI McAdoo, the original field notes that identified which plots were hand broadcast seeded and which were unseeded controls could not be found. This problem became somewhat moot by 2018 (second growing season) as only one seedling occurred in any non-cache treatment plot.

A census of all seedlings in each 15-m^2 plot occurred in the late spring and fall of 2017, and in June of 2018 and 2019. Seedlings were not marked to determine individual survival, or to help differentiate year of germination.

Plots Established in 2017. Additional work not described in the original proposal started in November 2017, with the establishment of three additional study sites: Oil Well, Coal, and Delano. The Oil Well and Coal Sites were Loamy 8-10 (025XY019NV) and Loamy 10-12 (.025XY014NV) Wyoming sagebrush ecological sites, respectively (NRCS 1987a, NRCS 1987b). The Delano site as a Shallow Calcareous Loam 8-10, black sagebrush (024XY030NV) ecological site (NRCS 1987a).

Each study location had the same number and general layout of treatment plots as described for plots established in November 2016. The only difference in methodology was for the cache seeding treatment. For these 2017 cache seeding treatments, several cut sagebrush plants were strung together and attached to a single t-post (in the center of the plot), and allowed to 'swing' back and forth with the wind. The November 2016 plots had sagebrush caches that were fixed to the ground with no movement possible. Seedling counts in each plot occurred from late May to mid-June from 2018 through 2020.

Data analysis: For 2017, raw seedling count data for all plots are unavailable. Following PI. McAdoo's passing the original data could not be located. All reported data below are summary the summary statistics presented by McAdoo and Davies (2018) at the annual meeting of the Society for Range Management.

In all years, in each treatment plot (five plots per treatment, 15 per site), we counted every sagebrush seedling in a 218-cm radius from the center stake (plot = 15-m^2). Raw data were summarized as mean seedling density, by treatment plot within years and study locations. We also determined the percent of plots occupied by one or more sagebrush seedlings.

We compared mean seedling density across treatments within years with a parametric one-way analysis of variance (AOV: Analytical Software 1985-2013). When the Levene's test, Obrien's Test or Brown and Forsythe Test suggested variance was not homogeneous, we subsequently analyzed the data with the non-parametric Kruskal -Wallis (KW) one-way AOV. Mean separation occurred with the Tukey's test for the parametric AOV and the Dunn's all ways comparison for the KW AOV. For both tests, the alpha levels for mean comparison were 0.05 or 0.10, when the AOV showed statistical significance at $p \leq 0.05$. For the most part, the parametric and non-parametric tests provided the same result. Differences are noted in the summary data table (Table 1).

To understand the possible influence of annual precipitation toward seedling counts we used precipitation data from the four NOAA sites (with adequate annual data) closest to the study sites. These are Winnemucca, Battle Mountain, Beowawe, and Elko. Data reported include precipitation in the October-March, and April-June periods for each water year from 2015-16 through 2019-20. Precipitation in the October-March period largely influenced seed production of the harvested sagebrush plants because it recharges the deeper portions of the soil profile. Deep soil moisture supports sagebrush growth and seed development in the late summer and fall.

Precipitation across the entire October-June period provides insight into seed germination, initial seedling density and potentially seedling density across years. The precipitation amount for each period was compared with the long-term mean for that period, to calculate the percent of the mean and median precipitation by period, year, and weather station. The four stations provide perspective for precipitation across the region, not individual study sites.

Results and Discussion

Plots Established in November 2016

In May 2017, there was a "carpet" of sagebrush seedlings within 0.5-m of the sagebrush cache treatments, at each study site (McAdoo and Davies 2018; Figure 3). By October 2017, natural thinning had reduced survivors by about 50%. Across the cache treatment plots, sagebrush seedling survival was variable, but significantly greater ($P \leq 0.05$) seedling density occurred compared with BSB treatment (McAdoo and Davies 2018).

The aggregate mean seedling density in October 2017, in cache plots, across all three locations, was 5.7 seedlings/m^2 (86 per 15-m^2 plot). The October 2017 seedling density was about one-half that present in May 2017, but still more than two orders of magnitude greater than in either the BSB or control treatments. These data were summary values and statistics taken from Mr. McAdoo's 2018 presentation at the Annual Conference of the Society for Range Management.

In June 2018, seedling density in the cache plots ranged from 31.4 to 177.8 per 15-m^2 (Table 1). These amounts greatly exceeded those in the BSB and control treatments. Across all sites, only two seedlings were counted in the thirty non-cache treatment plots. For statistical analysis, these two seedlings were assigned to an SBS treatment. The rationale being that BSB plots had a much greater initial seed density than control plots; thus, were more likely to have a seedling, given the same precipitation and ecological site. Also, the small seedling density was found to have no appreciable influence on a statistical test regardless of which non-cache treatment we assigned the two seedlings. The small p-values, strongly indicate that the substantially greater seedling density in cache plots was likely due to the cache seeding treatment (Table 1). In June 2018, the cache treatment also had good dispersion of seedlings across all plots., with 60% to 100% of the cache plots having one or more sagebrush seedlings.

Amongst sites, and within the cache treatment, Maggie Creek had a much greater seedling density than the Squaw Valley or Izzenhood sites. Maggie Creek also had the best seedling dispersion, with all five cache plots occupied by at least one seedling (Range 1 to 327). The ecological site at Maggie Creek is a Loamy 10-12, which suggests this site is both wetter and probably slightly cooler than the Squaw Valley and Izzenhood sites. Both locations were slightly drier ecological sites, situated at lower elevation and had an open westerly exposure. The Maggie Creek site has an east to northeast exposure, with a tall ridgeline immediately to the west of the study area.

At all three study sites, in the cache plots, seedling density in June 2019 was substantially less than in 2018. At Squaw Valley there were no seedlings present in 2019, but almost 87 per 15-m^2 in 2018. At Izzenhood, seedling density declined from slightly more than 31 per 15-m^2 in 2018, to less than one per cache plot in 2019, with all four seedlings found in the same plot. At Maggie Creek, the proportion of cache plots with seedlings declined from 100% to 60% (n=3 of 5), and seedling density declined over 50% to just more than 81 seedlings per 15-m^2. The causes of these declines likely are many, but two observations are important.

At the Squaw Valley site, pronghorn (*Antilocapra americana*), were observed throughout the spring of 2019 (winter presence is unknown but likely as higher elevations to the north and east are typically covered with snow for several months or more). Forage Kochia (*Kochia prostrata*) occurs in and beyond the study site and all forage kochia plants in the study area had been intensively grazed, leaving residual heights of about 2.5 to 5 cm. Pronghorn will readily consume sagebrush (Severson et al. 1968; Yoakum 1978), especially in the spring (Olsen and Hansen 1977; Ngugi et al. 1992), and relatively few bites are needed to kill small, one to two-year old sagebrush. It is quite possible that many plants died from grazing by pronghorn between June 2018 and June 2019. Precipitation across this period, at the two closest sites (Battle Mountain and Winnemucca) was slightly below to well above average (Table 2).

The second observation was at Maggie Creek, where a cache treatment plot with over 100 sagebrush seedlings in 2018 had none in 2019. Sometime after June 218, this plot was entirely obliterated by a new badger den. The other plot that no longer had sagebrush seedlings had only one in 2018.

Across all three sites, for the non-cache treatment plots, there was a slight increase in seedlings – from two to four - by 2019. A two-sample t-test comparison (Sattertwaite unequal variances method) was used to compare seedling density from all cache plots across all three locations in 2019 (n=15 plots with 27.4 sagebrush seedlings per 15-m^2), with seedling density from non-cache treatments in 2019 (n=30 and 0.13 seedlings per 15-m^2). The resulting p-value of 0.10 is moderately strong evidence that cache seeding resulted in more seedlings in the third growing season, than did the non-cache treatments. The benefit, however, did not occur at all sites, and within sites was highly variable across cache treatment plots (Table 1).

Plots established in November 2017

In 2018, the first growing season after plot establishment, sagebrush seedlings were abundant at only one site, Oil Well, and only in the cache treatment (Table 1). All four cache treatment plots (field crews did not locate the fifth plot in 2018, but did in subsequent years) had seedlings, and counts ranged from 33 to 97 seedling per 15-m^2. The cache seeding treatments in the Coal and Delano sites had seedling densities of 1.0 and 0.2 seedlings per 15-m^2, respectively, and no more than 40% of each site's cache plots had sagebrush seedlings. There were no sagebrush seedlings in either the BSB or control plots. The AOV indicates provides strong evidence that the cache treatment at the Oil Well site increased seedling density, but not so at the other locations (Table 1). Observation noted that most seedlings occurred within 1-m of the plot's center stake, with the furthest being 2-m away.

Seedling density in the cache treatment at the Oil Well site declined almost ten-fold from 2018 to 2019, and by one-half from 2019 to 2020. The fifth cache plot was located in 2019, and all five cache plots had at least one sagebrush seedling in 2019. By 2020, two of the five cache plots had lost all sagebrush seedlings. Seedlings were never found in any of the BSB and control plots treatments at the Oil Well site. There was no statistical difference between mean seedling density amongst treatments in 2019 and 2020, at Oil Well (Table 1); however, the cache treatment did average at least 3.2 seedlings per 15-m^2 in both years. No sagebrush seedlings occurred in any non-cache treatment plot in either year. Despite a lack of statistical significance, the outcome strongly suggests that cache seeding treatments increase the potential for sagebrush presence compared to BSB and non-seeding treatments.

The Delano site was the only location across of all six study sites, with an increase in sagebrush seedling density in the cache treatment, each year of the study. In 2018, there was only one sagebrush seedling in one cache plot. That plot, however had five seedlings in 2019 and 15 plants in 2020. A second cache plot had six seedlings in 2020. Observation noted that these two plots had a spatial relationship to one-another, and a landform feature that funneled run-on water to them, but not other plots at the study site. The cache plot with 15 seedlings in 2020 was located in the northeast corner of the study area, on the upper portion of a small alluvial fan that merges into an adjacent hillslope. Traversing the hillslope and broadening just above the cache plot was a small ephemeral flow path that in some, and perhaps most years, carries run-on moisture to the cache plot. This likely influenced seed germination and/or seedling survival. In addition to the cache seed, seed could also have been carried down-gradient from the unburned hillslope into the cache plot, with the dead sagebrush cache slowing flow enough for seed to drop out of the flow. The cache plot with six seedlings in 2020 is immediately downslope of the aforementioned plot and in the same flow path, although it broadens substantially as the gradient of the fan declines. None of the remaining treatment plots, regardless of treatment, occurred in this flow-path. It is probable that run-on moisture on this site influenced the cache treatment response across time.

There were few seedlings on the Coal site in 2019 and 2020, and all were in the cache treatment (Table 1). Statistical support in 2019 for cache treatments having more seedlings than the BSB and control treatments was weak ($p = 0.15$), with stronger support in 2020 ($p = 0.01$). The total number sagebrush seedlings across all cache plots at the Coal site was the same in 2019 and 2020, but in 2020 seedling distribution was across three cache plots vs only two in 2019. Better (more even) distribution of the small number of seedlings influenced the result of the AOV test.

An important observation across plots established in November 2017 was that the ability for the sagebrush caches to move laterally across the 15-m^2 plot, with the wind. Sagebrush seedlings are fragile plants and it seems likely repeated lateral movement of large dead sagebrush plants and associated scouring of the soil surface could have resulted in substantial mortality. The Coal site, which supports a wetter more productive ecological site than either the Delano or Oil Well sites, was positioned on a west facing windward slope just below the ridgeline. The Delano site had a similar landform position but was lower on the slope and also had a catchment area with the potential to funnel surface flow into two of the cache treatments. The Oil Well site occurs on a very slight backslope, facing east to northeast; thus, is in a leeward location of the landscape. This leeward location may have resulted in less scouring by the mobile seed caches; hence, why this site had more sagebrush seedlings.

Weather and Seedling Density:

There are two important periods of precipitation that may influence the reproduction dynamics of sagebrush. The production of abundant, viable seed in the fall, requires adequate precipitation occurring during the previous wet season, and more specifically during the October-March period. Mature sagebrush plants extract deep soil moisture in the late summer and fall to produce seed, and deep soil moisture storage is a function of sufficient precipitation the previous winter when maximum infiltration is possible during the cool months, when evapotranspiration is minimal or absent. Dry winters will not provide enough moisture at depth to support growth all summer and fall, and abundant seed production in the October-November period. Seed germination, and more importantly seedling survival are more closely linked with precipitation in the spring months of April through June, when the developing roots of sagebrush seedlings are short and have not yet reached the large reservoir of stored soil moisture at deeper depths. Dry spring periods, or years where most moisture falls in a brief period, especially late in the spring period, are likely to reduce sagebrush seedling establishment.

Winter precipitation from October 2015 through March 2016 (hereafter winter) was well above the long-term average and median in all areas (Table 2). From April through June (hereafter spring period) 2016, precipitation was also well above the average and median at Bewowawe and Elko, near the average and median at Battle mountain, but almost 30% below average at Winnemucca (Table 2). Overall, the precipitation data suggest that seed production in November 2016 should have been very good. The seedling density in the cache treatment at all three study sites supports this outcome.

Winter precipitation in the 2016-17 water year was well above average at all four weather stations, with spring precipitation ranging from 4% below average at Elko to 6 to 11% above average at the other three locations (Table 2). These data suggest there was good soil moisture at shallow depths for initial seedling growth, and good soil moisture throughout the growing season as their tap roots elongated, reaching deeper soil moisture pools. The amount of moisture added to the cache seeding plots by the cluster of dead sagebrush is unknown, but observation and seedling density data suggest the caches captured more snow than the broadcast seeding and control plots, and/or modified the microclimate sufficient to benefit seed germination and seedling emergence,

The influence of weather for long-term seedling survival across time appears to decline, with seedling density influenced more by site specific factors (e.g., burrowing animals, mammalian herbivory). Evidence for this conclusion is a combination of the greater seedling density at the Maggie Creek Site cache treatments, and their distribution across most cache plots three years after seeding, but few seedlings and poor distribution among cache plots at the two other sites. This occurred despite precipitation being above average across the region, most of the study period (Tables 1 and 2).

Plots Established in Fall 2017: Plots established in November 2017 would have been influenced by weather in the 2016-17 water year and its influence for seed production for the seed caches established in November 2017. Also, the 2017-18 water year for initial seedling germination and establishment. Across the region, the 2016-17 water year was wet, with well above average winter precipitation at all four weather stations, and slightly below to slightly above spring precipitation. These data suggest no precipitation constraints for seed production for the plants used in the cache seeding treatment. The seedling density at the Oil Well site confirms this conclusion, at least for this location. For the 2017-18 water year – the period of influence for seed germination and seedling emergence - precipitation across the region ranged from 81 to 91% percent of average for the winter period, and 3 to 30% above average in the spring period. Hourihan et al. (2018) demonstrated that large-scale sagebrush recruitment is predominately a pulse event linked to wet periods. Winter precipitation in the 2017-18 water year was below average and probably insufficient to promote wide spread seedling emergence across the region. The one site with abundant seedlings in the cache treatment, Oil Well, had nearly a ten-fold decline in seedling density from 2018 to 2019, despite a generally wet spring in 2018, and a wet winter and spring across the 2018-19 water year. It is possible that the dry winter period in the 2017-18 resulted in insufficient deep infiltration to meet the water needs of most seedlings as their roots grew to greater soil depths, and /or spring precipitation was insufficient (amount or timing) to keep the shallow soil depths wet enough to meet the needs of recently emerged seedlings.

Conclusions and Management Recommendations

There is strong evidence that cut sagebrush plants, laden with viable seed, that are permanently staked in place (i.e., can't move with the wind) can facilitate the presence of a large number of seedlings two years later, when total winter precipitation and snowfall are well above average. Under these conditions, sagebrush caches will result in many more seedlings than the standard broadcast seeding method for sagebrush, or no seeding at all. It is likely that the large number of young plants found in 2018, on sagebrush pile plots established in November 2016 were yearling plants that germinated in 2017 and survived the first growing season. Because seedlings were not marked, a definitive conclusion is not possible. The lack of marked seedlings also makes it unknown for whether seedling survival was better directly under the cut shrubs, around their perimeter, or the same regardless of micro-location.

Seedling numbers on the three plots established in 2017 and counted in 2018, were markedly less than on plots established in 2016 and counted in 2017. This may have been due to the drier winter that coincided with sites established in 2017. It seems likely the different methodology for creating seed caches also influenced the outcome. In essence, the change in methodology confounds the results. The obvious scour marks at cache locations suggest an increased probability that regular lateral movement by the dead sagebrush skeletons could have increased seedling mortality. Potential interactions of all of the aforementioned variables are unknown. Regardless, the scouring that occurred on the cut sagebrush treatment plots strongly suggests that application of a cut sagebrush pile seeding technique should use cut sagebrush that are permanently staked to the soil surface to prevent their movement and disturbance to the seedbed.

Regardless of whether or not statistical significance occurred, there were consistently more sagebrush seedlings in cache seeded plots, compared to BSB and control treatments. We accept the hypothesis that the immediate placement of sagebrush plants, harvested at seed ripe, on recently burned areas and staking them in place so they cannot move laterally will result in more seedlings the following and subsequent years. Sagebrush has a greater probability of establishing in more locations, but across time numerous other factors exert a greater influence on long-term plant establishment. The potential for these influences to occur at any location should be evaluated before implementing the cache seeding treatment.

Guidelines and Management Considerations for Application of the Cache Seeding Treatment.

1. Seedlings can be established in the 8 to 10-inch precipitation zone, in dense cheatgrass in a good precipitation year. The probable outcome in an average to below average precipitation year remains unknown. An important question to address is: should one try to establish sagebrush in areas predominately inhabited with cheatgrass? Most likely, the fire cycle is 5-10 years and the young sagebrush they will burn up before they provide much if any ecological benefit. The fire cycle needs to match the biological needs of the plants established, and the animals that potentially use the sagebrush.
2. If there are pronghorn or mule deer using the site for extended periods, seedlings tend to disappear (this study wasn't designed to document whether these ungulates eat the seedlings, but it seems likely). A small green item in a sea of brown is tempting for any ungulate. Rabbits or ground squirrels were likely problems as well but were difficult to document.
3. An important unanswered question is what spacing of caches should occur to help overcome herbivory issues. This study had single plants staked an average of 20-m from the next closest cache, with only five caches per study area. On some sites many seedlings occurred at the cache, with substantial self-thinning the first two years after emergence. Eventually the few seedlings left were easy targets for an herbivore. Should caches be spread further apart, with many of them across many acres? Or, should caches be established at a greater cache density on smaller areas (patch size)? The answer is unknown and likely specific to each situation, but anyone implementing the technique should ask these questions.
4. Some caches (sagebrush skeletons) were removed after the first year and some not. I would leave them in place so they provide some physical protection for as long as possible.
5. Consider topography when placing caches. Caches do catch and retain snow, but placement in areas where there is some additional run-on moisture, is likely to confer additional benefits to germination, seedling establishment and long-term seedling survival.
6. Ungulate herbivory is likely to be exasperated when forage kochia is present amongst the caches. One site still had quite a few seedlings after 2-3 years, but the next spring, after a wet winter, there were none. Antelope were in the vicinity and all the forage kochia plants were heavily used. Establishing sagebrush caches amongst an attractant feed that may hold pronghorn or other herbivores on a site for a long period, may counter the benefit of the cache seeding approach, particularly when cache numbers are few. There has to be enough seedlings established to survive several years of herbivory, until the surviving plants are large enough to cope with that herbivory..
7. The cache seeding technique may prove most useful when applied to locations with a good perennial herbaceous component but not sagebrush. Such sites have the perennial herbaceous species, particularly forbs, that meet the needs of many wildlife but also are less likely to burn as frequently as sites infested with annual grasses. Establishing sagebrush on these sites, quicker rather than later, is likely to confer greater short and long-term benefits. On sites with very dense bunchgrass communities there may need to be some disturbance to the grasses at

cache sites to reduce competition. Daubenmire (1970) in his publication, Steppe Vegetation of Washington noted that dense stands of Palouse Prairie grasslands required some disturbance by digging rodents to lessen grass competition so sagebrush could establish.

8. The cache seeding technique has potential but it's not a silver bullet. It probably works best in conjunction with other treatments or land management approaches. Increasing seed germination and emergence with caches is the easy part of the process, especially in a wet year, but having plants alive after 3-4 years likely will take some thought and a long-term strategy. Numerous ecological processes and mechanisms factors can eliminate many plants from an area in that timeframe.
9. Implementation of the cache treatment should be applied to areas where the ecological sites are well known so the right sagebrush seed is placed in the correct location. Many areas have a heterogenous mixture of different sagebrush species across short distances. Without good knowledge about soils and ecological sites, the wrong harvested sagebrush cache can easily be placed on a mismatched soil, with a seeding failure the probable outcome.

Presentations

McAdoo, J. K. and K.W. Davies. 2018. Shrub Island Establishment Innovation: Sacrificing a Few Sagebrush to Plant Many. Proceedings of the 71st SRM Annual Meeting, Empowerment through Applied Science. January 28, to Feb. 2, 2018, Sparks, NV. Published Abstract available at: http://rangelands.org/wp-content/uploads/2018/01/2018-Abstracts.pdf

Abstract*: Several studies have indicated unreliable or sporadic establishment of Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis) using conventional seeding methods. The primary objective of this study is to evaluate the fall placement of sacrificed sagebrush plants in recently burned areas. The harvested sagebrush could serve both as snow catchments and seed source as the seeds dehisce, with the accumulating dead leaves potentially providing litter/mulch that could also enhance germination by increasing soil moisture. We established treatments within three newly burned sites in northern Nevada, 30 to 60 km apart and having variable elevation, topography, and soils. We used a randomized block study design, with five blocks at each site. Within each block, three 15-m2 plots were randomly selected for either cut-shrub placement, broadcast seeding, or no treatment. At each of the cut-shrub plots, we placed Wyoming big sagebrush stems (harvested just before seed-ripe in November 2016). Seeded plots were hand-broadcast with seed zone-adapted sagebrush seed to simulate conventional broadcast-seeding practice. First year results showed that sagebrush seedling survival in cut-shrub plots, though quite variable, was significantly higher ($p < 0.05$) at each of the sites than in the broadcast-seeded plots. In May, some cut-shrub plots had a "carpet" of sagebrush within 0.5 m of the cut sagebrush, but by October, natural thinning had reduced survivors by approximately 50%. Although more natural thinning is anticipated, the October aggregate survival density mean for cut-shrub plots (5.7/m2) was still two orders of magnitude higher than that for broadcast-seeded plots. Precipitation was higher than normal during this first year of study. For comparison, we will establish additional plots in at least three new wildfire sites during November 2017. Preliminary results indicate potential utility of this technique where establishing sagebrush islands could serve as a seed source for successional recovery of critical sites over time.*

McAdoo, J. K. and K.W. Davies. 2018. Shrub Island Establishment Innovation: Sacrificing a Few Sagebrush to Plant Many. Presented by Gerry Miller, Nevada Division Conservation and Natural Resources, to the Northeast Nevada Stewardship Group. October 18, 2018. 50 attendees. Presented by Gerry Miller, Northeast Nevada Stewardship Group.

Publications

None. A final manuscript will be submitted for publication either in Rangelands or as an Extension Special Publication, through the University of Nevada, Reno, Extension.

Additional Products/Outcomes

- Members of the North Eastern Nevada Stewardship Group, Trout Unlimited and a Boy Scout Troop established three new plots in the fall of 2018, on two fires that burned in 2018. Two sites were in black sagebrush (Artemisia nova) community types and one in low sagebrush. The current PI on this project will continue collaboration with those groups to expand knowledge about the conditions under which the cut-sagebrush seeding approach may work.
- Gerry Miller, Nevada Conservation Districts, established a large-scale cache seeding (approximately 1,500 caches) in Elko County in the fall and early winter of 2020. Seedlings were present in many caches in the spring of 2021.
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Figure 1. Study site locations in northern Nevada.

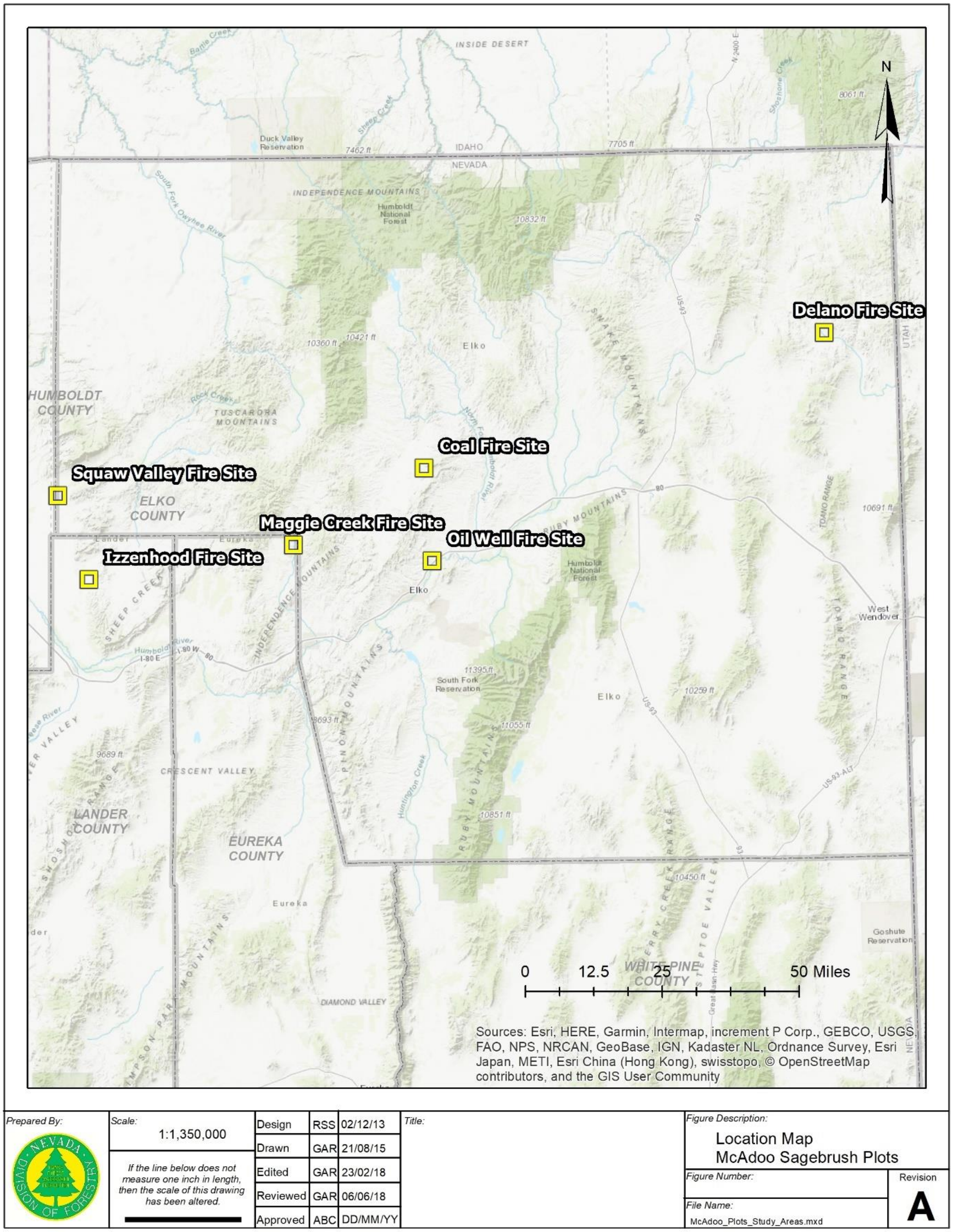

Figure 2. Example of a cache sagebrush plot established in November 2016.

Figure 3. Examples of the “carpet of seedlings” present in late May 2017 beneath and immediately adjacent to sagebrush cache’s established in November 2016.

Table 1. Mean seedling Density (#/15-m2) by study location, year and seeding treatment. Also shown are the number of plots by treatment sampled and number of plots occupied by at least one seedling each year. The p-value is for one-way analysis of variance. When variances were not equal among treatments, data analysis included the Kruskal-Wallis (KW) one-way nonparametric analysis of variance. Footnotes for p-values denote when variances were unequal and if KW test provided a different result. Mean separation was at p≤0.50, unless otherwise noted.

		Seedlings									
		Cache			Broadcast Sagebrush			Control			
Location	Year	Density (#/15-m^2)	Plots sampled (#)	Plots occupied (#)	Density (#/15-m^2)	Plots sampled (#)	Plots occupied (#)	Density (#/15-m^2)	Plots sampled (#)	Plots occupied (#)	P-value
Squaw Valley	2017[a]										
	2018	86.6[a]	5	4	0.0[b]	5	0	0.0[b]	5	0	0.01[b]
	2019	0.0[a]	5	0	0.0[a]	5	0	0.0[a]	5	0	NA[c]
Izzenhood	2017[a]										
	2018	31.4[a]	5	3	0.0[b]	5	0	0.0[b]	5	0	0.03[d]
	2019	0.8[a]	5	1	0.0[a]	5	0	0.0[a]	5	0	0.40
Maggie Creek	2017[a]										
	2018	177.8[a]	5	5	0.4[b]	5	1	0.0[b]	5	0	0.01[e]
	2019	81.4[a]	5	3	0.6[b]	5	1	0.2[b]	5	1	0.04[f]
Oil Well	2018	64.5[a]	4	4	0.0[b]	4	0	0.0 [b]	4	0	0.00[g]
	2019	6.8 [a]	5	5	0.0 [a]	5	0	0.0 [a]	5	0	0.13[h]
	2020	3.2 [a]	5	3	0.0 [a]	5	0	0.0 [a]	5	0	0.14[i]
Delano	2018	0.2 [a]	5	1	0.0 [a]	5	0	0.0 [a]	5	0	0.40[j]
	2019	1.0 [a]	5	1	0.0 [a]	5	0	0.0 [a]	5	0	0.40[j]
	2020	4.2 [a]	5	2	0.2 [a]	5	1	0.0 [a]	5	0	0.18[j]
Coal Fire	2018	1.0 [a]	5	2	0.0 [a]	5	0	0.0 [a]	5	0	0.12[k]

	2019	0.6 [a]	5	2	0.0 [a]	5	0	0.0 [a]	5	0	0.15[k]
	2020	0.6 [a]	5	3	0.0[b]	5	0	0.0 [b]	5	0	0.01[l]

a. Plot level data are unavailable for 2017. Across all sites and treatments, in October 2017, seedling density averaged 85.5 seedlings/15-m^2, which was two orders of magnitude greater than for sites with broadcast seeding of sagebrush.

b. Unequal variances. Parametric one-way AOV and non-parametric KW one-way AOV both had p-values ≤ 0.01, with cache plots separated from BSB and control plots at $p \leq 0.05$, for both parametric Tukey and non-parametric Dunn's all pairwise comparisons.

c. Insufficient sums of squares to calculate p-value.

d. Unequal variances. One-way AOV and KW one-way AOV both had p-values ≤ 0.03 and 0.02, respectively, with cache seeding separated from BSB and control treatments at $p \leq 0.10$, for both the Tukey and Dunn's all pairwise comparisons.

e. Unequal variances. One-way AOV and KW one-way AOV had p-values of $p \leq 0.007$ and 0.0001, respectively, with Cache seeding separated from BSB and control treatments at $p = 0.05$ for the Tukey and Dunn's all pairwise comparisons, respectively.

f. Unequal variances. One-way AOV and KW one-way AOV had p-values of $p \leq 0.04$ and 0.17, respectively, with cache seeding separated from BSB and control treatments at $p = 0.10$ for the Tukey all pairwise comparison.

g. Unequal variances. One-way AOV and KW one-way AOV both had p-values less than 0.00, with cache seeding separated from BSB and control treatments at $p = 0.05$ for both the Tukey (parametric)and Dunn's (non-parametric) all pairwise comparisons.

h. Equal variances for one-way AOV and Non-significant p-value. Non-parametric KW one-way AOV had p-value ≤ 0.00, with cache seeding separated from BSB and control treatments at $p = 0.05$.

i. Equal variances for one-way AOV and non-significant p-value. Non-parametric KW one-way AOV had p-value of 0.017, with cache seeding separated from BSB and control treatments at $p = 0.05$.

j. Equal variances and same large p-values for both the parametric one-way AOV, and KW non-parametric one-way AOV.

k. Unequal variances, but p-value $\geq$0.11 for both parametric one-way AOV and non-parametric KW one-way AOV.

l. Unequal variances. Parametric one-way AOV and non-parametric KW one-way AOV both had p-values = 0.02, with cache seeding separated from BSB and control by parametric Tukey Dunn's non-parametric all-way comparisons at p= 0.05 and 0.10, respectively

Table 2. Weather data for four long-term stations across the study area, their period of record, and amount of precipitation for the October-March and April-June period of each water year, of seedling data collection.

	Precipitation					
	October-March			April-June		
Station, period of record and water year	mm	Percent of Mean	Percent of Median	mm	Percent of Mean	Percent of Median
Winnemucca (1878-2021)						
2015-16	181	143	152	44	71	74
2016-17	214	168	179	66	106	111
2017-18	109	86	92	86	139	145
2018-19	185	146	155	78	127	132
2019-20	86	68	72	59	96	100
Mean (126 years)	127			62		
Median (128 years)	119			59		
Battle Mountain (1944-2020)						
2015-16	207	193	206	61	89	98
2016-17	251	233	248	77	111	123
2017-18	99	91	98	93	135	149
2018-19	154	143	152	114	165	183
2019-20	69	64	68	50	72	78
Mean (75 years)	108			69		
Median (78 years)	101			55		
Beowawe (1950-2021)						
2015-16	160	142	153	93	131	140
2016-17	185	164	177	76	107	114
2017-18	96	85	92	72	103	109
2018-19	196	174	189	112	158	168
2019-20	84	83	90	63	90	95
Mean (70 years)	113			71		
Median (71 years)	104			66		
Elko (1888-2021)						
2015-16	199	136	149	109	166	182
2016-17	279	191	208	63	96	105
2017-18	119	81	89	83	125	138
2018-19	221	151	165	109	166	182
2019-20	121	83	90	34	51	56
Mean (122 years)	146			66		
Median (120 years)	134			70		