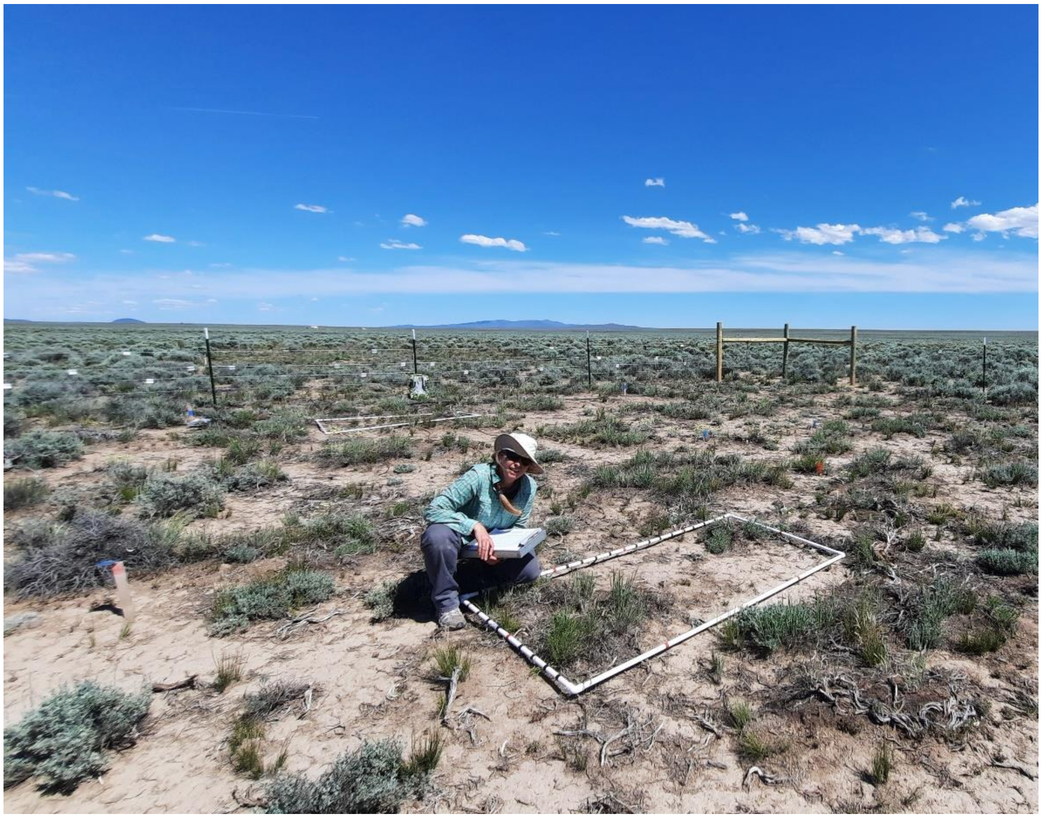
Restoring depleted understory plant communities to benefit greater sage-grouse, 2023 progress report



November 2023

Report for East Cascades Audubon Society

Report prepared by Scott Harris

Institute for Applied Ecology

PREFACE

IAE is a non-profit organization whose mission is the conservation of native ecosystems through restoration, research, and education. IAE provides services to public and private agencies and individuals through development and communication of information on ecosystems, species, and effective management strategies. Restoration of habitats, with a concentration on rare and invasive species, is a primary focus. IAE conducts its work through partnerships with a diverse group of agencies, organizations, and the private sector. IAE aims to link its community with native habitats through education and outreach.

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Cover photographs: Jill Welborn monitoring vegetation responses to restoration treatments. IAE photo.

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EXECUTIVE SUMMARY

Despite substantial collaborative efforts to conserve greater sage-grouse (*Centrocercus urophasianus*), and its critical habitat, the dramatic decline in populations over the past 50 years has yet to be arrested. The habitat threats of juniper encroachment, invasion of annual grasses, and altered fire regimes receive much conservation and management attention. However, removing or mitigating these threats does not guarantee the restoration of critical habitat elements, in particular understory plant communities. Forbs, perennial grasses, and forb-associated arthropods in sagebrush understories are critical for chick-rearing and reproductive success. Studies have shown that annual recruitment is directly correlated to availability of grass and forb-associated arthropods. Therefore, restoration of these habitat elements should be a high priority, as they are scarce or missing in many priority sage-grouse conservation areas.

The goal of this study is to identify best practices for restoring forb and grass understories in core sage-grouse habitat. We tested how various treatments (seeding methods, mowing, micro-irrigation, and grazing exclusion) affect restoration success in a crossed and replicated experiment near Brothers, Oregon.

This report summarizes our preliminary results from the first 2 years of this 3-year study. Results varied by year, likely due to differences in growing conditions. Therefore, results following the 3rd year of measurements that will be presented in the final report will be the most useful for assessing treatment responses. After two growing seasons, the pellet seeding method had significantly higher establishment of seeded species compared to both the control and by using a manual seed drill. We found that micro-irrigation (at the levels we provided) was ineffective at increasing understory resources for sage-grouse. Mowing increased annual forb and perennial graminoid cover, but not perennial forb nor annual graminoids (cheatgrass). We were unable to test the effect of livestock grazing because the landowner removed all livestock from the study area. Therefore, at this stage of the study it appears that the most promising protocol is to use pellet seeding after mowing. As previously mentioned, the 3rd year of measurements will further elucidate the vegetation responses to these treatments.

This study is being conducted by the Institute for Applied Ecology with funding, volunteer, and in-kind support from East Cascades Audubon Society, TerraWest Conservancy, and the Greenfield Hartline Habitat Restoration Fund.

1. INTRODUCTION

The population of greater sage-grouse (C*entrocerus urophasianus*) has declined nearly 80% across its 11-state range in the last 50-years (Coates et al. 2016). In 2015, the USFWS found that listing of greater sage-grouse as an endangered species was “warranted but precluded” – meaning that the available science justifies a listing but that other species are considered higher priority. Populations have continued to decline even following substantial collaborative efforts across the region to address conservation threats. In Oregon in 2023, the sage-grouse breeding population was estimated to be 15,503, the third lowest population estimate since 1980, and in the monitoring unit encompassing this study (Bureau of Land Management Prineville District) the population declined 9.7% (Vold 2023).

While the primary diet for adult sage-grouse is sagebrush; forbs, grasses, and their associated arthropods are critical for hens during the brooding season and for chick survival. Chicks in particular are completely reliant on forbs and forb-associated arthropods (e.g., ants, caterpillars, grasshoppers, spiders, etc.) during the first two weeks of life (Johnson and Boyce 1990) and continue to consume appreciable amounts of arthropods during the subsequent four months (Dahlgren et al. 2015).

Forbs and grasses comprise the understory plant community in sagebrush steppe ecosystems. The sagebrush steppe ecosystem and associated understory plant communities have become increasingly degraded since European settlement (Davies and Bates 2014, Doherty et al. 2022). Restoration of this ecosystem has focused on mitigating the threats of altered wildfire regimes, invasive annual grasses, conifer expansion, and human land use. However, addressing these landscape-scale threats does not guarantee increased health of the forb and grass understory (Bates et al. 2017), and without forbs sage-grouse will never recover.

Restoring understory plant communities at landscape scales has many operational challenges, such as very limited supplies of native seed, variable plant responses due to seasonal and interannual climate variability, difficult site access, and incomplete knowledge of the optimal field conditions for the germination and maturation of selected plant species. Therefore, targeting the restoration of forbs in core sage grouse habitat (particularly early brood-rearing habitat) seems necessary. Unlike grasses, there is a paucity of information on the best practices for restoring forbs in sagebrush steppe ecosystems. Our study will fill this knowledge gap by assessing the efficacy of four restoration practices that can be used to create forb restoration islands to benefit greater sage grouse and other sagebrush steppe species.

2. GOALS AND OBJECTIVES

The goal of this study is to identify best practices for restoring forb islands in core sage-grouse habitat. Specific study objectives are to:

1) Assess the efficacy of the following restoration treatments (alone and in combination) at restoring grass and forb understories in sagebrush steppe ecosystems
    a. Different seeding methods
    b. Mowing
    c. Micro-irrigation
    d. Livestock exclusion
2) Communicate study results with sage-grouse conservation stakeholders

3. METHODS

3.1. Site Description

Our study site is in the northwestern-most corner of the current distribution of greater sage-grouse in Oregon (Figure 1, Aldridge et al. 2008). It is in the Brothers Priority Area for Conservation (PAC, Figure 2). PAC's are identified by Oregon Dept. of Fish and Wildlife as essential for the long-term conservation of sage-grouse.

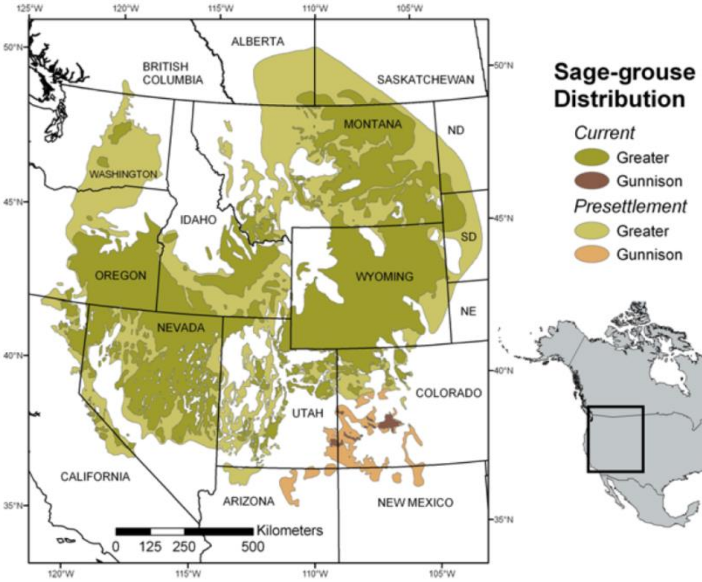

Figure 1. Historic and current distribution of sage-grouse.

The study site is approximately four miles NNE of Brothers, Oregon in the Northern Basin and Range Ecoregion, High Lava Plains physiographic province (McClaughry et al. 2019). Soils are predominantly classified as the Ninemile-Dester Complex: shallow, well-drained soils derived from volcanic ash and weathered basalt. Typical soil profile is gravelly-sandy loam, clay, gravelly clay, then bedrock at 19-29 inches (USDA 2022b). The 30-year (1991-2020) climate normals are: 9.1 in of mean annual precipitation, monthly mean minimum temperatures ranging from 19 to 45 deg F, and monthly mean maximum temperatures ranging from 38 to 84 deg F (PRISM Climate Group 2023).

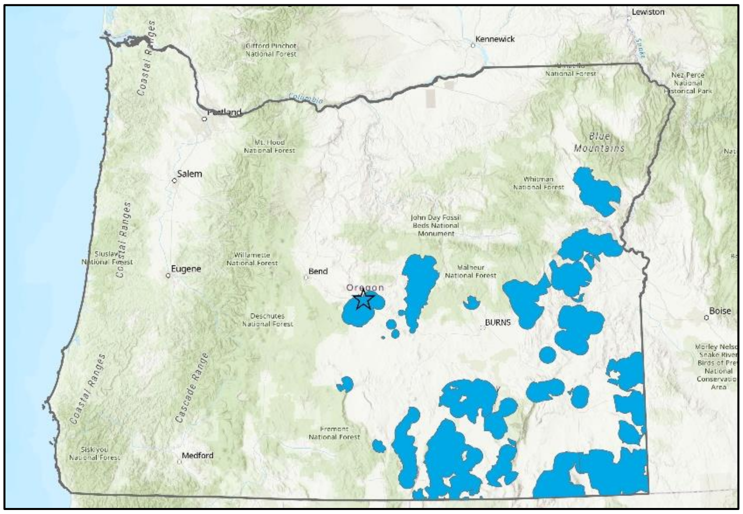

Figure 2. Priority areas for sage-grouse conservation (PACs) in Oregon shown in blue. Location of the Brothers Study site is shown by the star.

However, average climatic conditions do not tell the full story of site conditions. The Oregon high desert is characterized by weather extremes. Snow can be present at any time of the year, including during an early spring survey in 2023 (Figure 3), and small-scale thunderstorms can provide abundant rain to an area while adjacent areas receive none.

Figure 3. 3.5" of snow at the study site on May 9, 2023 that was gone 5 hours later.

The site consists of 2 pastures (named "Cody" and "West Reservoir") approximately 1.4 km apart on private land managed by TerraWest Conservancy, adjacent to public land managed by the Bureau of Land Management (Figure 4). The study area has historically been used for livestock grazing. Invasive annual grasses and juniper are uncommon in the immediate vicinity. Average shrub cover is 12% and consists of mostly of Wyoming big sagebrush (*Artemisia tridentata spp wyomingensis*) and green rabbitbrush (C*hrysothamnus viscidiflorus*). Understory graminoid and forb cover is 6% and 1%, respectively (Figure 5). Cover of non-native annual grass species is < 0.1%, consisting of only cheatgrass (*Bromus tectorum*).

Figure 4. The Cody Pasture at the Brothers study site.

3.2. Seed Mix

Figure 5. Typical site conditions in October 2021.

We developed a seed mix specifically tailored to benefit greater sage-grouse. Prior research describes the relative values that different plant families, genera, and in some cases species contribute to the sage-grouse diet during the critical early brood-rearing stage (Rosentreter 2015). We selected species from this information that also had locally available seed. Finding locally available seed was a significant hurdle and we were unable to find most of our highest priority species. The seed mix we planted in November 2021 (Figure 6) consisted of yarrow (*Achillea millefolium*), limestone hawksbeard

(*Crepis intermedia*), Lewis' flax (*Linum lewisii*), and squirreltail grass (*Elymus elymoides*) – all perennial species. Due to poor germination we observed in May 2022, we decided to increase the seeding rate and species mix when we seeded only the pellet plots (see below for description of seeding methods) for a second time in November 2022. The perennial grass was added for its value as cover for nesting and brooding hens, and we wanted the proportion (by weight) of grass to be less than 10% of the mix. Seeding rates were 5.01 and 15.45 lbs per acre in 2021 and 2022, respectively (Table 1).

Figure 6. Species in our 2021 seed mix: yarrow, limestone hawksbeard, Lewis' flax, and squirreltail grass.

Table 1. Species composition and seeding rates. In 2021, seed was applied to all 96 Jang and pellet plots. In 2022, seed was only applied to the 48 pellet plots. PLS = proportion of live seed.

				Lbs planted	
Species	**Common name**	**Seeds per lb**	**PLS**	**Jang & Pellet plots (2021)**	**Pellet plots (2022)**
Achillea millefolium	yarrow	3,490,791	0.92	1.00	1.00
Crepis intermedia	limestone hawksbeard	120,039	0.30	0.77	
Crepis occidentalis	western hawksbeard	120,039	0.30		0.38
Linum lewisii	Lewis' flax	295,800	0.94	1.00	1.00
Lomatium triternatum	Lewis' lomatium	42,000	unknown		1.00
Phacelia hastata	silverleaf phacelia	153,000	unknown		1.00
Elymus elymoides	squirreltail grass	192,000	0.90	0.20	0.20
Achillea millefolium	yarrow	3,490,791	0.92	1.00	1.00
Crepis intermedia	limstone hawksbeard	120,039	0.30	0.77	
			Lbs Total	**2.97**	**4.58**
			Lbs per acre	**5.01**	**15.45**

3.3. Experimental Design & Treatments

We selected four types of restoration treatments, based on prior knowledge and review of the literature, to test with an experimental design. Treatments are seeding method, mowing, micro-irrigation, and grazing exclusion. A no-treatment control is also included. Mowing, micro-irrigation, and grazing exclusion each have two levels (present or absent) while seeding method has three levels (seed pellets, Jang seeder, or no seeding control). A fully-crossed experiment for assessing the efficacy of all possible combinations of treatments would necessitate 3x2x2x2 = 24 replicates per block, or 192 replicates over eight blocks. Due to logistical constraints and limited seed supply, we eliminated some of the treatment combinations and only replicate micro-irrigation in four of the eight blocks. Grazing exclusion is accomplished with a permanent fenced exclosure and represents a split plot in our experimental design. The final experimental design of 128 plots includes replicates of the treatment combinations shown in Table 2.

The Jang seeder (Jang Automation Co.) is a commercially-available precision seed drill (Figure 7A) that creates a shallow furrow, drops seed at a regulated rate, and then covers the furrow. We used a manual push seeder, but this tool can be scaled-up to be pulled behind a small tractor and have up to six seed hoppers. Seed pellets (Figure 7B) were made following established methods for dry-land restoration (Gornish et al. 2019) and using the specific protocol in Appendix A. Seed pellets were spread more or less evenly by hand.

Table 2. Treatment matrix. 0 = not treated or exclusion, 1 = treated, J = jang seeder, P = pelleted seeds.

	Treatment				
Label	**Irrigation**	**Seeding**	**Mowing**	**Grazing**	***Replicates***
1	1	0	0	0	4
2	1	J	0	0	4
3	1	P	0	0	4
4	1	J	1	0	4
5	1	P	1	0	4
7	0	0	0	0	8
8	0	J	0	0	8
9	0	P	0	0	8
10	0	J	1	0	8
11	0	P	1	0	8
12	0	0	1	0	4
13	1	0	0	1	4
14	1	J	0	1	4
15	1	P	0	1	4
16	1	J	1	1	4
17	1	P	1	1	3[a]
19	0	0	0	1	8
20	0	J	0	1	8
21	0	P	0	1	8
22	0	J	1	1	8
23	0	P	1	1	7[a]
24	0	0	1	1	4

a. Two plots in one of the blocks were mistakenly not mowed.

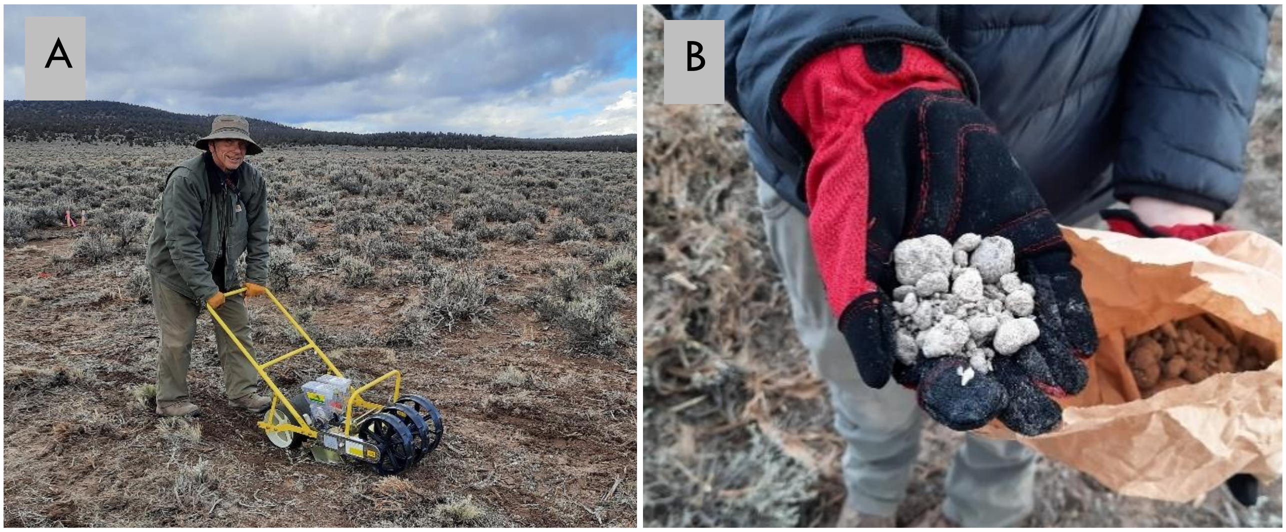

Figure 7. A) The Jang seeder. B) Seed pellets.

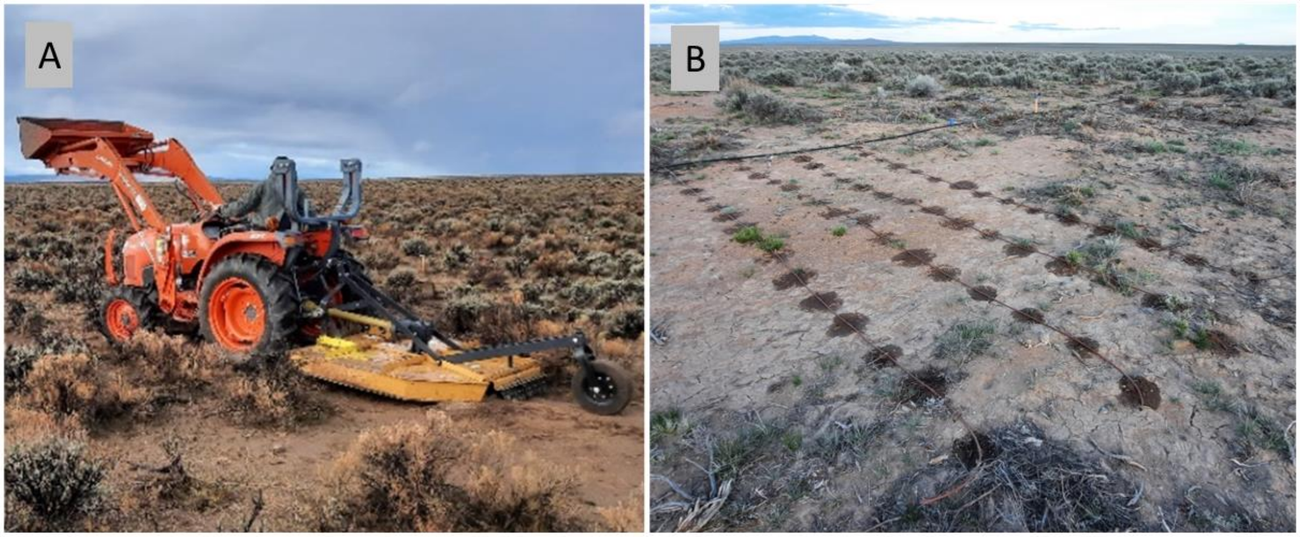

Figure 8. A) Mowing, and B) micro-irrigation treatments

Mowing was done with a brush hog pulled behind a medium-sized tractor (Figure 8A). The cutting height was set to approximately 8 inches. Micro-irrigation utilized the existing water infrastructure on site (for livestock) and was accomplished with a combination of drip irrigation (Figure 8B), water tank mounted on an ATV, and manual irrigation with a water jug.

Treatment combinations are replicated in each of eight blocks, four in the Cody Pasture and 4 in the West Reservoir Pasture. All treatment plots are 5 m x 5 m with a 2 m buffer between plots. The grazed and ungrazed plots are separated by 10 m. Distance between blocks, and distance of blocks from livestock watering troughs is at least 250 m. Distance between the Cody and West Reservoir Pastures is 1.4 km. Orientation of blocks was randomly determined, but the arrangement of treatment plots within blocks were held constant to aid logistics. Appendix B shows block locations, orientation, and plot arrangement.

We installed the study plots and applied all treatments except grazing exclusion November 8-12, 2021. Exclosure fences were installed January through March 2022. The exclosures were designed to only exclude livestock. We also placed small white triangles on the fence wires to avoid injury to flying grouse. There were no managed livestock in the two pastures once the study was installed, although we were unable to monitor for "trespass" livestock (loose, unmanaged livestock). The 48 pellet plots were seeded a second time on November 3, 2022.

3.4. Field Data Collection

We conducted pre-treatment surveys November 8-9, 2021. Because these surveys were outside of the growing season, we only estimated the percent cover of woody species and biological and physical soil crusts (see Belnap 2001 for a description of these crusts). We also noted the presence of grouse scat and livestock tracks. All grouse scats observed were removed from plots.

Post-treatment surveys were conducted in both May and June of 2022 and 2023. The intent of the May survey was to record any early germinants from our seed mix that might be consumed or difficult to identify by the June survey. The later survey was timed for the peak of the growing season (approximately mid-June depending on growing conditions). We counted grouse scat and livestock tracks, estimated the percent cover of each woody and forb species and graminoids by group (native annual, non-native annual, perennial), the dominant perennial graminoid species, and the counts of individual plants of our seeded species. All grouse scats observed were removed from plots.

3.5. Analysis

Each treatment plot has two 1m x 2m quadrats in which all responses were assessed. Estimates from the two quadrats were averaged to represent the response for each treatment plot. Unfortunately, there were no livestock in the study area – meaning that the grazing exclusion treatment cannot be assessed. Therefore, we pooled the grazed and ungrazed treatment plots in each block by calculating the average measurement values for each treatment in that block. This means that the estimates for each treatment in each block is the average of four quadrats. We could have considered the grazed and ungrazed plots as additional replicates, meaning that each treatment combination would have been replicated twice at each block. We did not do so because we felt the plots were insufficiently independent and would have represented a case of pseudo-replication.

All analyses were conducted in R (R Core Team 2022). We report cover estimates for all plants, seedling densities of the seeded species, and rarefied richness of forbs. Rarefied richness, which accounts for uneven sampling effort, was calculated with the vegan package in R (Oksanen and et al. 2022) with subsampling size set at 16. Prior to statistical tests, all response variables were assessed as to whether they met appropriate assumptions. Response variables were log-transformed to meet normalcy. Homogeneity of variance was assessed with Levene's test. Residuals were visually assessed for homoscedasticity with Q-Q and residual plots. Statistical tests used 3-way ANOVA F-tests with either cover or density of seeded species as the response variable. Blocks were treated as a random effect. Post-hoc assessment of effect sizes was conducted by calculating the difference in estimated marginal means between treatments using Tukey's HSD in the emmeans package in R (Lenth 2022). Estimated marginal means adjust the mean response for each factor level by accounting for other model variables and unbalanced data. Our data set is essentially unbalanced because we replicated irrigation in 4 blocks and all other treatment combinations in 8 blocks. However, ANOVA is robust to departures from balanced data as long as the homogeneity of variance assumption is met.

4. RESULTS

4.1. Mowing and irrigation

Mowing reduced shrub cover from approximately 12% to 2%. We had multiple challenges with the irrigation system. In early June 2022, the irrigation line was crushed by a vehicle and then lightning disabled the pump. These events stopped irrigation for approximately four weeks. In 2023, the irrigation pump was again disabled by weather and was not activated until June. Figure 9 shows both precipitation and supplemental irrigation levels for 2022 and 2023 compared to the 1991-2020 normals (PRISM Climate Group 2023). The PRISM estimates are at 800m resolution. By integrating weather data from all nearby weather stations with topographic models to account for localized orographic effects, we believe the PRISM data are the most accurate precipitation estimates available for our study site.

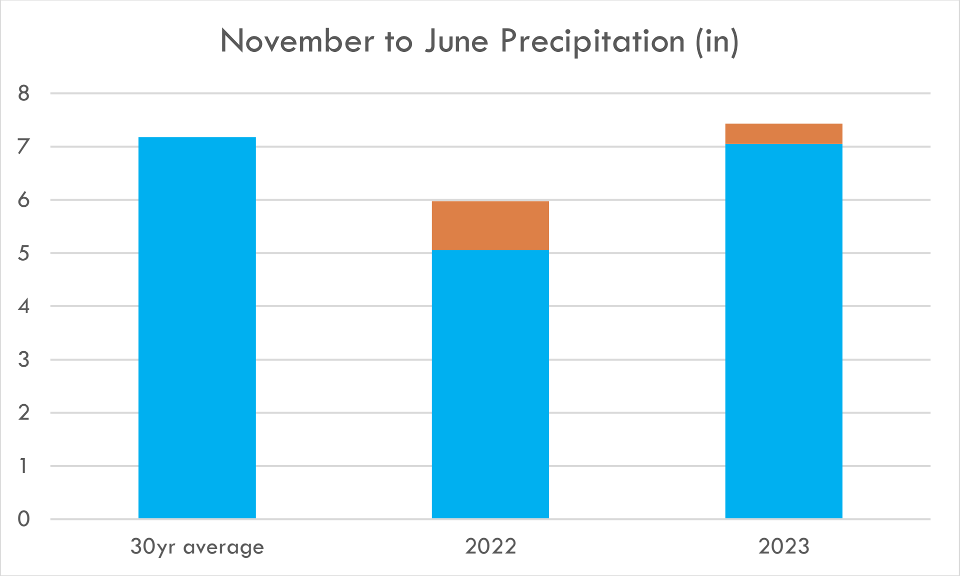

Figure 9. Precipitation (blue) and supplemental irrigation (orange) on the study plots during the growing periods (November to June) of 2022 and 2023. Precipitation from PRISM (2023).

4.2. Livestock and grouse

We observed no livestock with a game camera set up on at the Cody 3 (or Cody D) block from May 5 to August 26, 2022. We saw several raptors perched on the exclosure fence and pronghorn in the area on two occasions. We have not seen any grouse scat in the West Reservoir blocks and 6 scat in November 2021, 13 in May 2022, and none in June of either year. However, we have consistently observed grouse scat when walking between blocks at both West Reservoir and Cody.

4.3. Plant cover

Cover values and rarefied forb richness by growth form (e.g., forb, shrub, etc) are shown in Appendix C. The cover of all growth forms increased from 2022 to 2023, including shrub cover. The cover of non-native annual graminoids (which are all cheatgrass in this study) is below 1% - a level too low to statistically detect any responses to treatments. After 2 growing seasons, mowing increased annual forb cover ($p < 0.001$) 200% and graminoid cover ($p < 0.001$) 40%, but did not increase perennial forb cover

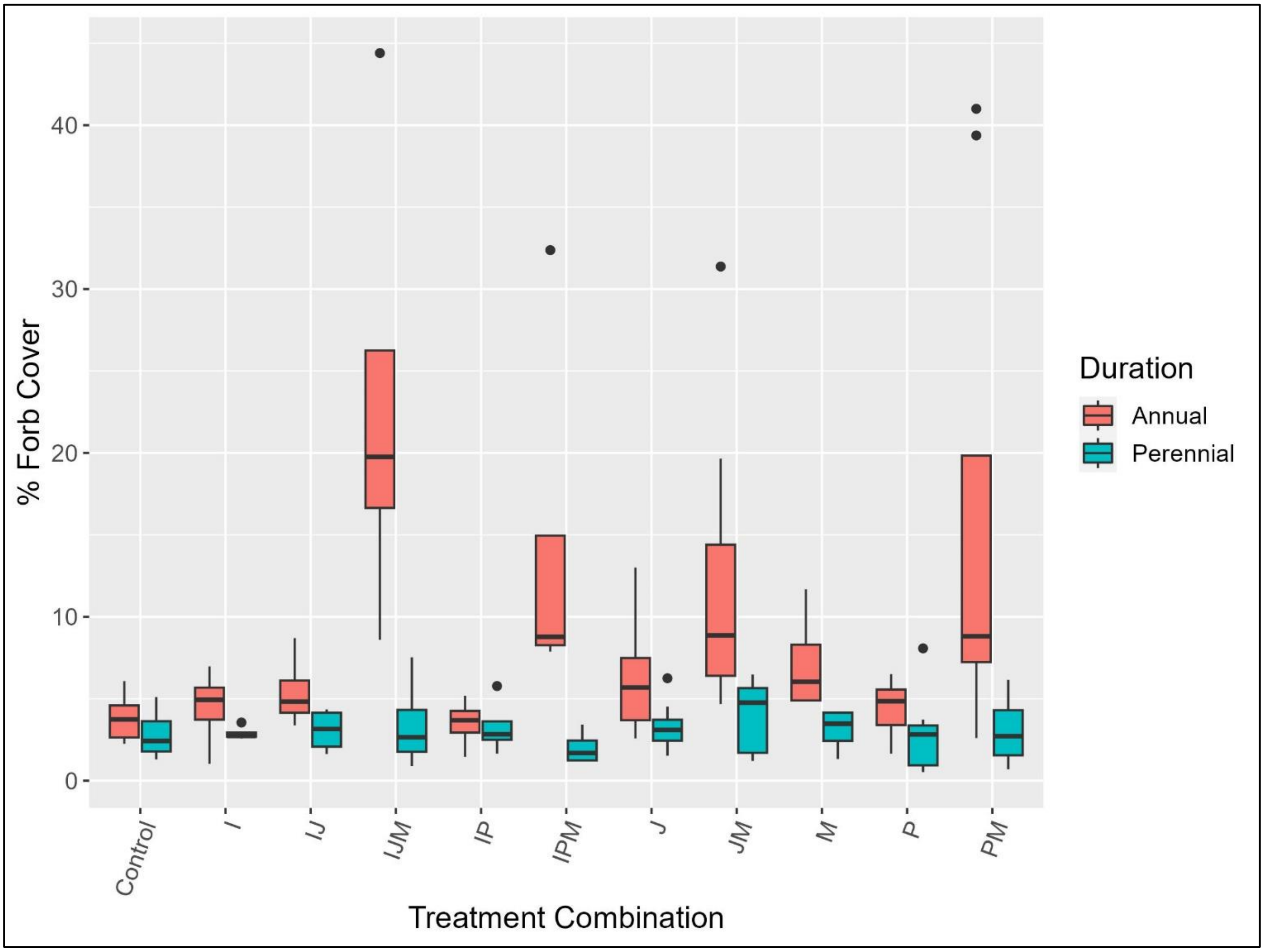

Figure 10. Annual and perennial forb cover for each treatment combination (I = irrigated, M=mowed, J=Jang seeder, P=pelleted seeds, etc.). See Appendix C for sample sizes.

(p = 0.99, Figure 10). There were no significant interactions at the 0.10 significance level. We were unable to test the grazing exclusion treatment because the landowner removed all livestock approximately the same time we set up the experiment in November 2021. Results of statistical tests, using 2023 survey results, are shown in Table 3. In 2022 following an extreme drought, irrigation (p = 0.052) and mowing (p=0.022) increased total forb cover. See Appendix D for a list of all shrub and forb species observed in the study plots.

Table 3. Results of 3-way ANOVA tests using June 2023 (after 2 growing seasons) survey estimates. The pellet plots were seeded twice with a seeding rate 3 times higher in 2022 than 2021. Treatment interactions were assumed to be insignificant at alpha > 0.10.

Response variable	Explanatory variable	p-value	effect	Treatment interactions
perennial forb cover	seeding method	0.18	n/a	none
	irrigation	0.42		
	mowing	0.99		
annual forb cover	seeding method	0.11	n/a	none
	irrigation	0.67		
	mowing	**<0.001**	increased 200% with mowing	
native graminoid cover	seeding method	0.39	n/a	none
	irrigation	0.45		
	mowing	**<0.001**	increased 40% with mowing	
seedling density	seeding method	**<0.001**	pellet increased 130% over Jang	none
	irrigation	0.31	n/a	
	mowing	0.26		

4.4. Seedlings of planted species

We found seedlings of all our seeded species except for the two *Crepis* species (limestone hawksbeard and western hawksbeard). All of the flax seedlings observed were very small – less than approximately 2 in tall (Figure 11). Therefore, we were confident that the flax seedlings germinated from our seed mix. We found both tall and short seedlings of yarrow, up to 8 in and less than 2 in respectively. Therefore, some yarrow seedlings were likely from the existing seed bank. Many of the yarrow seedlings were at

Figure 11. Lewis' flax seedling.

Figure 12. yarrow seedlings under the edge of the sagebrush canopy.

the edge or under the shrub canopy (Figure 12). Yarrow was the most successful of all the species planted (Figure 13). The plots that were pellet-seeded had 2.3 times higher seedling density than the plots that were Jang-seeded ($p < 0.001$, Figure 14). However, the pellet-seeded plots were planted twice with a higher seeding rate (3 times) in 2022 than 2021.

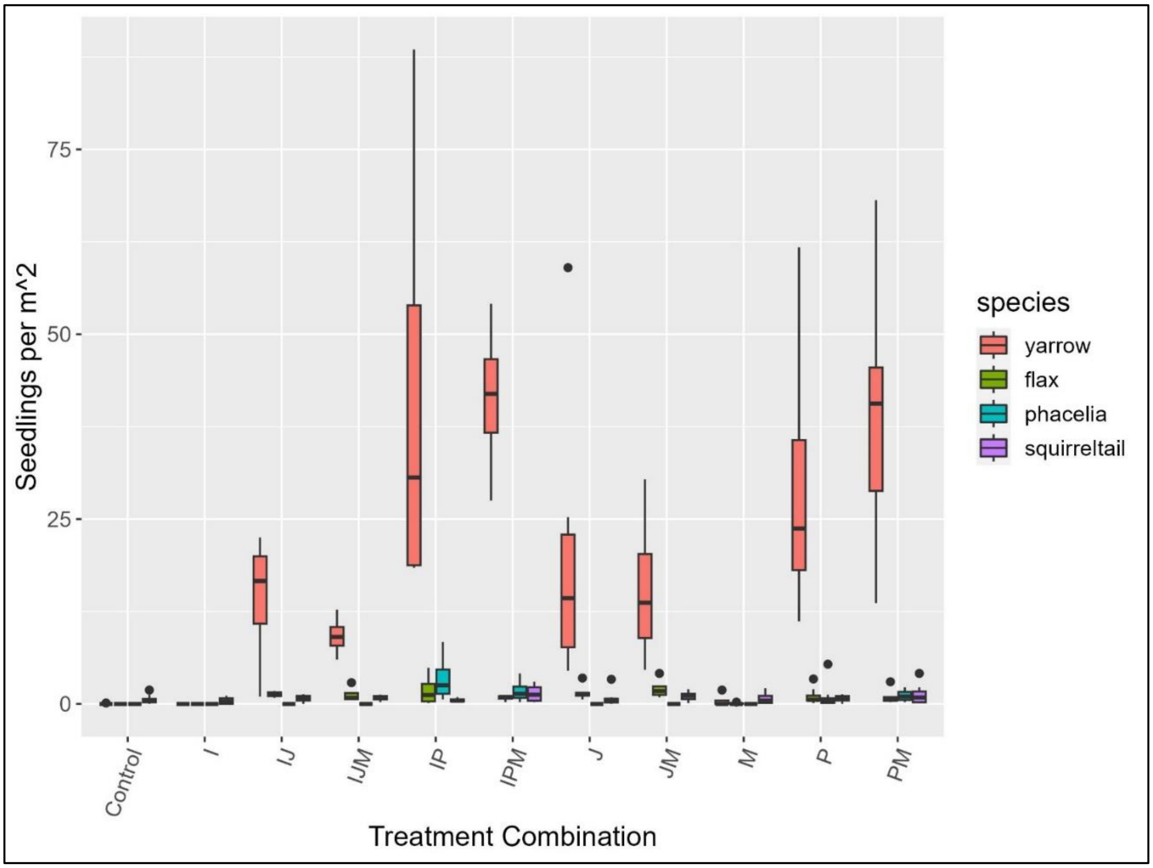

Figure 13. Seedling density by treatment combination (I = irrigated, M=mowed, J=Jang seeder, P=pelleted seeds, etc.) and species after two growing seasons. See Appendix C for sample sizes.

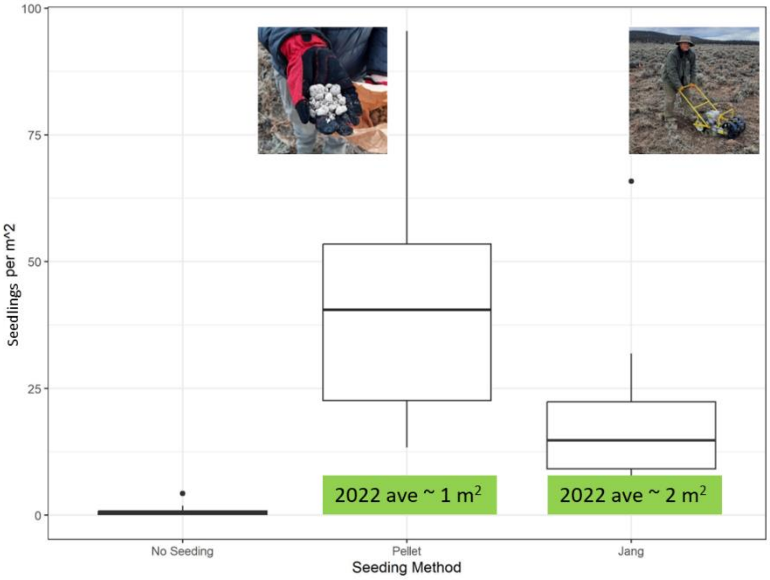

Figure 14. Seedling density of planted species after two growing seasons. The average densities in 2022 (green boxes) were substantially lower. Seedling density by species are shown in Appendix E.

5. DISCUSSION

Our study site experienced extreme drought during the 2021-2022 growing season and then more favorable, but still below average precipitation, during the 2023-2023 growing season (Figure 9). Both plant cover for all growth forms and the germination of our seeded species was low. The plant response rebounded in 2023. The percent cover of all growth forms was higher in 2023 than 2022.

The mowing treatment increased annual but not perennial forbs. This is somewhat expected as the mowing disturbance and clearing of the shrub canopy improved conditions for fast-growing annuals. For example, some of our plots had cover as high as 50-60% of *Gayophytum* (groundsmoke). Mowing also increased the cover of perennial graminoids. This annual forb and perennial grass response raises the concern that cheatgrass will rapidly colonize mowed areas, but we have yet to observe a cheatgrass response. The highest cheatgrass cover in any plot was 0.7% in 2023.

Irrigation also increased forb cover in 2022, but not in 2023. This suggests that supplemental irrigation can be beneficial during extreme drought years, but less so during more average growing conditions. We had many problems with the irrigation system which highlighted the challenges of “watering the desert”. Because irrigation is labor- and cost-intensive, our results suggest that regular irrigation may not be justified except during drought and to help with initial seeding.

The seeding method showed significant differences in establishing our target species. In 2022, the Jang seeder was slightly more effective for seedling establishment, but seedling densities were very low compared to 2023. In 2023, the pellet method was more effective. However, the 2023 test is really a comparison of Jang seeding at a rate of 5 lbs per acre versus pellet seeding at a rate of 5 lbs per acres then again one year later at a rate of 15 lbs per acre. We did not repeat the Jang seeding in order to not disturb the ground. Repeated pellet seeding is more representative of operational restoration practices.

Multiple years are needed to accurately assess the effects of restoration treatments on plant communities and establishment (Applestein et al. 2018), particularly in arid environments and for perennial species. We will continue monitoring plant response for one more year. The extreme variability in annual and inter-annual weather in the arid high desert will also greatly influence our observed responses. The Brothers area experienced an exceptional drought during the entire first growing season (USDA 2022a). Annual precipitation between November 2021 and May 2022 was 63% of the 30-year average, and there was no precipitation in February.

There are many factors that can affect the plant community at the study site that were not addressed in this study. The effects of herbivorous ants may be especially important. Both thatch ants (*Formica Obscuripes*) and harvester ants (*Pogonomyrmex* spp) occur at the site. Harvester ants are especially abundant. Figure 15 shows an aerial view of the Cody portion of the study site. The bare round areas are harvester ant mounds. Within the few study plots that encompassed such mounds, there was almost no plant cover. The relationship between ants and plant community structure at the study site warrants further investigation.

6. CONCLUSIONS

Multiple years of repeated monitoring can be required to fully assess the effects of experimental treatments on plant community structure in arid environments such as the sagebrush steppe of Central Oregon. Our conclusions based on two consecutive years of monitoring are therefore preliminary. We will conduct another year of monitoring in 2024 and hope to continue monitoring farther into the future. For forb restoration to be conducted at spatial scales sufficiently large to benefit sage grouse, managers should consider achieving a balance between operational feasibility and plant responses. The seed pellet method shows promise for establishing target species, as long as seeding rates are high over multiple seasons. Irrigation can benefit forbs and grasses in drought years, but so far does not seem to provide sufficient benefit to justify the logistics and cost. Mowing shows promise, but one more year of data would further elucidate the benefits for perennial forbs and assess the risk of cheatgrass invasion.

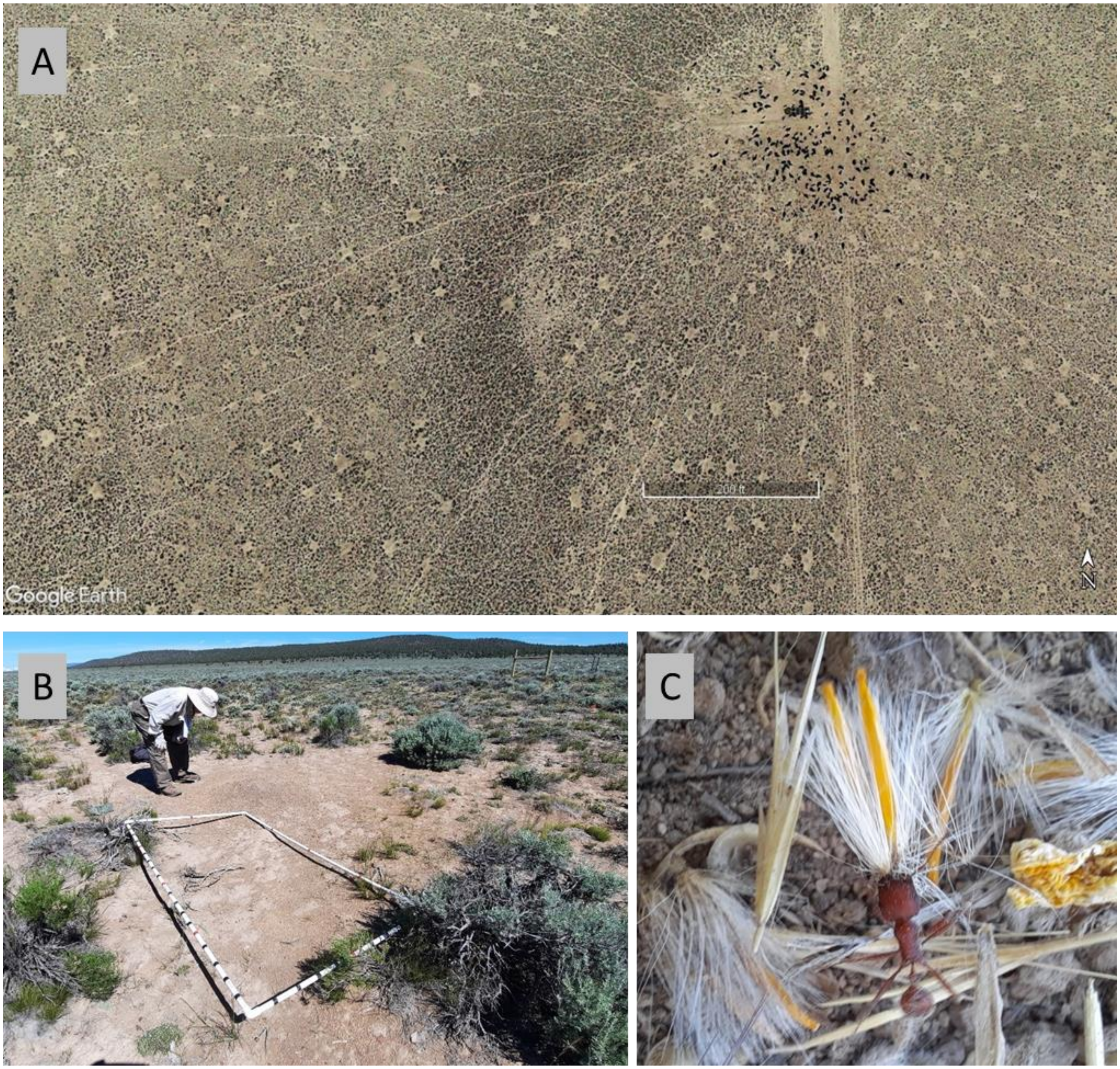

Figure 15. A) 2017 Google image of the Cody area. The scale bar is 200 ft. The trails converge on the watering trough. Note the presence of ant mounds. B) At some plots, an ant mound would comprise the entire plot area. C) In the vicinity of the Cody plots, we observed active ant predation on *Crepis* seeds

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APPENDIX A. SEED PELLET PROTOCOL

October 2022

Materials

- 1 part seed mix
- 1 part diatomaceous earth
- 4-5 parts clay (we used dry kaolin)
- 1 part nutrient (finely sieved potting soil)
- Distilled water to feel
- Large container to combine ingredients (in 2021 we used a 5 gallon bucket and in 2022 we used a cement mixer)
- N95 mask (diatomaceous earth and kaolin clay both can cause lung irritation and/or cancer with enough exposure)
- Air purifier with HEPA filter if working indoors
- Eye protection
- 42” plastic kiddie pool or tarp

Method

1. Place down newspaper/tarp/etc if available. Be prepared to get very messy and take appropriate caution (gloves, rags, clothes you don’t mind getting dirty)
2. Combine seed, diatomaceous earth, nutrient (potting soil/compost), and clay in the large container. Don’t add everything at once. Depending on your container you may need to make several smaller batches. So start with a small batch to see how it goes. If you add too much material early it can turn into a poorly mixed clumpy mess.
3. Thoroughly mix dry ingredients together in large container. You can do this by hand or by shutting the lid on the container and shaking it. Allow the mixture to settle before opening it to minimize airborne particulates that may cause lung irritation.
4. Add a small splash of distilled water to the dry mix
5. Thoroughly mix the dry ingredients with the distilled water by rolling the large container. It is easiest to place the 5 gallon bin on its side atop a table with the elevated bits/lid just off the edge of the table. This enables you to use the metal handle to roll the container, almost like rocking a cradle (if you weren’t concerned for the safety of the baby).
6. Continue adding small amounts of distilled water and rolling the large container. When balls begin to form, you have likely added enough water.
7. As balls form, place them one layer deep on a tarp or in a kiddie pool. It is best to place them somewhere warm and dry for quick drying.
8. If using kaolin clay, balls are dry when light grey in color.

APPENDIX B. EXPERIMENTAL LAYOUT

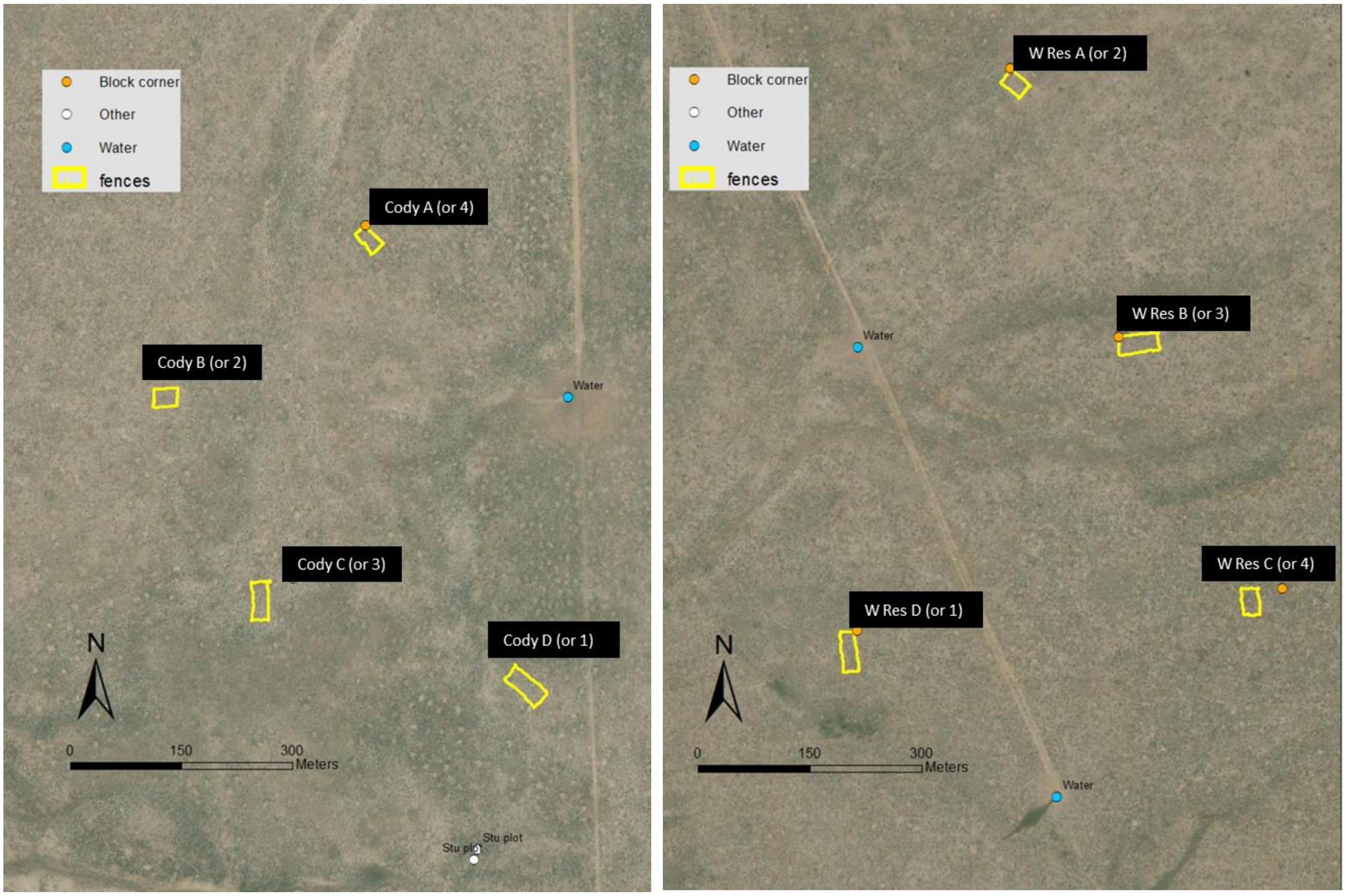


Figure B.1. Location of each block in the Cody and West Reservoir Pastures.

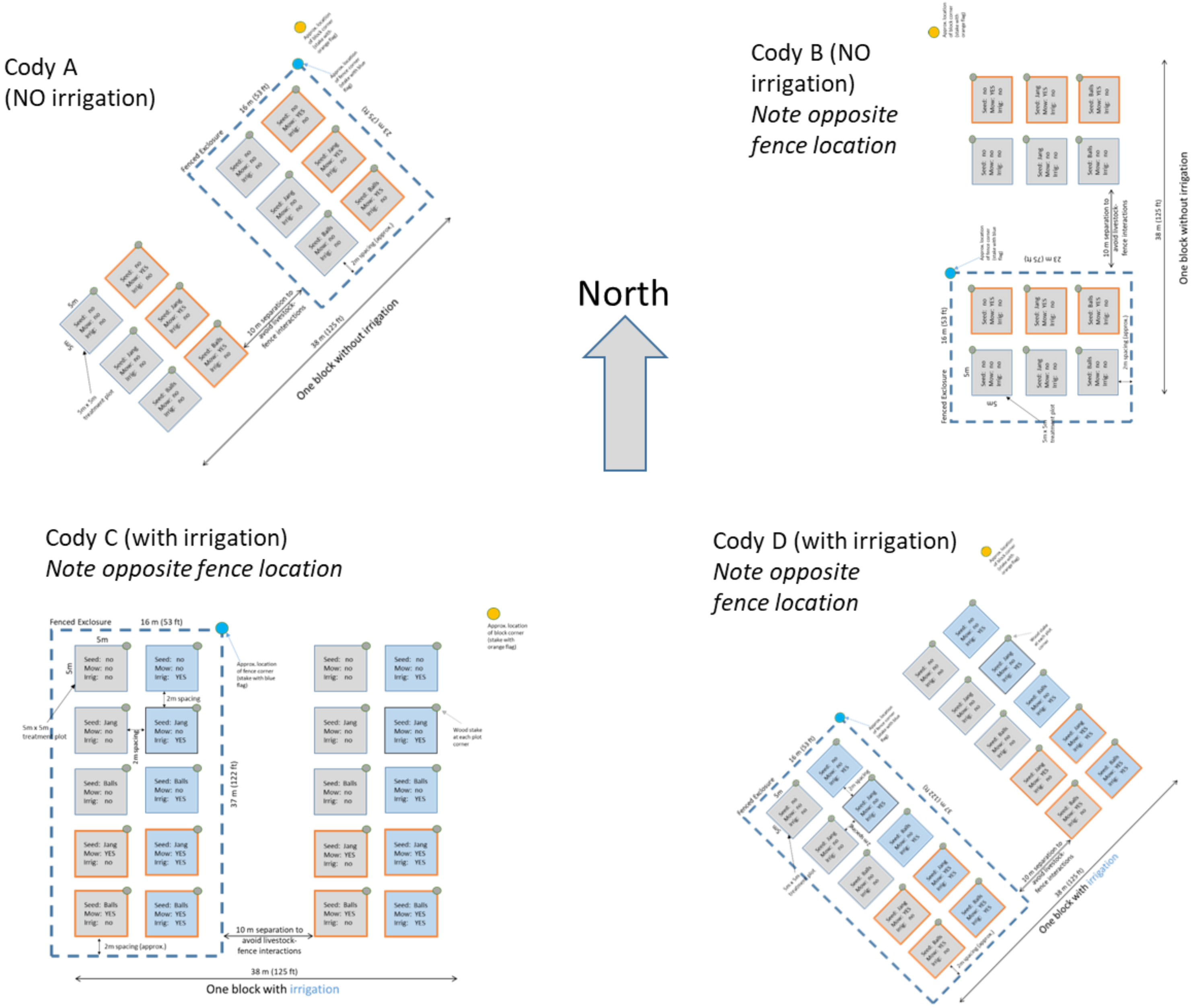
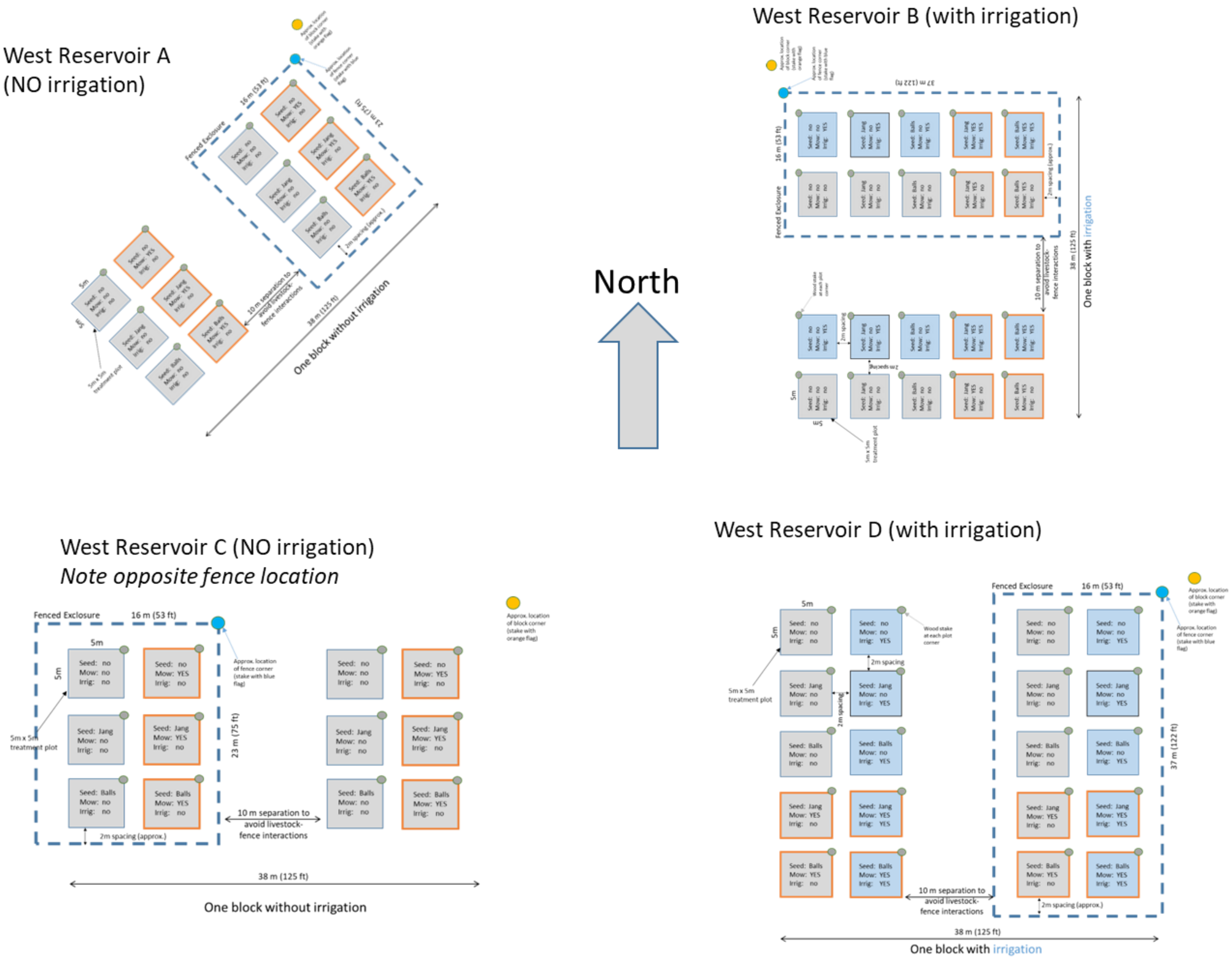


Figure B.2. Block orientation and fence positions (blue dashed line) at the Cody blocks.



West Reservoir A (NO irrigation)

West Reservoir B (with irrigation)

West Reservoir C (NO irrigation) *Note opposite fence location*

West Reservoir D (with irrigation)

Figure B.3. Block orientation and fence positions at the West Reservoir blocks.

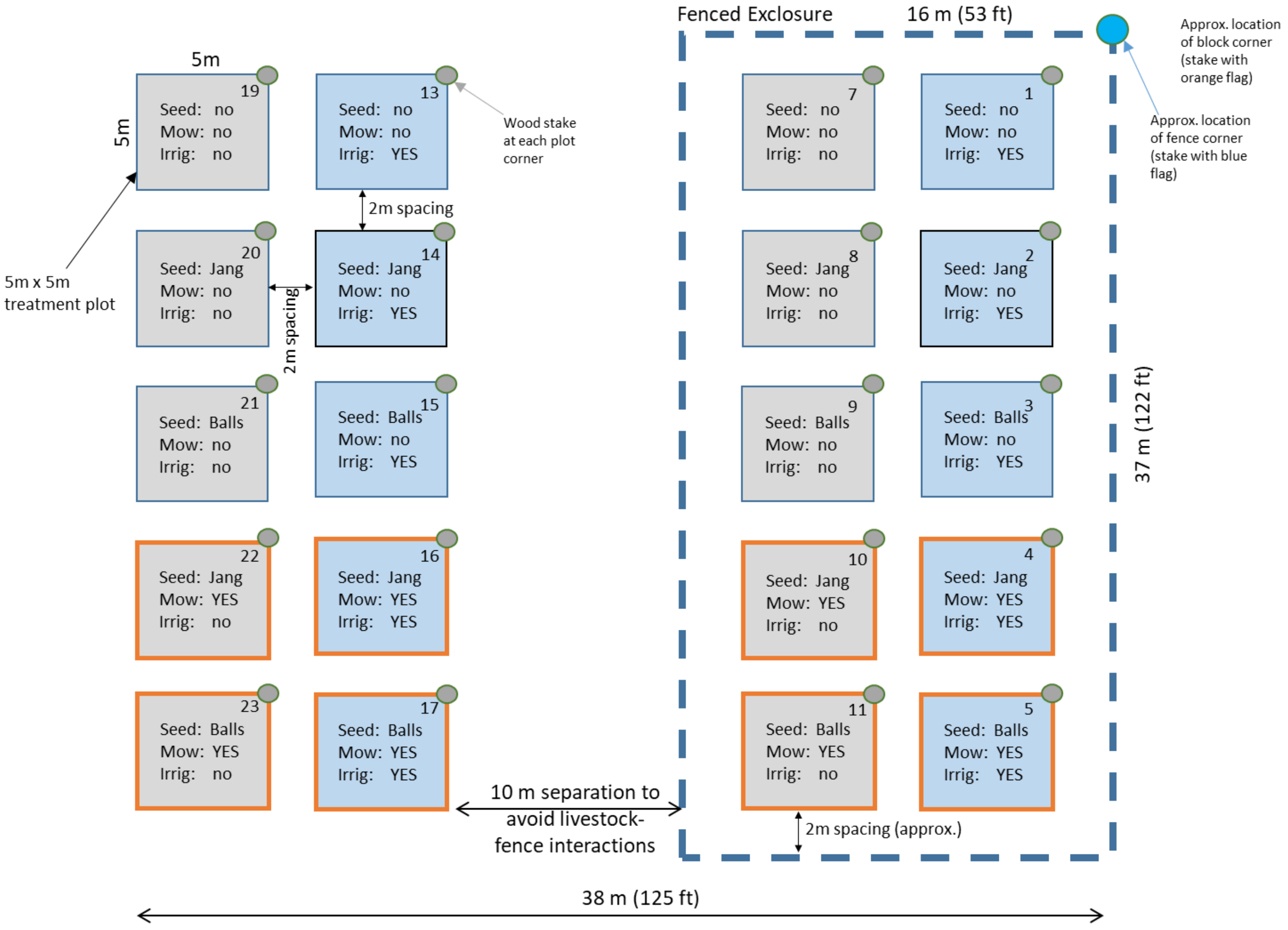


Figure B.4. Plot arrangement for a block that includes irrigation. Treatment label numbers are in the upper right corner of each plot.

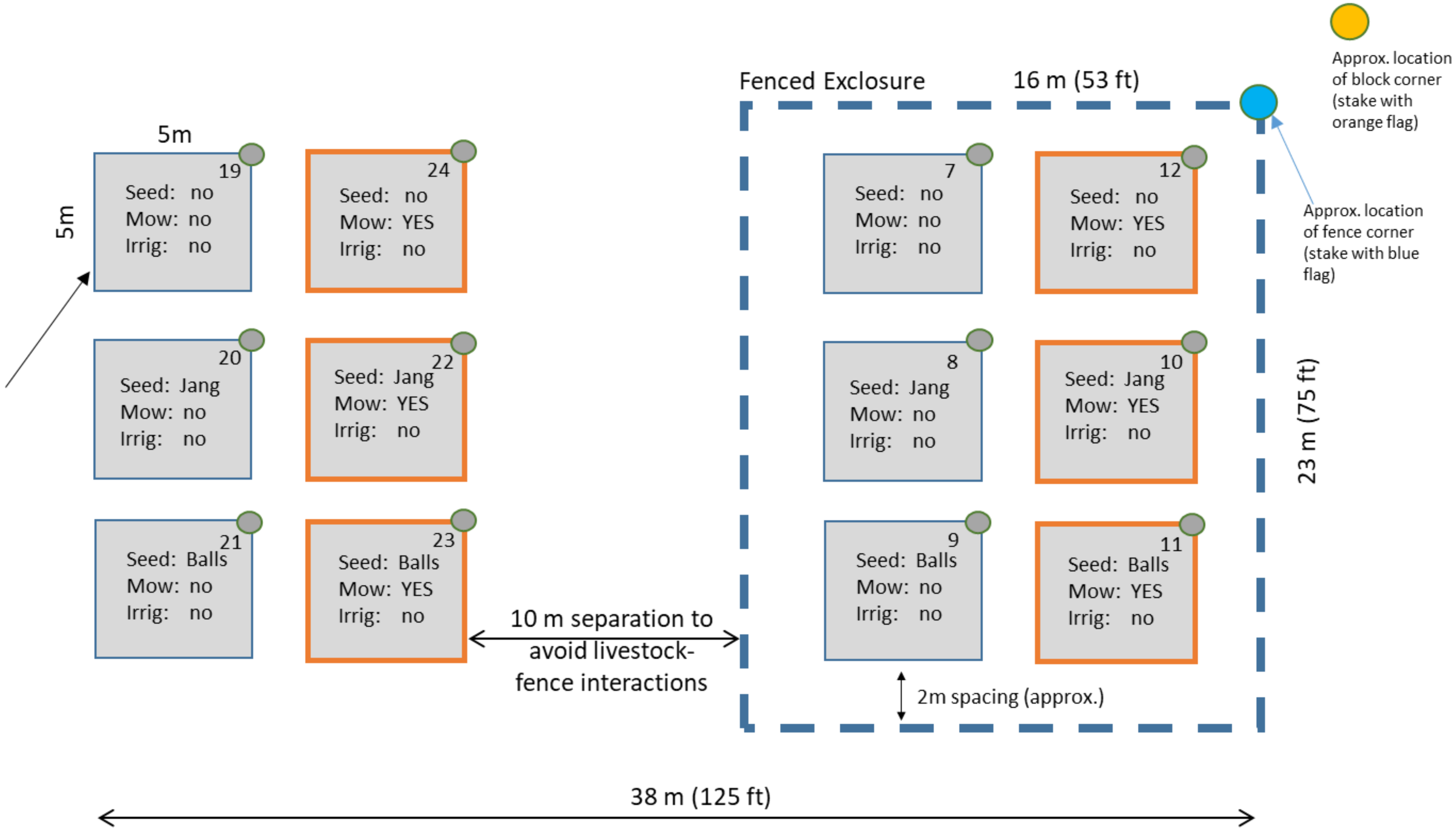


Figure B.5. Plot arrangement for a block without irrigation. Treatment label numbers are in the upper right corner of each plot.

APPENDIX C. PLANT COVER AND RICHNESS BY GROWTH FORM

Percent cover and standard error (SE) of plant growth forms by treatment in June of 2022 and 2023. Treatment combination codes are the same as those used in Figure 9. Richness is rarefied species richness (with subsampling set at 16).

	Treatment			Forb Richness		Shrubs		Sagebrush		Forbs		Native Forbs		Non-native Forbs	Perennial Forbs		Annual Forbs		Graminoids		Native Perennial Graminoids		Non-native Annual Graminoids	
Treatment	**code**	**N**	**Year**	**Native**	**Non-native**	**cover**	***SE***	**cover**	***SE***	**cover**	***SE***	**cover**	***SE***	**cover**	**cover**	***SE***	**cover**	***SE***	**cover**	***SE***	**cover**	***SE***	**cover**	***SE***
Control	Control	8	2022	8.4	2.0	13.7	*2.0*	11.9	*1.8*	1.2	*0.2*	1.2	*0.2*	0.0	0.8	*0.1*	0.4	*0.1*	5.5	*0.5*	5.5	*0.5*	0.0	*0.0*
			2023	8.7	2.0	23.5	*2.6*	19.7	*2.6*	6.7	*0.9*	6.6	*0.9*	0.1	2.8	*0.5*	3.9	*0.5*	9.4	*2.3*	9.3	*2.3*	0.0	*0.0*
Irrigation	I	4	2022	8.5	1.0	11.2	*2.3*	8.9	*0.7*	2.3	*0.5*	2.2	*0.5*	0.1	1.8	*0.4*	0.5	*0.2*	4.7	*0.2*	4.7	*0.2*	0.0	*0.0*
			2023	8.8	2.0	19.0	*3.9*	14.8	*1.9*	7.4	*1.0*	7.0	*1.0*	0.4	2.9	*0.2*	4.5	*1.3*	6.9	*0.3*	6.9	*0.3*	0.0	*0.0*
Irrigation + Jang Seed	IJ	4	2022	9.2	3.0	14.6	*5.3*	12.5	*5.6*	2.0	*0.6*	1.8	*0.4*	0.1	1.5	*0.4*	0.5	*0.2*	6.4	*1.0*	6.4	*1.0*	0.0	*0.0*
			2023	9.4	2.0	23.6	*5.4*	18.6	*5.3*	8.5	*1.6*	7.7	*1.0*	0.8	3.1	*0.7*	5.4	*1.2*	9.5	*0.9*	9.5	*0.9*	0.0	*0.0*
Irrigation + Jang Seed + Mow	IJM	4	2022	9.2	1.0	3.0	*1.5*	2.3	*1.5*	3.0	*0.3*	3.0	*0.3*	0.0	1.2	*0.3*	1.9	*0.4*	6.9	*1.2*	6.4	*1.3*	0.4	*0.3*
			2023	9.4	2.0	7.3	*2.2*	5.1	*2.1*	26.6	*6.9*	26.5	*7.0*	0.0	3.4	*1.4*	23.1	*7.6*	10.4	*2.0*	9.9	*1.6*	0.6	*0.5*
Irrigation + Pellet Seed	IP	4	2022	9.1	4.0	15.5	*2.0*	14.8	*2.3*	1.7	*0.4*	1.6	*0.5*	0.0	1.3	*0.5*	0.4	*0.1*	5.9	*0.8*	5.8	*0.8*	0.0	*0.0*
			2023	9.7	2.0	26.2	*1.9*	23.8	*2.3*	6.8	*1.5*	6.7	*1.4*	0.1	3.3	*0.9*	3.5	*0.8*	7.6	*0.7*	7.6	*0.7*	0.0	*0.0*
Irrigation + Pellet Seed + Mow	IPM	4	2022	9.3	3.0	3.5	*0.6*	2.9	*0.6*	2.5	*0.5*	2.4	*0.5*	0.0	0.7	*0.1*	1.8	*0.6*	5.8	*0.6*	5.8	*0.6*	0.0	*0.0*
			2023	10.2	1.0	8.4	*1.8*	6.1	*1.6*	16.5	*5.7*	16.4	*5.8*	0.1	2.0	*0.5*	14.4	*6.0*	9.6	*1.8*	9.4	*1.9*	0.2	*0.2*
Jand Seed	J	8	2022	8.6	1.0	12.1	*2.1*	10.0	*1.7*	1.6	*0.3*	1.5	*0.2*	0.1	1.0	*0.2*	0.6	*0.1*	5.6	*0.6*	5.3	*0.4*	0.3	*0.3*
			2023	9.5	2.0	20.0	*2.6*	15.8	*2.3*	10.0	*1.2*	9.7	*1.1*	0.1	3.3	*0.5*	6.5	*1.4*	10.4	*3.0*	10.2	*2.8*	0.2	*0.2*
Jand Seed + Mow	JM	8	2022	9.0	4.0	3.3	*0.7*	2.2	*0.6*	3.7	*1.3*	3.7	*1.3*	0.0	1.5	*0.3*	2.2	*1.2*	7.1	*1.3*	6.2	*0.5*	0.9	*0.8*
			2023	9.1	3.0	8.6	*1.3*	5.4	*1.2*	16.4	*3.2*	16.2	*3.2*	0.0	4.0	*0.8*	12.2	*3.2*	12.9	*2.1*	12.7	*1.9*	0.2	*0.2*
Mow	M	4	2022	8.4	1.0	5.1	*1.2*	3.7	*1.2*	1.9	*0.7*	1.8	*0.6*	0.0	1.0	*0.7*	0.8	*0.1*	7.0	*1.4*	6.8	*1.3*	0.2	*0.2*
			2023	8.8	1.0	12.9	*2.4*	8.4	*2.7*	10.3	*2.0*	10.1	*2.0*	0.2	3.1	*0.7*	7.2	*1.6*	13.6	*5.5*	13.5	*5.4*	0.1	*0.1*
Pellet Seed	P	8	2022	8.3	4.0	12.7	*2.5*	10.6	*2.4*	1.5	*0.2*	1.4	*0.2*	0.1	0.8	*0.2*	0.7	*0.2*	6.0	*0.5*	6.0	*0.5*	0.0	*0.0*
			2023	9.7	2.0	23.0	*3.4*	19.2	*3.7*	7.5	*1.3*	7.3	*1.3*	0.1	2.9	*0.9*	4.5	*0.6*	8.4	*0.7*	8.3	*0.7*	0.0	*0.0*
Pellet Seed + Mow	PM	8	2022	8.4	3.0	3.4	*0.8*	2.6	*0.7*	2.8	*1.2*	2.7	*1.2*	0.0	0.9	*0.3*	1.8	*1.1*	7.9	*1.7*	6.3	*0.6*	1.6	*1.5*
			2023	10.0	3.0	8.1	*2.0*	5.5	*1.7*	19.0	*5.6*	18.9	*5.6*	0.1	3.1	*0.7*	15.9	*5.4*	13.9	*1.4*	13.2	*1.5*	0.7	*0.7*

APPENDIX D. LIST OF SHRUB AND FORB SPECIES AT THE BROTHERS STUDY SITE

	Species	Common name	Status	Duration	Species code
Shrubs	*Artemisia arbuscula*	sagebrush	Native	Perennial	ARAR
	Artemisia tridentata spp. Wyomingensis	sagebrush	Native	Perennial	ARWY
	Chrysothamnus humilis	Truckee rabbitbrush	Native	Perennial	CHHU
	Chrysothamnus viscidiflorus	rabbitbrush	Native	Perennial	CHVI
	Ericameria nauseosa	rubber rabbitbrush	Native	Perennial	ERNA
	Linanthus pungens	granite prickly-phlox	Native	Perennial	LIPU
Forbs	*Achillea millefolium*	common yarrow	Native	Perennial	ACMI
	Agoseris parviflora	false dandelion	Native	Perennial	AGPA
	Alyssum desertorum	desert alyssum	Non-native	Annual	ALDE
	Antennaria dimorpha	low pussytoes	Native	Perennial	ANDI
	Antennaria microphylla	littleleaf pussytoes	Native	Perennial	ANTEsp
	Arabis sp.	rockcress		Perennial	ARABsp
	Arabis sparsiflora	hairystem rockcress	Native	Perennial	ARSP
	Astagalus lentiginosus	freckled milkvetch	Native	Perennial	ASLE
	Astragalus misellus	pauper milkvetch	Native	Perennial	ASMI
	Astragalus newberryi	Newberry's milkvetch	Native	Perennial	ASNE
	Astragalus purshii	Pursh's milkvetch	Native	Perennial	ASPU
	Astragalus sp.	milkvetch	Native	Perennial	ASTRsp
	Blepharipappus scaber	rough eyelashweed	Native	Annual	BLSC
	Castilleja pilosa	parrothead Indian paintbrush	Native	Perennial	CAPI
	Collinsia parviflora	maiden blue eyed Mary	Native	Annual	COPA
	Crepis intermedia	intermediate hawksbeard	Native	Perennial	CRIN
	Crepis occidentalis	western hawksbeard	Native	Perennial	CROC
	Delphinium nuttallianum	upland larkspur	Native	Perennial	DENU
	Descurainia longipedicellata	thread-stalk cutleaf tansymustard	Native	Annual	DELO
	Descurainia pinnata	intermediate tansymustard	Native	Annual	DEPI
	Diplacus nanus	dwarf monkeyflower	Native	Annual	DINA
	Draba verna	spring draba	Non-native	Annual	DRVE
	Epilobium sp.	willowherb	Native	Annual	EPILsp
	Erigeron filifolius	threadleaf fleabane	Native	Perennial	ERFI
	Erigeron sp.	fleabane			ERIGsp
	Eriogonum ovalifolium	cushion buckwheat	Native	Perennial	EROV
	Eriogonum umbellatum	sulfur-flower buckwheat	Native	Perennial	ERUM
	Gayophytum racemosum	racemed groundsmoke	Native	Annual	GARA
	Greeneocharis circumscissa	cushion cryptantha	Native	Annual	GRCI

Species list (continued)

	Species	Common name	Status	Duration	Species code
Forbs	*Holosteum umbellatum*	jagged chickweed	Non-native	Annual	HOUM
	Lepidium perfoliatum	clasping pepperweed	Non-native	Annual	LEPE
	Linum lewisii	western blue flax	Native	Perennial	LILE
	Lomatium nevadense	Nevada biscuitroot	Native	Perennial	LONE
	Lomatium triternatum	nineleaf biscuitroot	Native	Perennial	LOTR
	Lupinus argenteus	silvery lupine	Native	Perennial	LUAR
	Lupinus sp.	lupine	Native	Perennial	LUPIsp
	Microsteris gracilis	slender phlox	Native	Annual	MIGR
	Nama sp.	nama			NAMAsp
	Nothocalais troximoides	sagebrush false dandelion	Native	Perennial	NOTR
	Packera cana	woolly groundsel	Native	Perennial	PACA
	Phacelia hastata	silverleaf phacelia	Native	Perennial	PHHA
	Phlox hoodii	Hood's phlox	Native	Perennial	PHHO
	Polemonium micranthum	annual polemonium	Native	Annual	POME
	Townsendia florifer	showy townsendia	Native	Biennial	TOFL
	Tragopogon dubius	yellow salsify	Non-native	Annual	TRDU

APPENDIX E. SEEDLING DENSITY OF PLANTED SPECIES BY TREATMENT IN JUNE OF 2022 AND 2023.

		seedlings per m^2	
Treatment	**species**	**2023**	**2022**
Control	yarrow	0.02	0.00
	flax	0.00	0.02
	phacelia	0.00	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	0.61	0.53
Irrigation	yarrow	0.00	0.00
	flax	0.00	0.06
	phacelia	0.00	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	0.44	0.41
Irrigation + Jang Seed	yarrow	14.19	0.28
	flax	1.30	2.16
	phacelia	0.00	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	0.74	0.63
Irrigation + Jang Seed + Mow	yarrow	9.22	0.22
	flax	1.29	1.03
	phacelia	0.00	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	0.81	0.56
Irrigation + Pellet Seed	yarrow	42.04	0.55
	flax	1.85	0.08
	phacelia	3.51	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	0.51	0.69
Irrigation + Pellet Seed + Mow	yarrow	41.38	0.47
	flax	0.81	0.09
	phacelia	1.78	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	1.44	1.25
Jand Seed	yarrow	19.30	0.08
	flax	1.48	1.72
	phacelia	0.00	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	0.78	0.52

		seedlings per m^2	
Treatment	**species**	**2023**	**2022**
Jand Seed + Mow	yarrow	15.08	0.06
	flax	1.95	0.89
	phacelia	0.00	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	1.06	1.13
Mow	yarrow	0.47	0.00
	flax	0.06	0.16
	phacelia	0.00	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	0.78	0.66
Pellet Seed	yarrow	29.69	0.00
	flax	1.05	0.05
	phacelia	1.04	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	0.76	0.59
Pellet Seed + Mow	yarrow	38.63	0.03
	flax	0.92	0.05
	phacelia	1.11	
	limestone hawksbeard	0.00	0.00
	western hawksbeard	0.00	
	squirreltail	1.27	0.88