Astragalus mulfordiae (Mulford's milkvetch): Population dynamics and the effect of cattle grazing in the Vale District, BLM

2019

Progress Report to the USDI Bureau of Land Management, Vale District

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Preface

IAE is a non-profit organization whose mission is 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: Mulford's milkvetch (*Astragalus mulfordiae*) habitat and monitoring plots at North Harper North, 2018. Photo by Lisa Schomaker.

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EXECUTIVE SUMMARY

This document summarizes 11 years of *Astragalus mulfordiae* (Mulford's milkvetch) population monitoring on land managed by the Vale District of the Bureau of Land Management. In 2019, we revisited 72 permanent plots testing for the effects of herbivory on *A. mulfordiae*, as well as five permanent transects looking at long-term population trends and plant community composition in *A. mulfordiae* habitat. Total population size has decreased across all sites, but a small increase in live plant count and decrease in mortality was recorded from 2018 to 2019. Despite two seedling-rich seasons (2015, 2017), recruitment has not been successful and population size has not reached the level recorded at the beginning of this study in 2008.

In recent years, the distribution of plant size (measured by canopy diameter) has skewed towards smaller plants, indicating the die-off of older, established plants. Without successful establishment of new seedling generations, we expect to see continued population decline. Reproductive effort increased from 2018 to 2019, and in some sites rose to the highest level since 2010 (in terms of the total number of reproductive plants), which may signal future increases in recruitment, but these fluctuations may be driven primarily by climatic conditions. We expect annual variation in reproductive effort and seedling count, but the trend remains negative over 11 years of monitoring.

We have not observed a consistent difference between caged and uncaged plots testing for the direct effects of large mammal herbivory. It is unlikely that large herbivores are greatly impacting the populations in our study; rather, we presume that environmental factors are more important drivers when it comes to *A. mulfordiae* survival, reproductive effort, and population health in this region. An in-depth analysis of climate patterns over 10 consecutive years of data collection for plots established in 2012 will help to elucidate the drivers of *A. mulfordiae* population health and to guide both monitoring and potential management activities into the future.

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INTRODUCTION

Astragalus mulfordiae (Fabaceae, Mulford's milkvetch; Figure 1) is listed as a Sensitive Plant Species by the USDI Bureau of Land Management (BLM), a Species of Concern by the United States Fish and Wildlife Service, and endangered by the State of Oregon Department of Agriculture (Oregon Biodiversity Information Center 2016). In 1995, there were 34 known *A. mulfordiae* populations in Idaho and 38 in Oregon (DeBolt 1995). The NatureServe Encyclopedia of Life now notes less than 20 occurrences in Oregon (Roth and Joyal 2018).

FIGURE 1. MULFORD'S MILKVETCH (*ASTRAGALUS MULFORDIAE*) IN FRUIT.

Astragalus mulfordiae is found from the Owyhee Uplands of Malheur County, Oregon east to the Owyhee Front and Boise Foothills of western Idaho. It primarily occurs in shrub-steppe and desert shrub communities on sandy substrates derived from lacustrine and alluvial sediments, including old river deposits, sandy areas near rivers, sandy bluffs, and dune-like talus. Primary plant associates include *Hesperostipa comata* (needle-and-thread grass), *Achnatherum hymenoides* (Indian ricegrass), *Chrysothamnus viscidiflorus* (green rabbitbrush), *Penstemon acuminatus* (sharpleaf penstemon), and *Poa secunda* (Sandberg bluegrass).

Astragalus mulfordiae relies on environmental cues in late winter and early spring to initiate its regrowth and flowering phenology. In general, regrowth begins in early March, followed by flowering in April, May, and sometimes into June. The pollination mechanism is unknown; flying insects and/or self-pollination are likely. Fruits mature in June and July and plants senesce shortly thereafter. *Astragalus mulfordiae* reproduces only by seed, which is dispersed by gravity and wind (Roth and Joyal 2018).

Monitoring studies of *A. mulfordiae* show evidence of a drastic decline in population sizes over the last half-century (Center for Plant Conservation 2009). Some populations have been extirpated through Off Road Vehicle (ORV) use, cattle grazing, and fire. In a study of areas seeded with *Agropyron desertorum* (desert wheatgrass), fruits per inflorescence, inflorescences per plant, and adult plant survival of *A. mulfordiae* were all lower in areas grazed by cattle (Pyke 2001, Center for Plant Conservation 2009). However, populations appear to vary in their ability to withstand disturbances, and there may be genetic differences between populations that are more susceptible to or more tolerant of disturbance (DeBolt 1995). Competition with non-native plant species, particularly *A. desertorum* and *Bromus tectorum* (cheatgrass), may also impact populations of *A. mulfordiae*. These interactions may be particularly problematic in areas that have recently burned and/or are heavily grazed.

GOALS AND OBJECTIVES

This project provides long-term data on the population dynamics of *A. mulfordiae* in the Owyhee Uplands of eastern Oregon. In order to determine the effects of ungulates on *A. mulfordiae*, we used small cages to protect groups of plants that experience different levels and types of grazing. Data resulting from this project will continue to provide valuable information to assist agencies in making listing decisions for the species, managing livestock grazing in various allotments, and planning conservation strategies and recovery plans. Specifically, this study was designed to:

1. Document long-term trends in population size and structure.
2. Document long-term trends in habitat quality and plant community dynamics in areas occupied by *A. mulfordiae*.
3. Determine the effect of grazing on population size and reproduction.
4. Determine the role of climatic variation (e.g., annual changes in precipitation) on population size and reproduction (requires 10 consecutive years of data).
5. Compare Oregon population dynamics with Idaho population dynamics.

METHODS

Field Sites

All sites are located near Vale, Oregon in the Vale District, BLM. After initial site visits in 2007, five *A. mulfordiae* populations (and additional sub-populations or sub-sites) were chosen for plot establishment: Brown Butte, Double Mountain, North Harper, South Alkali ACEC, and Snively (Table 1, Appendix Table 1).

TABLE 1. FIELD SITE CHARACTERISTICS INCLUDING TOTAL NUMBER OF PLOTS PRESENT IN 2019.

Site/Subsite (location of coordinates)	Location (NAD83, zone 11)	Fire History	Grazing	# plots
South Alkali #1 (plot 648)	0484252E 4878746N	unknown	fall cattle	3 caged 3 uncaged
South Alkali #2 (plot 653)	0486054E 4878989N	unknown	fall cattle	3 caged 4 uncaged
South Alkali #3 (transect start)	0485982E 4877837N	unknown	fall cattle	4 caged 4 uncaged
Brown Butte (transect start)	0489997E 4842103N	fire: late 90's	summer cattle	6 caged 5 uncaged
Snively (transect start)	0484372E 4840786N	unknown	spring cattle	5 caged 4 uncaged
Double Mountain (transect start)	0476635E 4853382N	fire: 2005	spring cattle	5 caged 3 uncaged
North Harper North (transect start)	0481055E 4857204N	unknown	summer cattle	5 caged 5 uncaged
North Harper South (transect start)	0481446E 4856682N	unknown	summer cattle	6 caged 6 uncaged

Population and Plant Community Monitoring Transects

At each site, long-term monitoring transects were established to track plant community changes through time. This monitoring protocol follows the methods used by the Idaho Conservation Data Center to monitor populations of *A. mulfordiae* in southwestern Idaho (Mancuso 2002, Mancuso and Colket 2005, Idaho Conservation Data Center 2008). The monitoring protocol details procedures to collect *A. mulfordiae* and other plant species abundance, ground disturbance data, plant community information, and photo points. Five monitoring transects were established in 2009, one at each site. Each transect was 20 meters long and monumented with a piece of red-painted rebar at the starting point and a large metal spike at the ending point. Sampling occurred along a meter tape running between the rebar and spike (Figure 2). A 1m^2 quadrat frame was placed flush against the tape beginning at the 0m mark. Sampling occurred at each consecutive meter mark along the transect tape. We documented the GPS coordinates of the starting and ending point, azimuth, and side of the tape sampled for each transect (Table 2). We also completed a transect information form that included directions for relocating transects.

Each *A. mulfordiae* individual rooted within the quadrat was counted and assigned to one of three life stage class categories:

1. Reproductive (R) – individuals with flowers and/or fruits
2. Non-reproductive (N) – individuals > 4 cm tall without flowers or fruits
3. Seedling (S) – non-reproductive individuals < 4 cm tall (or taller if cotyledons present)

Application of the size standard may inadvertently result in small plants greater than one year old being recorded as seedlings. The seedling life stage should therefore be interpreted as potentially including individuals that did not recently germinate. If two *A. mulfordiae* stems were less than 3cm apart, they were considered one plant. Each plant was also inspected for evidence of insect/disease damage and non-insect herbivory/trampling damage. These data were recorded as presence/absence.

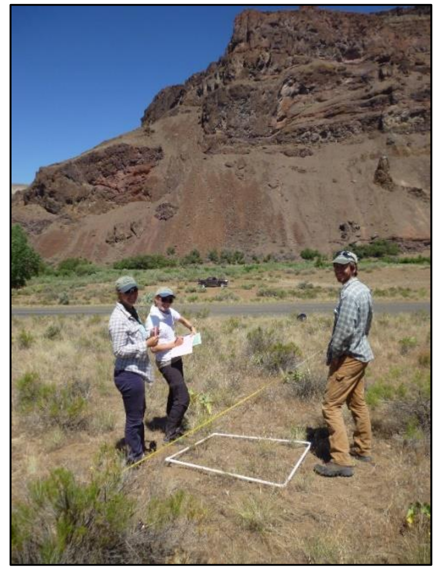

FIGURE 2. *ASTRAGALUS MULFORDIAE* POPULATION AND COMMUNITY MONITORING PLOT AT SNIVELY, 2013.

The location of each *A. mulfordiae* plant was recorded by referencing the appropriate quadrat cell in which it occurred. We divided the quadrat frame into nine equal cells referenced by the letters "A" through "I" (Figure 3). Cell "A" was positioned at the top left corner and cell "I" at the bottom right corner, similar to reading a page of text. Cells "G", "H", and "I" were positioned flush against the transect tape, whether sampling started on the left or right side of the tape.

TABLE 2. LOCATIONS OF *ASTRAGALUS MULFORDIAE* POPULATION AND COMMUNITY MONITORING TRANSECTS.

Site	Transect	Azimuth/side of tape monitored
Brown Butte	198	200° / east
Double Mountain	196	281° / south
North Harper N.	200	26° / west
Snively	199	0° / east
South Alkali	197	354° / west

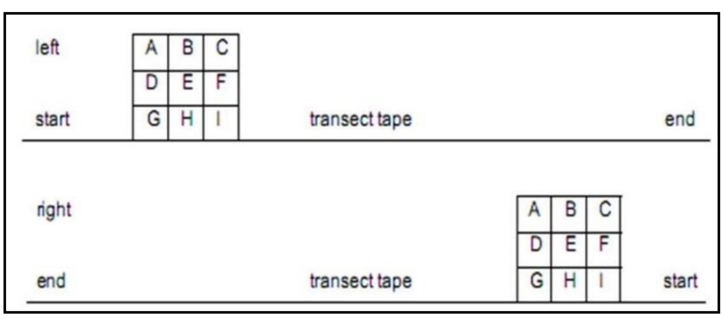

FIGURE 3. TRANSECT DESIGN FOR *ASTRAGALUS MULFORDIAE* POPULATION AND COMMUNITY MONITORING.

The cover of each native and non-native plant species (shrubs, graminoids, and forbs) rooted in or hanging over each quadrat was estimated and assigned a cover class (Table 3). Ground covers of basal vegetation, bare ground, biological crust, rock/gravel (≥ 2mm), litter (< 2mm, including scat), completely dead attached shrub, and detached wood (≥ 2mm from shrub or tree) were also estimated and assigned cover classes. Nomenclature followed the U.S. Department of Agriculture Plants Database (USDA NRCS 2018).

The total area occupied by surface disturbances (e.g. ORV tracks, wildlife and cattle prints, gopher tunnels) within each quadrat was estimated and assigned a cover class. Surface disturbances were additionally broken down by disturbance type; the cover class represented the percentage of ground surface within the quadrat that was clearly broken, crushed, or sloughed.

We took a minimum of six photos at each monitoring site. The origin rebar served as the reference point for four photos, taken at bearings of 0°, 90°, 180°, and 270°, providing a panoramic overview of the monitoring area. We took a fifth photo standing 3m behind the origin rebar looking towards the end spike, and a sixth photo standing 3m behind the end spike looking towards the origin rebar. We took additional photos to show the plant community, disturbances, and other landscape features as needed. Sighting report forms were completed for each monitoring site, including a form for each sub-site (ex. South Alkali #1, #2, and #3).

TABLE 3. COVER CLASSES USED WHEN MONITORING PLANT SPECIES, GROUND COVER, AND SURFACE DISTURBANCES IN POPULATION AND COMMUNITY MONITORING PLOTS.

Cover class	Percent cover range (%)	Midpoint for conversion (%)
0	0	0
1	<1 (trace)	0.5
2	1-4.9	3
3	5-9.9	7.5
4	10-24.9	17.5
5	25-49.9	37.5
6	50-74.9	62.5
7	75-94.9	85
8	95-100	97.5

Herbivory Plots

In 2008, we established 10-15 plots at each study site to test for the effects of ungulate (primarily sheep and cattle) grazing on *A. mulfordiae* and to track individual plants over time, contributing to our understanding of overall population trends. Plot locations were systematically selected to maximize the number of *A. mulfordiae* individuals within a 1m^2 area, and cages were established over half of the plots. We did not use a random sampling design to ensure that there were enough plants within each plot to detect differences in growth, survival, and reproduction; we also wanted caged and control plots to be well-distributed throughout the population. All plots were marked in each corner with 10-inch steel nails and/or wooden stakes protruding from the soil surface. The plots were aligned with the cardinal directions; an aluminum tag noting the plot number was tied with wire around the plot marker in the southeast corner of each plot. Caged plots allowed us to measure the approximate effects of grazing and trampling by livestock on *A. mulfordiae* by comparing the data to those collected from uncaged plots. The cage design inhibits native ungulate grazing and trampling, but small mammals and birds can still access the space within the cage. Although we did not pair caged and uncaged plots, we attempted to locate one of each type within close proximity to mitigate the effects of microclimate and micro-topography. Each caged plot stood approximately 0.3m high, was covered on the top and sides with hogwire, and was slightly larger than 1m^2. They were secured with wire tied to wooden stakes sunk into the corners of the plots. Plots were monitored in 2008-2010 and 2012-2019.

FIGURE 4. *ASTRAGALUS MULFORDIAE* CONTROL (UNCAGED) MONITORING PLOT. CORNERS AND PERMANENTLY MARKED WITH 10" NAILS.

Twenty-five additional plots were added in 2012 due to high mortality observed and the lack of *A. mulfordiae* in 22 of the existing plots (two of which were not present in 2009 monitoring). We targeted areas where there would be at least two *A. mulfordiae* per plot, which were often difficult to find due to low densities. We sought to replace caged and uncaged plots in their general proximity to maintain similar numbers of each treatment while targeting areas with *A. mulfordiae* (Figure 4). Though in 2013 many plots had no *A. mulfordiae* present, we did not replace them because at many sites it was difficult to find locations that fulfilled our minimum qualification of at least two plants per plot. Given the large number of empty plots, we removed plot markings for plots that had been empty from 2012-2014 (16 plots, Appendix Table 3).

Within each monitoring plot, we mapped all *A. mulfordiae* individuals using a one cm^2 grid system so that recruitment, mortality, and overall trends in the plants' growth could be ascertained over time. We also measured the maximum diameter (cm), length of longest stem (cm), number of fruits (or number of flowers depending on phenology at the time of sampling), and evidence of insect and large ungulate grazing (presence/absence) of every plant. Similar methods have been used to monitor the population dynamics of *A. tyghensis* in the Tygh Valley (Prineville District, BLM; Thorpe and Kaye 2008).

Data Analysis

Population and community monitoring data were summarized descriptively at the functional group level. All data given cover classes were converted to midpoint percent cover values (Table 3). Raw data were used for analysis, except for specific cases where data were log-transformed to meet assumptions of statistical procedure(s). All analyses were carried out in R version 3.6.1 (R Core Team 2019).

The effect of caging on plant performance (plant size and reproduction) was tested using data from 2019. We used a two-way ANOVA to test for differences in plant size (diameter), using site and treatment (caged vs. uncaged) as fixed factors. At the site level, the parametric Student's t-test (or non-parametric Wilcoxon rank sum test where appropriate) was used to test for differences between treatments. To test for the response of number of fruits (count data), we used a generalized linear model with a quasipoisson distribution, using site and treatment as predictors. For transect data, we used the Kruskal-Wallis χ^2 metric to test for differences in plant cover over time (2009 to 2019). For all tests, we considered $p < 0.05$ to represent moderate evidence of significance.

We acquired grazing information from 2008-2019 including names of the allotment and pasture, allotment size, dates grazed, and number of animals (cows only). We used this information to calculate stocking rates ((# of animals X # of days)/acres) for each site. These values were tested for linear correlation (Pearson's r) with the number of plants in continuously monitored uncaged plots from 2008 to 2018 to explore the relationship between stocking rates and population dynamics.

Climate data (monthly precipitation (in) and monthly maximum temperature (°F)) were collected, with North Harper North as the representative site, for 2011-2019 (and normals for 1971-2000) from the PRISM climate group database (PRISM Climate Group Oregon State University). Monthly averages were combined into seasonal means (winter = December-February, spring = March-May, summer = June-August, fall = September-November) to examine trends over time but no formal statistics will be run on climate data until we have acquired 10 consecutive years of monitoring data (expected in 2021).

RESULTS

Population and Plant Community Monitoring Transects

In 2019, a total of 108 *A. mulfordiae* plants were observed along five community monitoring transects. The majority of these occurred along the transects at Brown Butte (39) and South Alkali (38). This was the first year in which no seedlings were found along transects, dropping from 28% of the total plant count in 2018. Reproductive plants accounted for 45% of total plants observed, dropping from 65% in 2018. Non-reproductive plants (> 4 cm tall) constituted 55% of the total, nearly six times the relative proportion observed in 2018 (Figure 5).

Mean cover of *A. mulfordiae* ranged from 0.2% to 5.0% in 2019, with South Alkali having the highest cover and Double Mountain the lowest. From 2009 to 2019, mean cover of *A. mulfordiae* declined significantly at all sites except for South Alkali (Kruskal-Wallis $\chi^2 = 35.9$, $p < 0.0001$). At South Alkali, *A. mulfordiae* mean cover increased from about 2.5% in 2009 to just over 5% in 2019. *Bromus tectorum* went through a population boom and bust from 2009 to 2019, exhibiting parallel fluctuations in mean cover across sites, with the highest covers recorded in 2015 and 2017 and the lowest in 2009 and 2019 (Figure 6).

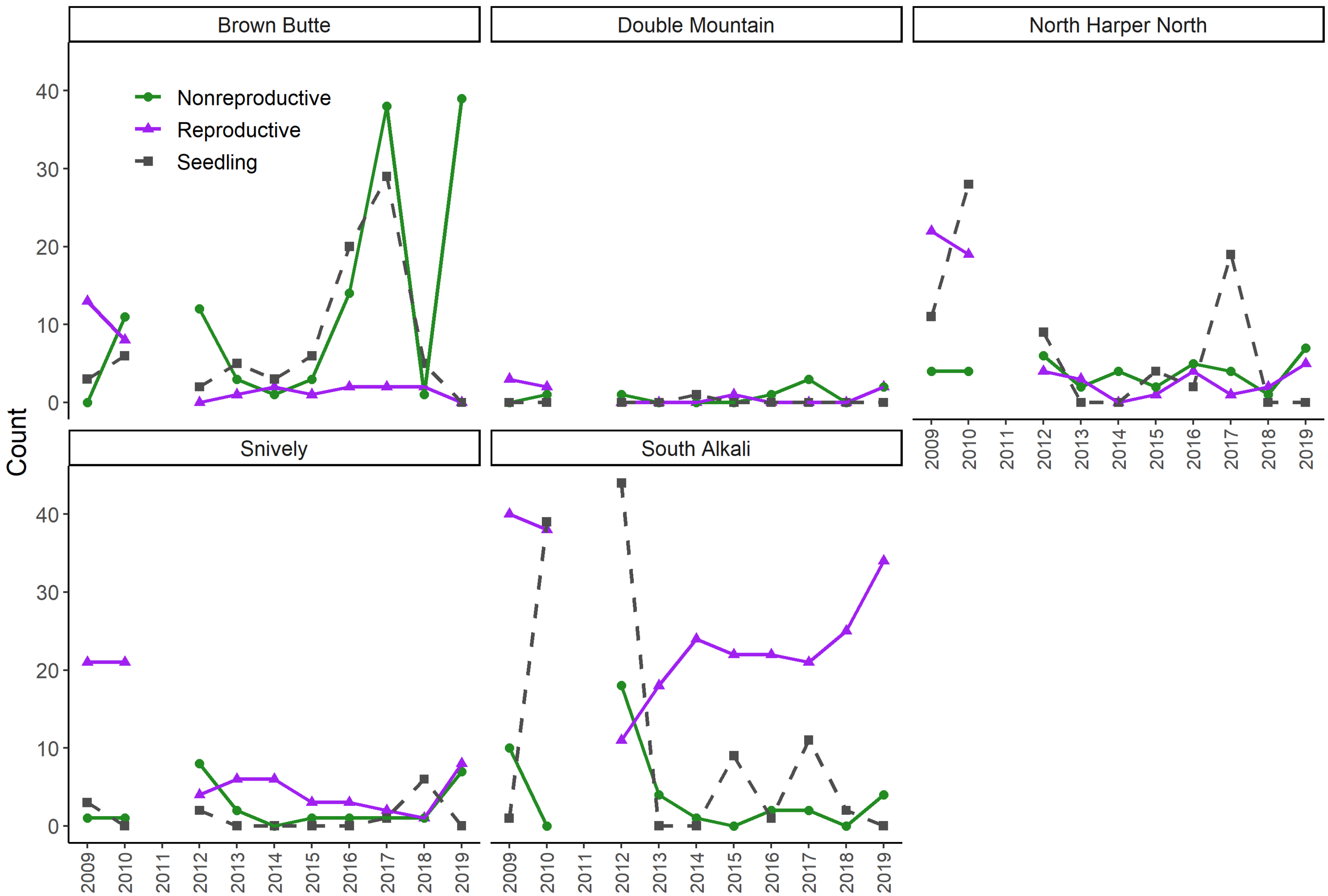

FIGURE 5. CHANGES IN *A. MULFORDIAE* COUNTS ALONG TRANSECTS OVER TIME, SEPARATED BY REPRODUCTIVE STAGE AND SITE. NO DATA WERE COLLECTED IN 2011.

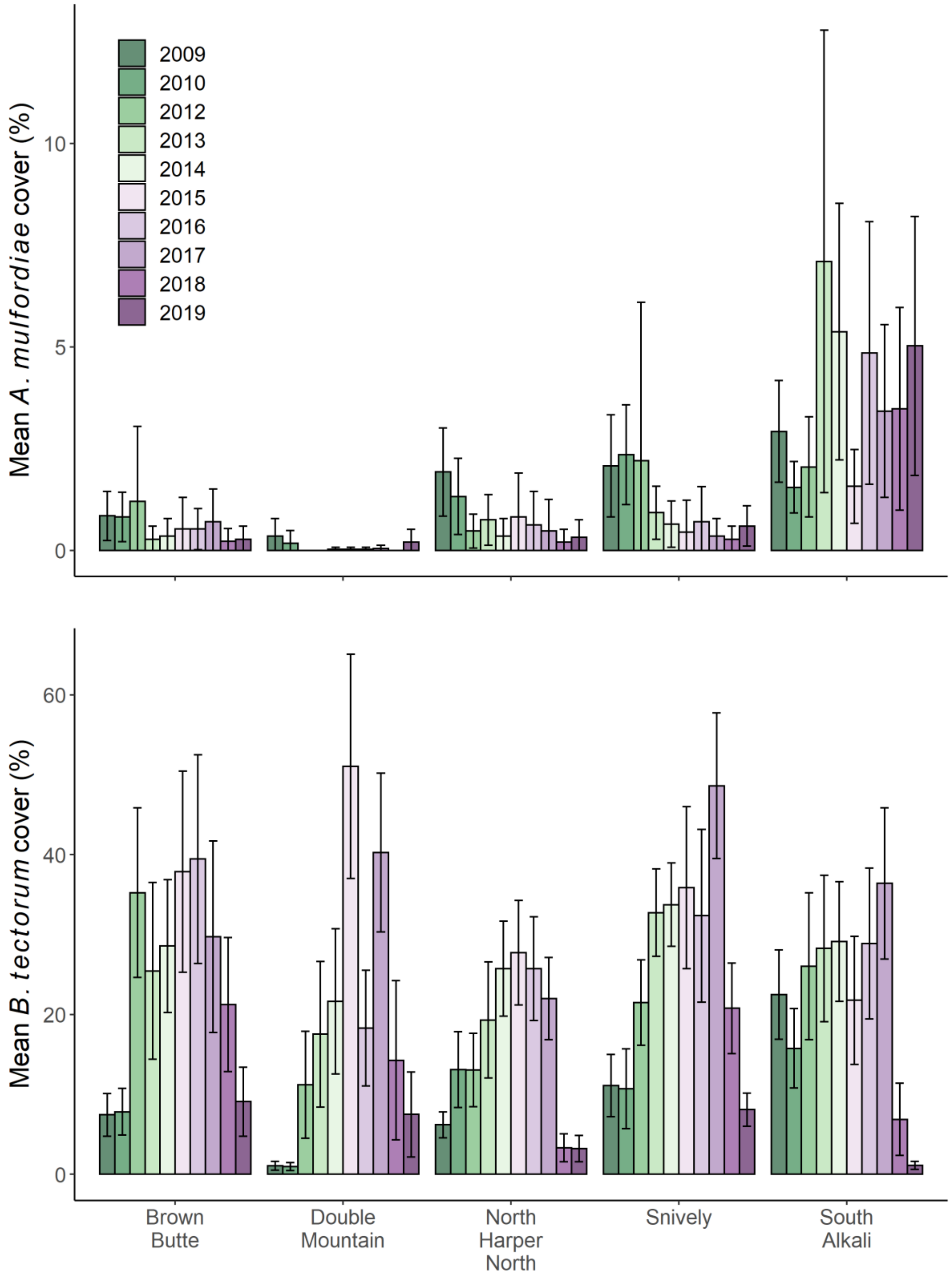

FIGURE 6. MEAN *A. MULFORDIAE* (TOP) AND *B. TECTORUM* (BOTTOM) COVER (%) IN COMMUNITY MONITORING TRANSECTS FROM 2009 TO 2019. ERROR BARS ARE ± 95% C.I. NOTE THE DIFFERENCE IN Y-AXIS SCALE.

Of the six non-native species recorded along transects in 2019, two were graminoids and four were forbs (Appendix Table 3). *Bromus tectorum* dominated non-native species cover ranging from a mean of 1.1% to 9.1% cover across all transects, and composing 81-97% of total non-native species cover. Other non-native species included *Erodium cicutarium, Lactuca serriola, Sisymbrium altissimum*, and *Poa bulbosa.* The most abundant native species present along transects were perennial bunchgrasses *Achnatherum thurberianum, Poa secunda,* and *Hesperostipa comata,* and the perennial forb *Balsamorhiza sagittata. Chrysothamnus viscidiflorus* was the primary shrub present at all transects.

The non-vegetated ground surface was composed largely of bare ground accounting for 50-83% of total ground cover. Litter cover increased over three-fold between 2010 (19%) and 2017 (61%), fell in 2018 to 37%, and fell again in 2019 to 33%; these changes are in large part due to the population dynamics of *B. tectorum*, which produces the majority of the litter across all sites. Smaller amounts of rock/gravel, dead shrub, and biological crust were also present (Table 4).

TABLE 4. MEAN PERCENT COVER (± 95% C.I.) OF GROUND COVER CATEGORIES BY SITE IN 2019.

	Brown Butte	**Double Mountain**	**North Harper North**	**Snively**	**South Alkali**
Bare ground	55.3 (16.6)	65.7 (14.4)	73.5 (7.5)	45.9 (12.5)	66.9 (5.7)
Biological crust	0.1 (0.1)	1.2 (0.6)	1.4 (0.9)	0.8 (0.6)	0.2 (0.3)
Rock/gravel (≥ 2mm)	0.8 (0.5)	0	0	1.4 (0.6)	0.5 (0.1)
Litter (< 2mm), including scats	40.7 (14.2)	31.8 (15.8)	13.6 (4.6)	45.5 (11.1)	25.5 (8.1)
Completely dead shrub, attached	0	0	0	0	0
Wood (≥ 2mm), not attached -- must be wood from shrub/tree	1.0 (0.9)	0	0	0	0

Disturbances recorded in 2019 varied by site, but overall were lower than observed in 2018. Brown Butte experienced the greatest mean cover of disturbance, which was composed primarily of cattle prints and erosion rills. North Harper North experienced the second-highest amount of disturbance, primarily due to livestock and human impacts. Individual disturbance categories with the highest abundance included erosion rills, insect burrows, human footprints, and old cattle feces (Table 5). No ungulate herbivory or trampling was observed on any *A. mulfordiae* individuals, but insect damage was found on five plants.

At the time of this report, updated data from Idaho were not available. We will delay comparing population dynamics from the two states until data are available from Idaho. Likewise, after collecting 10 consecutive years of consistent data we will be able to make comparisons between population dynamics and climate variability at the Oregon occurrences.

TABLE 5. MEAN PERCENT COVER (± 95% C.I.) OF GROUND DISTURBANCES BY SITE IN 2019.

Disturbance Category	Brown Butte	Double Mountain	North Harper North	Snively	South Alkali
Anthill	0	0	0.03 (0.05)	0.1 (0.1)	0
Burrow	0	0	10.6 (9.7)	0	0
Cattle feces-recent (<1 yr)	0	0	0.6 (0.5)	0	0
Cattle feces-older (>1 yr)	0	0	0.3 (0.3)	0.4 (0.7)	1.1 (0.6)
Cattle prints	0.7 (0.8)	0	0	0	0
Human footprints (researcher)	3.3 (2.4)	0.3 (0.4)	0.2 (0.3)	0	2.7 (0.4)
Insect burrow (diameter < 1 cm)	0.2 (0.1)	0.5 (0.3)	0.3 (0.1)	0.1 (0.1)	0.1 (0.1)
Pronghorn feces	0	0	0.1 (0.1)	0	0.2 (0.1)
Pronghorn prints	0	0.6 (0.5)	0	0	0
Medium sized rodents (pocket gopher, kangaroo rat, ground squirrel)	0.5 (0.05)	0.03 (0.05)	0.2 (0.3)	0.3 (0.4)	0
Rills (erosion)	23.4 (10.6)	5.0 (2.2)	1.3 (1.7)	6.6 (2.7)	0
Unknown animal prints	0.2 (0.1)	1.1 (0.6)	0.2 (0.3)	0.03 (0.05)	0

Herbivory Plots

In 2019, a total of 166 *A. mulfordiae* plants were encountered in 72 experimental herbivory plots; 49 plants were found in caged plots and 116 in uncaged. For comparison through time, we considered only the plots that were surveyed in every year of the study (n = 46, 24 caged and 22 uncaged; hereafter "continuous plots"). In 2019, a total of 89 plants were found in continuous plots, 33 plants in caged plots and 56 in uncaged. This was an increase from 2018, but remains far below initial counts (Table 6).

TABLE 6. LIVE PLANTS, MORTALITY, AND NUMBER OF NEW PLANTS FOUND FROM 2008 TO 2019, INCLUDING ONLY PLOTS THAT WERE MONITORED CONSISTENTLY IN ALL YEARS (N = 46). NO PLOTS WERE MONITORED IN 2011.

	2008	2009	2010	2012	2013	2014	2015	2016	2017	2018	2019
Live	215	206	208	127	70	64	100	99	127	59	89
Mortality	--	30	31	138	68	11	14	44	38	74	9
New	--	2	33	67	12	4	49	43	65	5	34

Mortality in 2019 (as measured by loss of individuals found in 2018) was the lowest on record at only 18 plants (nine plants in continuous plots). Plants died or went dormant at almost all sites in both caged and uncaged plots, with the highest mortality at South Alkali (seven plants total, four in uncaged plots and three in caged; Table 7). North Harper South had the greatest number of "new" or returned plants (29), primarily found in uncaged plots, while Double Mountain had only one new plant. Across all sites, 61 "new" or returned plants were found (34 in continuous plots), six in caged plots and 55 in uncaged (Table 7).

TABLE 7. LIVE PLANTS, MORTALITY, AND NEW PLANT TOTALS FOR EACH SITE/SUBSITE IN 2019, INCLUDING ALL PLOTS, SEPARATED BY TREATMENT. SOUTH ALKALI SUBSITES ARE CLUMPED.

	Brown Butte	Double Mountain	North Harper	Snively	South Alkali
Live	**17**	**12**	**77**	**14**	**46**
Caged	5	10	9	3	23
Uncaged	12	2	68	11	23
Mortality	**3**	**5**	**3**	**0**	**7**
Caged	0	4	0	0	3
Uncaged	3	1	3	0	4
New	**11**	**1**	**34**	**7**	**8**
Caged	2	1	2	0	1
Uncaged	9	0	32	7	7

The density of *A. mulfordiae* in 1 m^2 plots ranged from zero to 35 across all 72 plots in 2019. Twenty-six plots had no living *A. mulfordiae*, a decrease from 32 found empty in 2018; only one of these was unoccupied for the first time in our monitoring effort. A total of eight plots were newly empty after containing living specimens in both 2017 and 2018, but four empty plots from prior years gained "new" or resprouting plants.

The total number of *A. mulfordiae* in continuous plots in 2019 was higher than observed in recent years, but remains far below the numbers observed in our first three years of study. From 2008 to 2014, 83% of plants initially present either died or could not be re-located. 2015 was the first year since 2008 in which the number of plants across all sites increased from the previous year. In 2016 and 2017 we continued to observe an increase in the total number of plants across all sites, but in 2018 numbers fell to 2014 levels. In 2018, North Harper experienced a major decrease in number of plants from the previous year, indicating the die-off of seedlings found in 2017. In 2019, we observed some population rebound with counts increasing at all sites except Double Mountain (Figure 7).

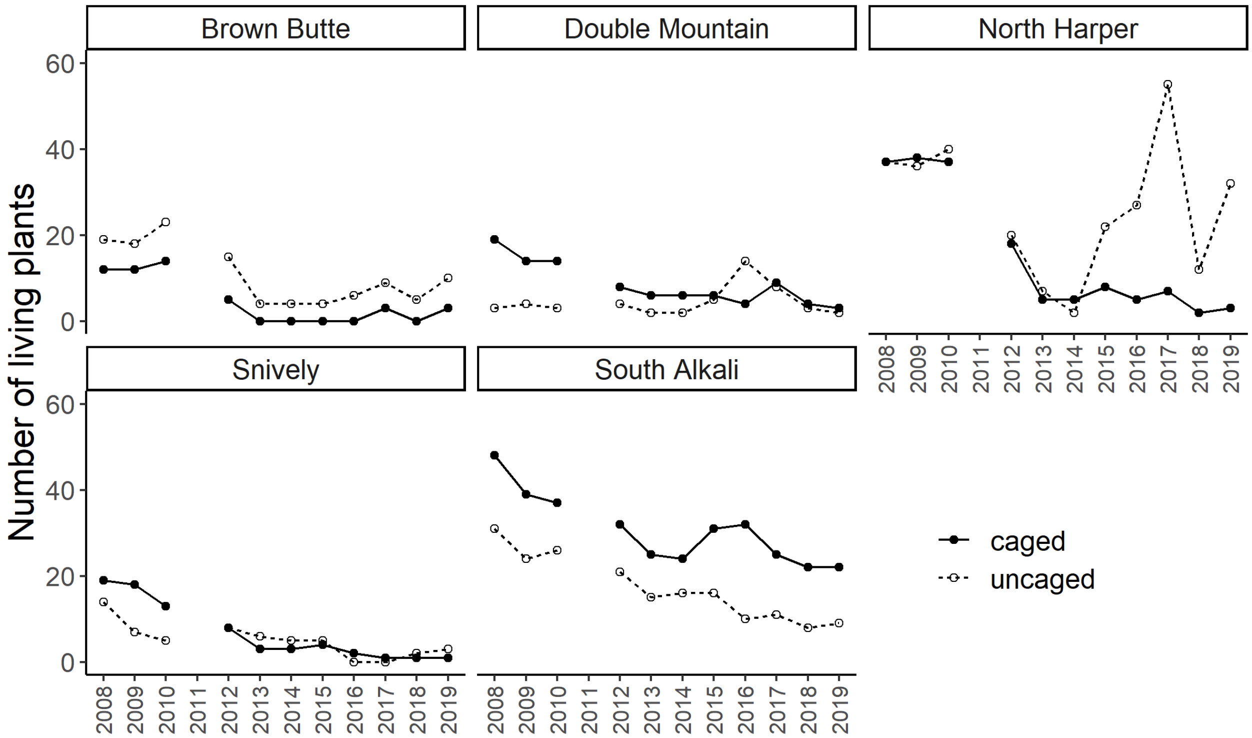

FIGURE 7. TOTAL *A. MULFORDIAE* IN MONITORING PLOTS FROM 2008 TO 2019 (INCLUDING ONLY PLOTS THAT WERE FOUND IN ALL 11 YEARS OF SURVEYS; N=46), SEPARATED BY SITE AND TREATMENT. PLANTS < 5CM DIAMETER WERE INCLUDED IN THIS ANALYSIS, AND NO DATA WERE COLLECTED IN 2011.

Plants ranged from one to 72 cm in diameter in 2019 and, for the subset of plants greater than five cm in diameter (N = 119), did not differ significantly between caging treatments across all sites (two-way ANOVA, df = 1, F = 1.1, p = 0.288). That said, there was moderate evidence for an interactive effect of site and treatment on plant size (site*treatment interaction, two-way ANOVA, df = 4, F = 3.0, p = 0.021). The strongest evidence for difference in plant diameter was between sites (two-way ANOVA, df = 4, F = 6.0, p = 0.0002, Appendix Table 4), emphasizing the likelihood of alternative environmental factors (other than ungulate grazing) as primary drivers of plant diameter. In 2019, there was weak evidence for plants being significantly larger in caged plots at Snively (Wilcoxon t-test, p = 0.057), as has been the case in previous years, but no other significant differences in size have proven consistent over time (Appendix Figure 14, Appendix Figure 15). Significant differences discussed in reports prior to 2018 included plants less than five cm in diameter in the analysis.

Like plant size, the number of fruits per reproductive plant was variable across sites, with Double Mountain and Snively at the low end and South Alkali and North Harper at the high end; at the latter, a single plant was found with almost 850 fruits. The average number of fruits per reproductive plant increased across all sites except Double Mountain (decrease from 36 to 24 fruits per plant). South Alkali had the highest mean number of fruits per reproductive plant (146 fruits per plant). Neither treatment nor site showed correlation with the number of fruits per reproductive individual (quasipoisson GLM, p > 0.2, Appendix Table 5). The mean proportion of live, reproductive plants was higher than observed in 2018 across all sites and increased at three of five sites, ranging from 8% at Brown Butte to 100% at Double Mountain (Table 8), but has been highly variable over time (Appendix Figure 16).

TABLE 8. PROPORTION (%) OF REPRODUCTIVE *A. MULFORDIAE* PLANTS AND MEAN NUMBER OF FRUITS PER REPRODUCTIVE PLANT (± 95% C.I.) BY SITE IN 2018 AND 2019 (INCLUDING ONLY CONTINUOUS PLOTS).

	2018		2019	
Site	**Percent repro**	**Fruits / plant**	**Percent repro**	**Fruits / plant**
Brown Butte	20	10 (7)	8	90 (30)
Double Mountain	29	36 (45)	100	24 (13)
North Harper	71	60 (33)	31	145 (81)
Snively	33	12 (32)	75	24 (35)
South Alkali	37	33 (25)	94	146 (47)

Grazing summary

Stocking rates are summarized in Table 9. No linear correlation between stocking rates and number of plants in uncaged plots was observed from 2008 to 2018 (Pearson's r = 0.13).

TABLE 9. STOCKING RATES AT FIVE MONITORING SITES FROM 2008 TO 2019. NA = DATA NOT AVAILABLE.

	Stocking rate (# of cows*days grazed/# acres)											
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
South Alkali	5.9	6.7	7.0	6.7	6.1	6.8	7.1	7.4	6.3	6.1	6.7	NA
Double Mountain	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Brown Butte	0.9	0.9	0.9	0.9	0.9	1.4	0.0	0.0	0.0	1.2	1.2	0.8
Sniveley	3.4	3.1	3.4	3.2	2.2	3.1	3.1	3.1	3.1	3.1	3.1	NA
North Harper	0.8	0.3	1.0	0.9	0.7	0.4	0.4	0.6	0.7	0.9	1.0	NA

Climate

Maximum and minimum temperature have followed somewhat similar trends to long-term normals (1971-2000, PRISM Climate Group 2019) over our study period, but maximum temperatures in 2015 and 2016 were greater than long-term normals across all seasons (Figure 8, top).

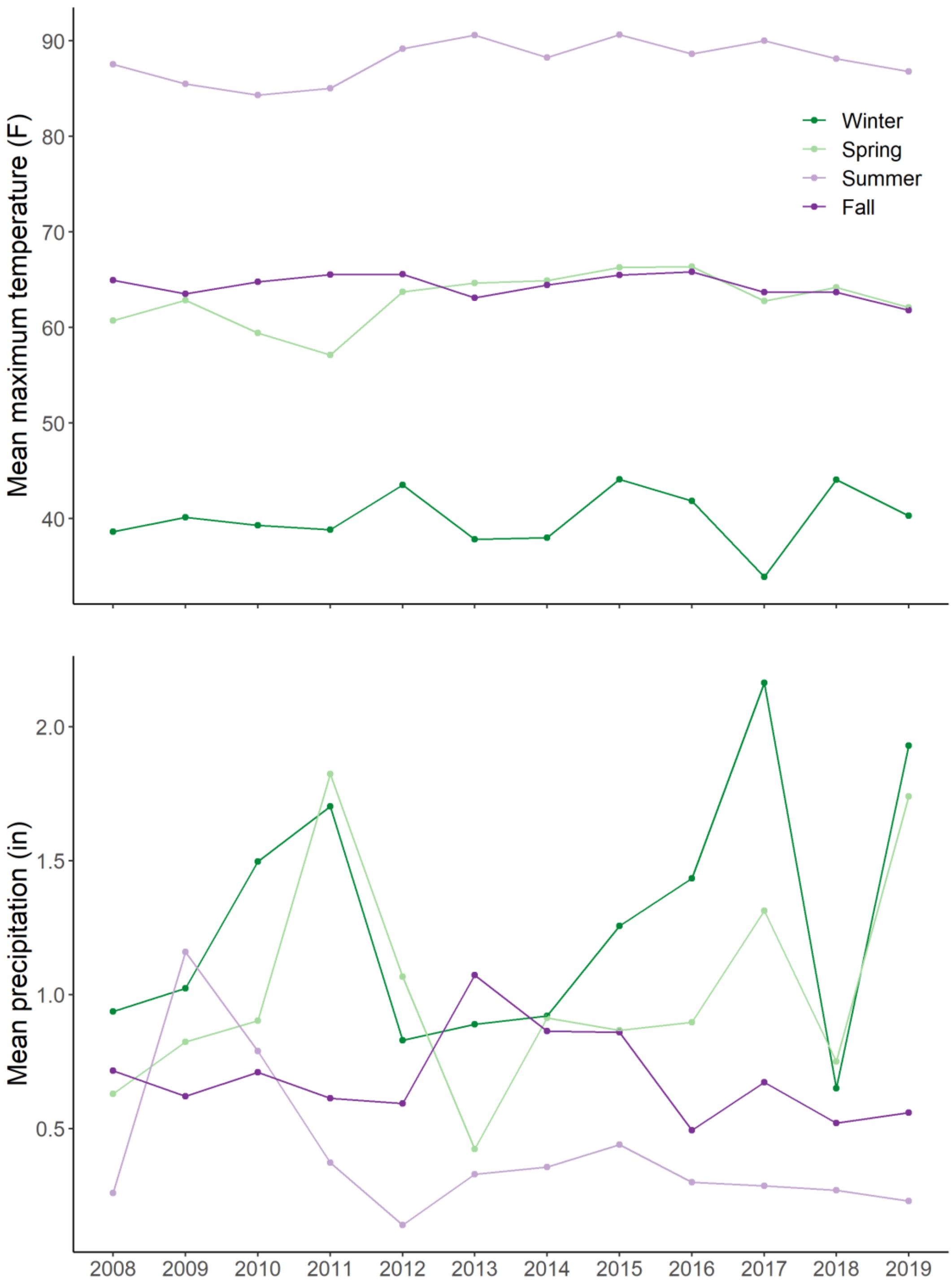

FIGURE 8. MEAN MAXIMUM TEMPERATURE AND MEAN PRECIPITATION FROM 2008 TO 2019 AT NORTH HARPER NORTH (PRISM CLIMATE GROUP 2019).

DISCUSSION

We observed an increase in plants along transects and in herbivory plots in 2019, but the counts remain much lower than our highest counts from 2008-2010. Along transects, reproductive plants accounted for 65% of total plants observed, and in herbivory plots, 62%, both increasing from the reproductive effort observed in 2018. Average number of fruits per reproductive plant was also higher in 2019. New plant counts were similar to some prior years of monitoring (2015, 2016) and were much higher than observed in 2018. That said, over 11 years of monitoring, population count and reproductive effort have declined overall. Though each site shows some annual variability, the declining trend is consistent across all sites and is likely indicative of climate variability and threats from other disturbances such as invasion by non-native plant species.

Plant canopy diameter and reproductive effort of *A. mulfordiae* have varied over the years and across experimental treatments. Though the caging treatment has correlated with significant differences in plant characteristics on a site by site or year by year basis, we do not have consistent evidence that grazing by ungulates (primarily cattle and/or sheep) directly affects *A. mulfordiae* population size and/or reproductive success. Further, sample sizes for testing differences between treatments have decreased with each season, impeding our ability to conduct robust statistical testing at most sites.

In 2014 we examined the potential effect of grazing on *A. mulfordiae* using data provided by the BLM. Stocking rates, which take into account the number of animals, number of days grazed, and acreage, have not changed significantly over the years with regard to each site, though stocking rates did differ between sites. We correlated stocking rates with total number of plants in uncaged plots in 2010, 2012, and 2013, and found no clear trends. South Alkali, which has consistently had among the highest number of plants, was the most heavily grazed; however, it was grazed in the winter which likely had minimal impact on *A. mulfordiae*. Other sites had relatively low stocking rates and varied seasonality (Schomaker and Bahm 2018). These data suggest that while grazing likely impacts *A. mulfordiae* plants and the associated plant community, it does not seem to be the major driver in the long-term patterns we have observed. These findings are not meant to be representative of all *A. mulfordiae* populations, particularly not those with heavier grazing during the growing season. We have also not observed a pattern associated with number of plants present in relation to stocking rates. While some sites are grazed annually, stocking rates have not varied between years within sites. The site with the highest stocking rate (South Alkali) has most likely shown a minimal plant population response because it was grazed during the winter.

The loose, sandy substrate characterizing *A. mulfordiae* habitat leaves evidence of many physical disturbances. In 2019 and over the course of the study, the most common and highest coverage ground disturbances were human and cattle footprints at most sites and severe erosion at Brown Butte. Livestock and humans may affect *A. mulfordiae* populations indirectly by disturbing the loose, sandy substrate either in or adjacent to plots. Livestock and human use may also alter surface hydrology and exacerbate erosion events that have led to plant mortality at many sites. The invasion of these areas by *B. tectorum* may also be influenced by disturbances occurring at these sites. Though non-researcher anthropogenic disturbances were uncommon in 2019, increased disturbance could act as a conduit to further invasion at these sites.

Non-native plant species were present in all *A. mulfordiae* sampling plots, and have generally increased over time, though we have seen overall decline in cover of the ubiquitous annual grass *B. tectorum* since 2016. Sites have transitioned from native-dominated to non-native-dominated communities (and back again), but these changes are non consistent year to year or site to site. In 2019, plant communities at all sites were dominated by *B. tectorum*, even though total cover of this species was lower than in recent years. *Bromus tectorum* germinates earlier than most native species and rapidly depletes soil moisture, increasing its competitive ability. Its prolific seed production also enables the species to rapidly invade spaces between other plants creating consistent fuel loads that can be detrimental in the case of a wildfire (Knapp 1996). This species thus poses a serious threat to *A. mulfordiae* and other native species in these sensitive habitats. Both high *A. mulfordiae* seedling mortality and the decrease in *B. tectorum* cover at all study sites observed this year may have been driven by especially dry conditions experienced in the winter and spring of 2018. Continued monitoring will be crucial to discern any persistent patterns.

Variability in seasonal precipitation and the drier conditions observed in 2018 and some earlier years of this study have likely influenced the long-term population decline observed since 2008. In these cold-desert ecosystems, most precipitation occurs during winter and early spring, and the increase in number of plants noted from 2015 to 2017 could be the result of wetter winters (and a wetter spring in 2017) after many years of drier-than-normal conditions. While large seedling die-off events are an expected consequence of years with high initial reproductive success, the seedling loss observed in summer of 2018 may also reflect the extremely dry conditions experienced in the preceding winter and spring. 2019 was another wet spring and summer year with increased seedling counts. Similar trends were observed for another rare plant species, *Lupinus lepidus* var. *cusickii* (Cusick's lupine), at Denny Flat, Baker County, OR, located about 70 miles to the northwest; *L. lepidus* var. *cusickii* counts were much higher in 2015 and 2016 following winters with greater precipitation than preceding years (Petix et al. 2016).

Climate change models predict increasing temperatures, especially in summer months, throughout the Pacific Northwest, and while forecasts for precipitation are more variable, they predict greater seasonal fluctuations (Mote and Salathé 2010). Increased temperatures, if coupled with decreased or sporadic precipitation, could greatly affect native species in sagebrush steppe habitats. In a recent model for climate change effects on sagebrush steppe ecosystems in Oregon, investigators concluded that climate change would yield increases in non-native grasses and an overall decline in sagebrush steppe habitat, transitioning these areas into salt desert shrub communities (Creutzburg et al. 2015). Such landscape-scale changes will seriously impact native species, particularly local endemics such as *A. mulfordiae*.

CONCLUSIONS

Over the course of this study, we have observed a decline in *A. mulfordiae* population size at all of our study sites. Since 2012, we have not attempted to establish new monitoring plots due to the low density of existing plants. Despite the increase in plants noted from 2015 to 2017, and again in 2019, the overall decline observed across recent years remains cause for concern. Though population dynamics were difficult to discern in prior studies (Newton et al. 2010), the consistent decline across all sites over 11 years of monitoring is evidence that this species is sensitive to one or more environmental factors (biotic, abiotic, or both) that are damaging to its survival and reproductive success. Plant size and reproductive effort of *A. mulfordiae* have both varied over the years and across caging treatments. Though large mammal exclusion has shown significant differences in plant characteristics (i.e. diameter) on a site by site or year by year basis, we do not have evidence that grazing by livestock directly affects *A. mulfordiae* population size and/or reproductive success in a consistent manner.

With regards to the objectives and goals laid out at the beginning of this study, summarized below are the general conclusions for 2019:

- Population size has declined over the long-term, but some sites have experienced seedling influx in recent years. The mean cover of *A. mulfordiae* has actually increased at South Alkali where cover was greater than was observed in 2009 for a majority of subsequent monitoring years.
- Habitat quality did not change dramatically, though we are seeing a decline in *B. tectorum* cover from the highs observed in 2015, perhaps associated with recent small increases in *A. mulfordiae* cover and counts.
- Large mammal herbivory does not appear to have a consistent effect on *A. mulfordiae* population count or plant size at these sites.
- Variation in winter and spring precipitation may correlate with seedling production, but we will wait for an additional two years of data collection to have 10 years of consecutive measurements to use in more robust climate analyses.
- We plan to compare our population data to those from Idaho in the future when the latter become available.

Given declines observed in recent years across all sites, we recommend continued monitoring in order to better understand long-term population trends and to describe areas where populations are particularly vulnerable or changes are occurring rapidly. To mitigate for future loss, we recommend efforts focused on seed banking, and potentially conducting a complete census of these and other populations to yield a more comprehensive understanding of the current status and extent.

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APPENDIX A: GPS COORDINATES, MAPS, AND DRIVING DIRECTIONS

GPS coordinates

APPENDIX TABLE 1. GPS LOCATIONS FOR ALL PLOTS AND TRANSECTS AT ALL SITES.

Site	Sub-site	Plot #	Treatment	Latitude[1,2]	Longitude[1,2]
Brown Butte		End	Transect	43.73173	-117.12424
Brown Butte		Start	Transect	43.73190	-117.12421
Brown Butte		86	Caged	43.73237	-117.12403
Brown Butte		88	Caged	43.73187	-117.12437
Brown Butte		538	Caged	43.73180	-117.12432
Brown Butte		541	Caged	43.73227	-117.12406
Brown Butte		543	Caged	43.73222	-117.12398
Brown Butte		545	Caged	43.73218	-117.12373
Brown Butte		87	Uncaged	43.73195	-117.12425
Brown Butte		537	Uncaged	43.73181	-117.12429
Brown Butte		540	Uncaged	43.73233	-117.12415
Brown Butte		544	Uncaged	43.73214	-117.12392
Brown Butte		546	Uncaged	43.73211	-117.12381
Double Mountain		End	Transect	43.83319	-117.29086
Double Mountain		Start	Transect	43.83315	-117.29061
Double Mountain		269	Caged	43.83327	-117.29037
Double Mountain		270	Caged	43.83346	-117.29051
Double Mountain		679	Caged	43.83325	-117.29030
Double Mountain		680	Caged	43.83332	-117.29047
Double Mountain		683	Caged	43.83306	-117.29095
Double Mountain		268	Uncaged	43.83334	-117.29044
Double Mountain		272	Uncaged	43.83269	-117.29130
Double Mountain		678	Uncaged	43.83326	-117.29034
Double Mountain		682	Uncaged	43.83302	-117.29093
North Harper	North	End	Transect	43.86769	-117.23576
North Harper	North	Start	Transect	43.86768	-117.23577
North Harper	North	528	Caged	43.86786	-117.23558
North Harper	North	530	Caged	43.86786	-117.23563
North Harper	North	532	Caged	43.86757	-117.23510
North Harper	North	534	Caged	43.86782	-117.23509
North Harper	North	79	Caged	43.86790	-117.23538
North Harper	North	78	Uncaged	43.86760	-117.23532
North Harper	North	527	Uncaged	43.86783	-117.23576
North Harper	North	529	Uncaged	43.86791	-117.23558
North Harper	North	533	Uncaged	43.86758	-117.23524
North Harper	North	535	Uncaged	43.86777	-117.23521
North Harper	South	73	Caged	43.86304	-117.23103
North Harper	South	667	Caged	43.86389	-117.23113

Site	Sub-site	Plot #	Treatment	Latitude[1,2]	Longitude[1,2]
North Harper	South	669	Caged	43.86382	-117.23115
North Harper	South	670	Caged	43.86317	-117.23102
North Harper	South	672	Caged	43.86305	-117.23102
North Harper	South	673	Caged	43.86269	-117.23064
North Harper	South	74	Caged	43.86284	-117.23062
North Harper	South	75	Uncaged	43.86292	-117.23095
North Harper	South	576	Uncaged	43.86385	-117.23113
North Harper	South	77	Uncaged	43.86381	-117.23113
North Harper	South	666	Uncaged	43.86392	-117.23116
North Harper	South	671	Uncaged	43.86308	-117.23099
North Harper	South	674	Uncaged	43.86293	-117.23082
North Harper	South	675	Uncaged	43.86300	-117.23089
Snively		End	Transect	43.72012	-117.19399
Snively		Start	Transect	43.71994	-117.19401
Snively		69	Caged	43.72001	-117.19503
Snively		71	Caged	43.71998	-117.19470
Snively		72	Caged	43.72005	-117.19387
Snively		547	Caged	43.71979	-117.19368
Snively		553	Caged	43.71994	-117.19364
Snively		70	Uncaged	43.72001	-117.19506
Snively		550	Uncaged	43.71977	-117.19473
Snively		552	Uncaged	43.72003	-117.19368
Snively		554	Uncaged	43.71993	-117.19353
South Alkali	#1	646	Caged	44.06173	-117.19659
South Alkali	#1	649	Caged	44.06177	-117.19658
South Alkali	#1	650	Caged	44.06161	-117.19660
South Alkali	#1	647	Uncaged	44.06175	-117.19654
South Alkali	#1	648	Uncaged	44.06171	-117.19662
South Alkali	#1	651	Uncaged	44.06160	-117.19636
South Alkali	#2	80	Caged	44.06403	-117.17443
South Alkali	#2	83	Caged	44.06392	-117.17404
South Alkali	#2	652	Caged	44.06392	-117.17407
South Alkali	#2	81	Uncaged	44.06406	-117.17443
South Alkali	#2	82	Uncaged	44.06408	-117.17443
South Alkali	#2	84	Uncaged	44.06385	-117.17415
South Alkali	#2	655	Uncaged	44.06407	-117.17423
South Alkali	#3	End	Transect	44.05372	-117.17505
South Alkali	#3	Start	Transect	44.05357	-117.17499
South Alkali	#3	659	Caged	44.05362	-117.17496
South Alkali	#3	660	Caged	44.05366	-117.17484
South Alkali	#3	663	Caged	44.05369	-117.17520

Site	Sub-site	Plot #	Treatment	Latitude[1,2]	Longitude[1,2]
South Alkali	#3	665	Caged	44.05336	-117.17495
South Alkali	#3	658	Uncaged	44.05360	-117.17479
South Alkali	#3	662	Uncaged	44.05367	-117.17519
South Alkali	#3	664	Uncaged	44.05332	-117.17494

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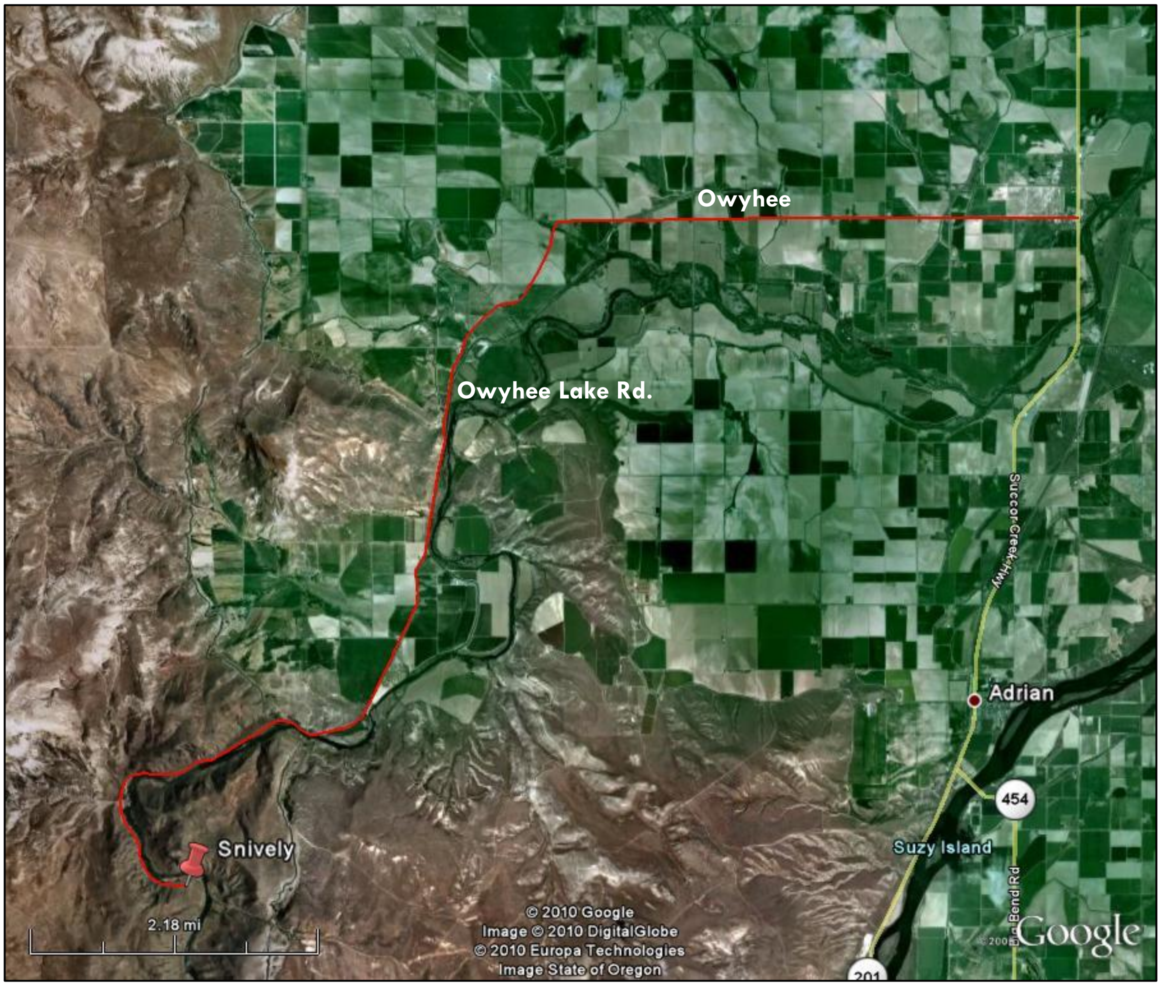
[2]Set Position Format to "hddd.ddddd"

Maps and directions

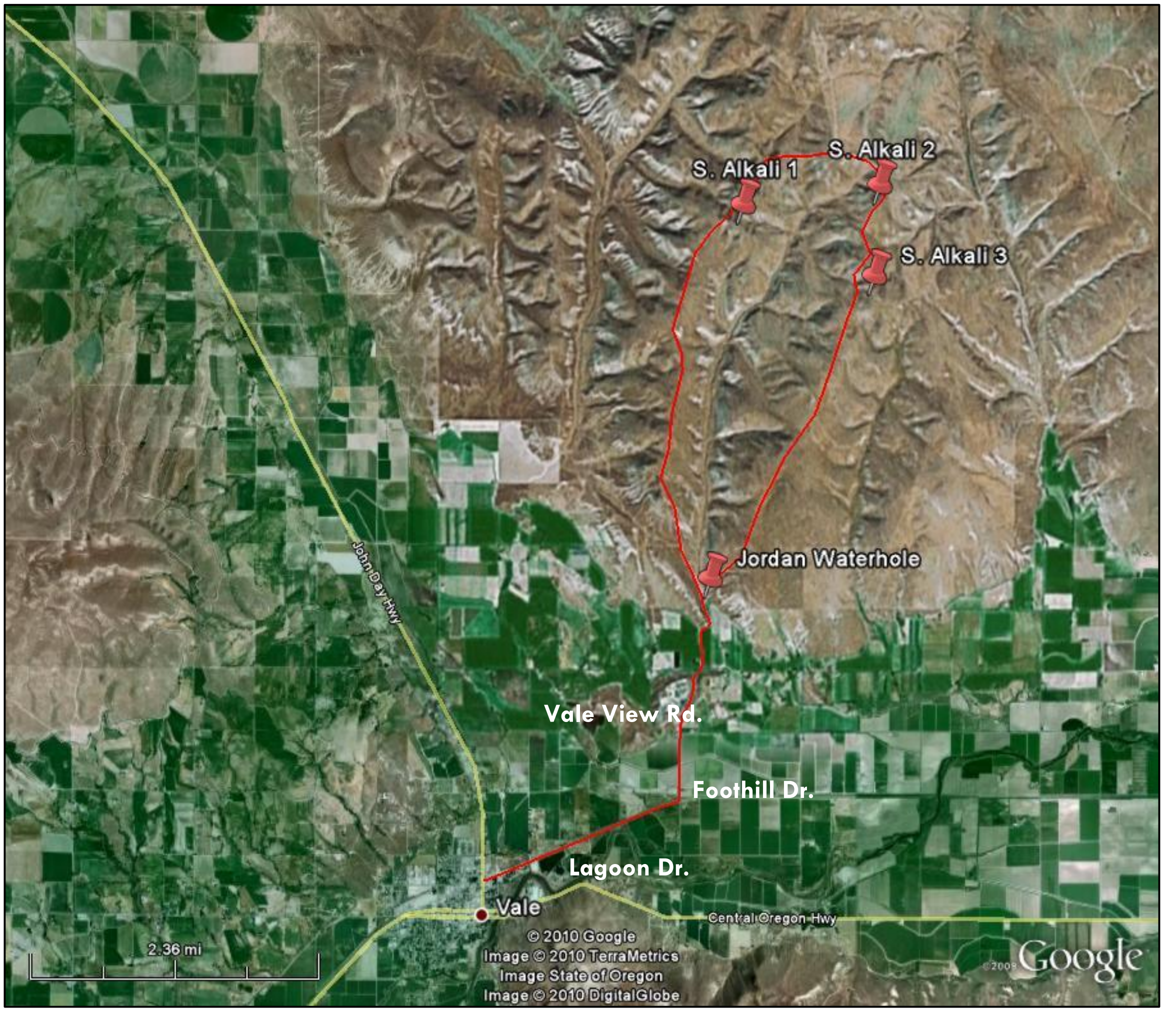


APPENDIX FIGURE 1. SNIVELY FIELD SITE (OWYHEE DAM SITE) AND DRIVING ROUTE.

From Vale: Follow Lytle BLVD south out of Vale towards Adrian. Take a sharp left on Janeta Ave, a sharp right on Jefferson Ave, and turn right onto Owyhee Avenue. Turn left onto Owyhee Lake Road. Follow past Snively Hot Springs, field site is across the road from a pull-out with cottonwoods.

SC 8/16: There is a shortcut between BB and Snively. Leaving BB, get back on Clover Ave. Pass Mendiola and Clover becomes Locust. Follow until it T's at Overstreet. Turn left on Overstreet. Follow until it T's on Owyhee Lake Rd, after crossing the Owyhee River. Turn left on Owyhee Lake Rd. Follow along river, pass Snively Hot Spring and keep an eye on the left hand side for a big pull-out. If you have access to google maps it will show up at Snively Gulch Rd. From the Owyhee River crossing to the pullout is ~4.6 miles.

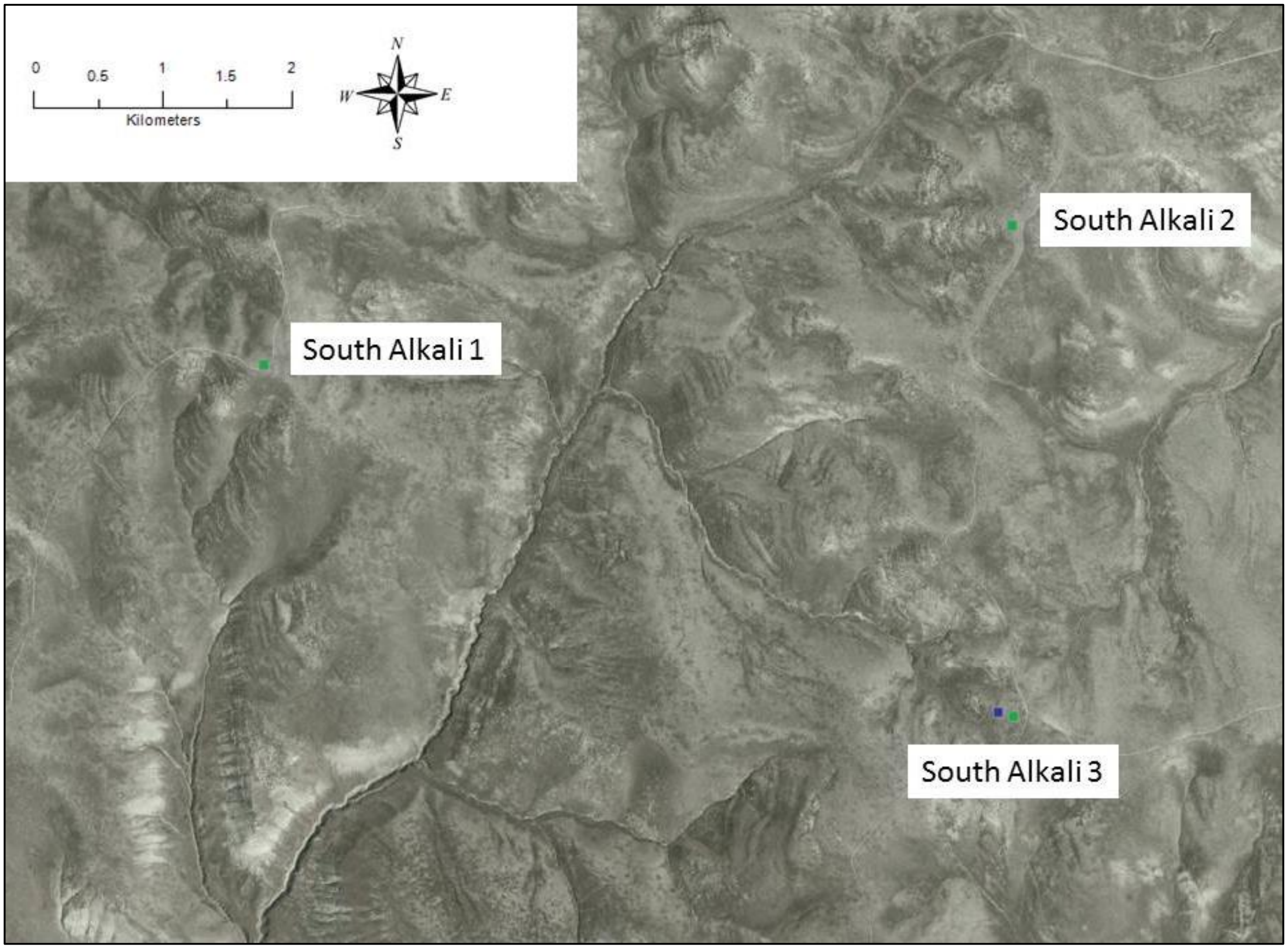
APPENDIX FIGURE 2. SNIVELY OVERVIEW (TOP) AND PLOT LOCATIONS (BOTTOM).



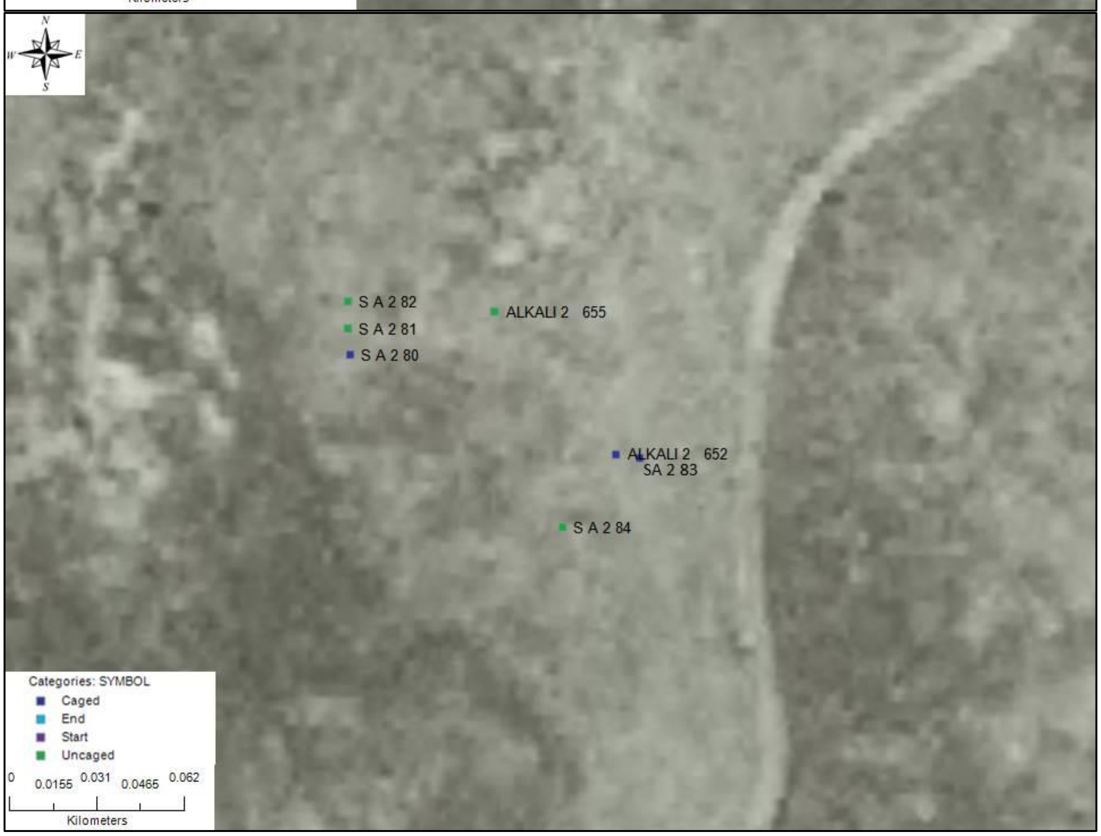
APPENDIX FIGURE 3. SOUTH ALKALI FIELD SITE AND DRIVING ROUTE.

South Alkali Field Site (Henry Gulch quad) - <u>NOTE: After South Alkali 3, it is safer to backtrack rather than making a circle.</u> From the BLM office, turn right onto Hwy 26/12th St/Glenn St. N and then left onto Hope St. E/Railroad Avenue E. After two blocks turn left onto 10th St. After one block, 10th curves to the right and turns into Lagoon Dr. Lagoon parallels railroad tracks until it dead ends, go left (north) onto Foothill Dr. At intersection, Foothill turns right, stay straight, road changes to Vale View Rd---RESET your odometer. After 0.5 miles Vale View will turn to the left (west)—don't do this. At this turn in the road, there will be a gravel road with a stop sign (may look like a driveway) → take this road. Go past Netcher Ln (on your right after ~0.1) and continue on this road (Right at the Y-intersection at 0.9) to a total of 1.2 miles where you will see a large gate with two tall rock columns. Go through this gate!

Follow the road to the right along the dyke and go through a gate that has two rock columns. Reset odometer—you are about to begin a 9 mile circuit of the ridge in front of you, following around the edge of the watershed/basin to your right. Reference a topo and/or aerial map of the area if you need help navigating. Continue on this road to the left (by Jordan Water Hole). The road goes up into the hills, along a ridge, with the valley on your right. At 0.4 → stay right. Stay Right at 1 mile. At 3.3 park at S. Alkali 1. At 4.7 go through gate and turn right. At 5.2 pass through a green gate. At 5.4 park at S. Alkali 2. At 6.2 park at S. Alkali 3. When finished, turn around and go back the way you came.

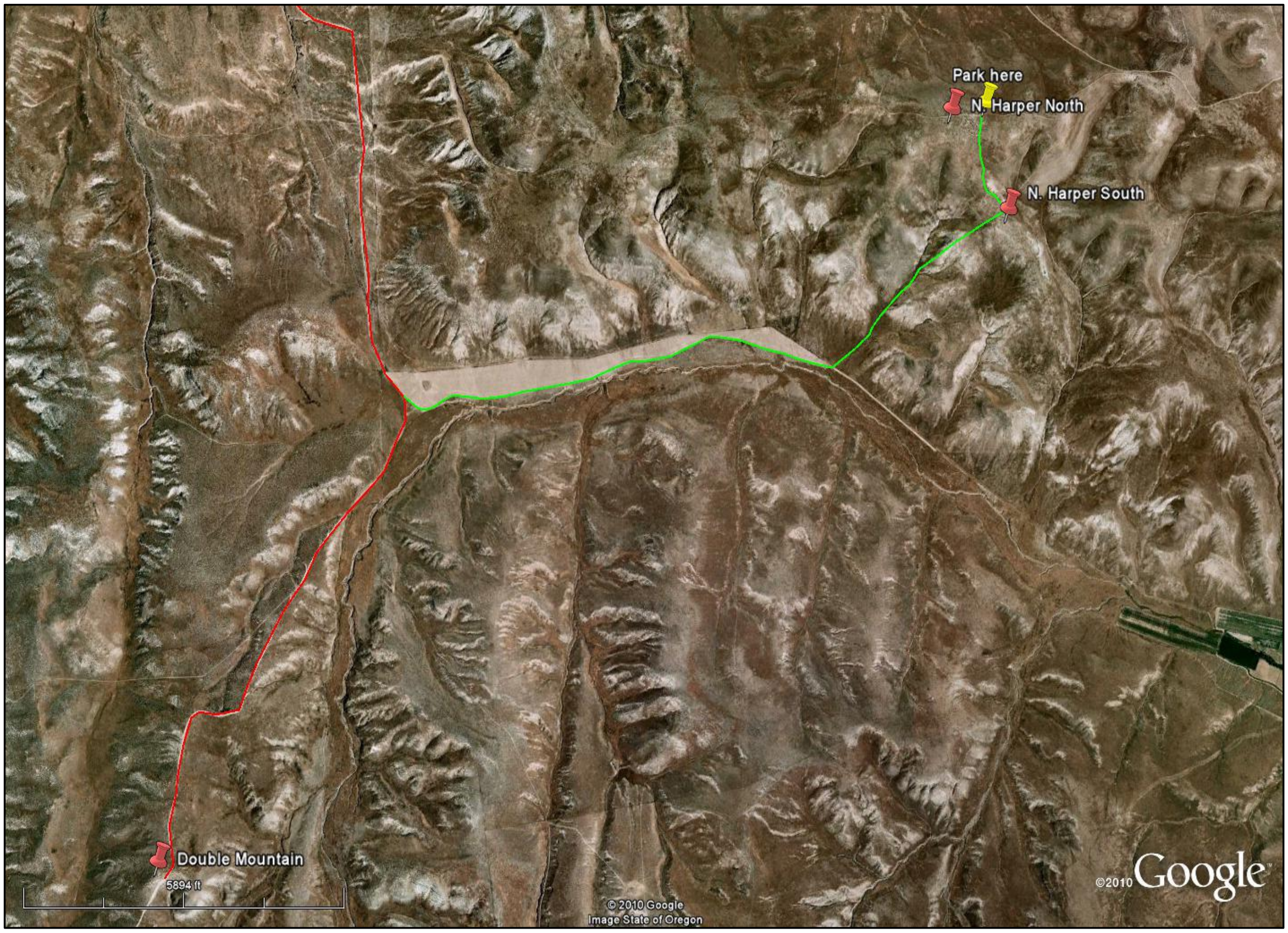


APPENDIX FIGURE 4. SOUTH ALKALI OVERVIEW.



APPENDIX FIGURE 5. SOUTH ALKALI 1 (TOP) AND 2 (BOTTOM) PLOT LOCATIONS.

APPENDIX FIGURE 6. SOUTH ALKALI 3 PLOT LOCATIONS.



APPENDIX FIGURE 7. NORTH HARPER SITE AND DRIVING ROUTE.

North Harper (North and South) (Mitchell Butte quad) ** **Do S first, then continue up road to N****

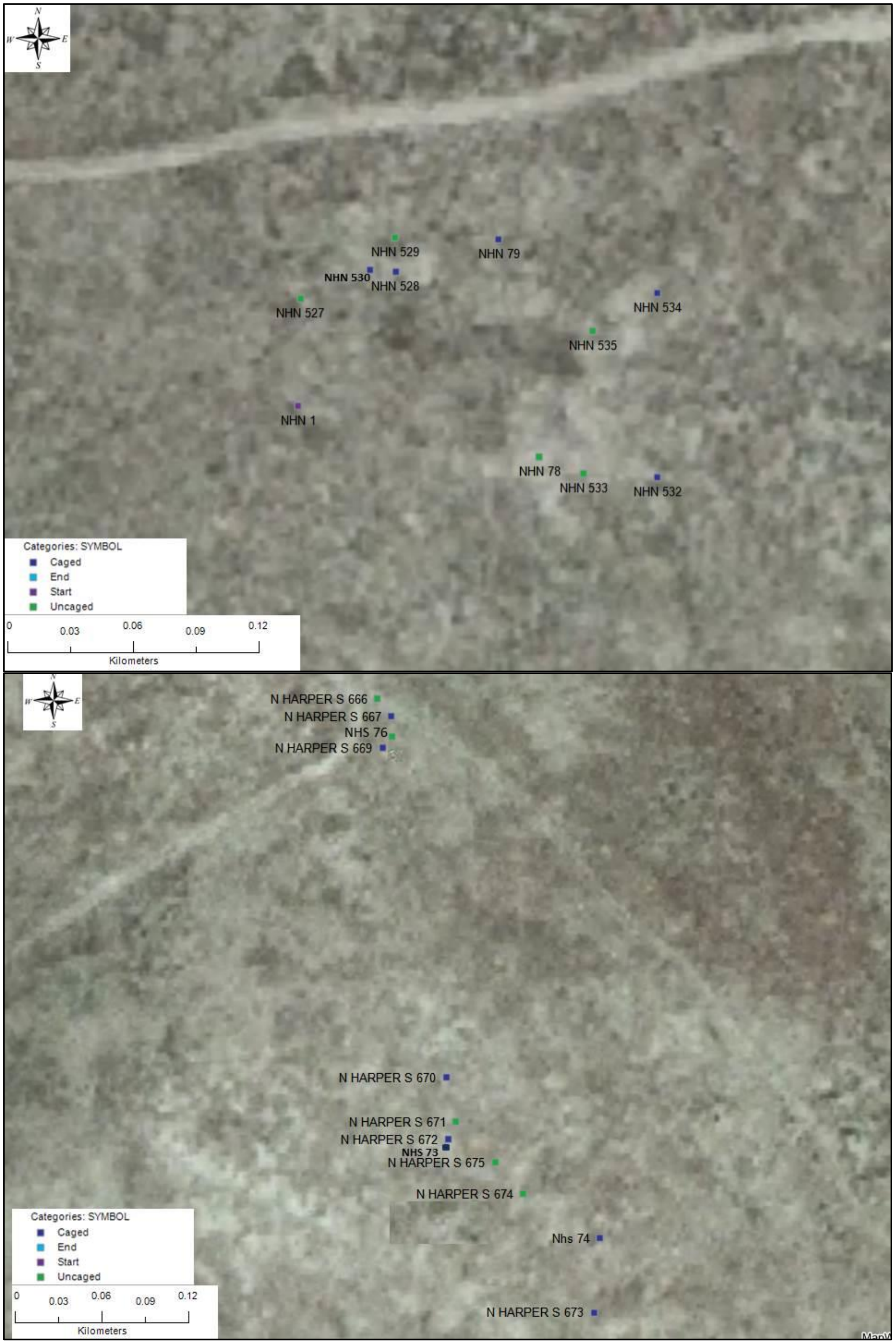
From Cow Hollow** [USE THESE]

From Vale, take 20 west. Turn left onto Russell Rd ~4miles out of town. Turn left onto Dry Creek/Twin Spring (Cow Hollow) → reset odometer. R at 0.1, after 4.5mi, turn left onto 2 track. At 5.2 stay straight and beware of large washout on right. At 5.7 go past cattle station (road goes through big thicket of Russian thistle, kind of invisible). Go through the gate on left (6.1) and continue to drive along the road. In 2015 the road was full of thistle! Follow the road to the left and up into the hills (along a drainage)—this has become increasingly hairy since 2012. This road will take you directly to the site-Park at 6.9. Stay on the road, continuing up the hill. For North Harper North, at the T in the road, go left and park ~7.3. ASMU is in the road. ****NOTE: In 2015, the road is getting increasingly sketchy/sandy from the cattle area to NHS → park below where it is flat and hike into both sites [bring plenty of food/water].**

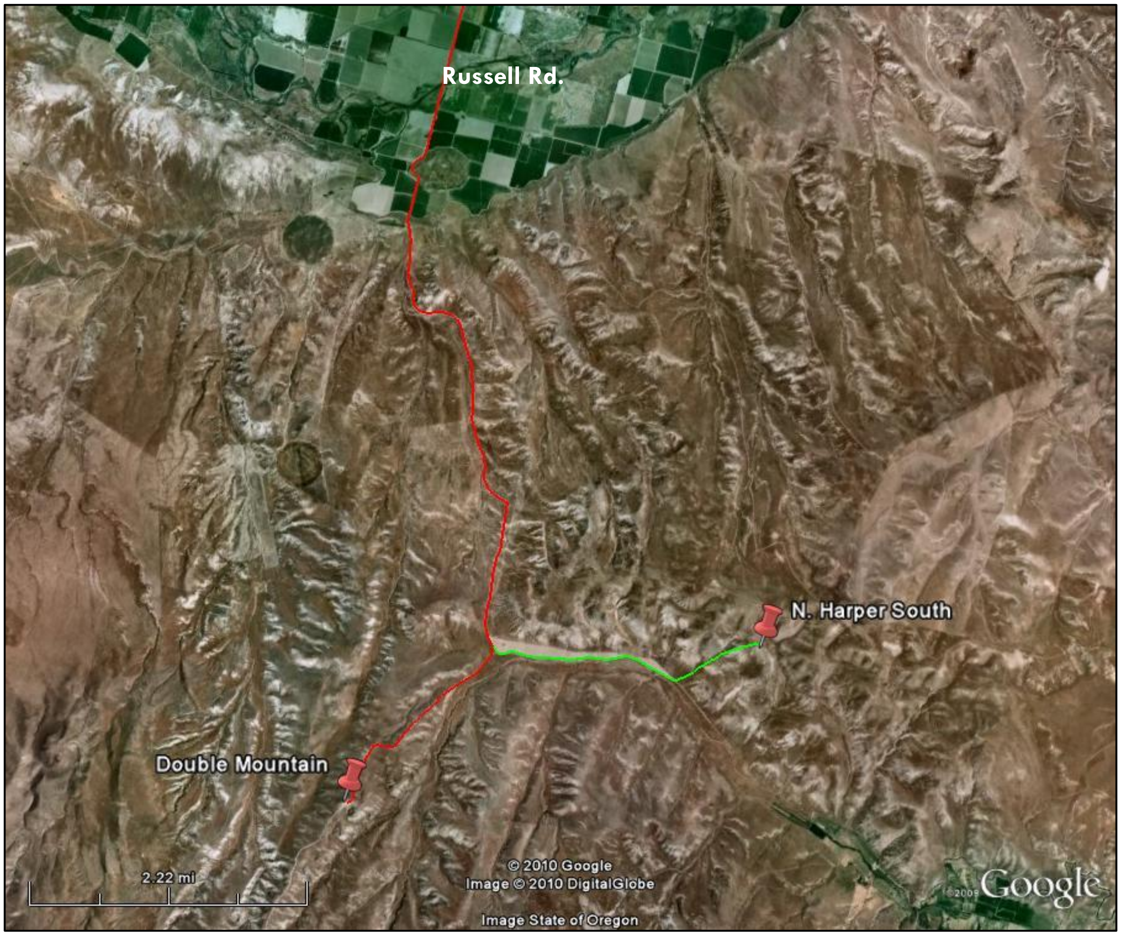
From Lytle Blvd. (Use only as backup- Follow Cow Hollow directions)

Turn right onto dirt road (if coming from Vale) that cuts to northwest and goes behind ridge paralleling road. If you pass the dump, you went too far. Keep on dirt road for ~2.5 miles (always going ±NW) until you come to a triangle junction, turn left (towards water tower). Road runs ~SW for 0.9 miles before turning WNW (near the water tower). Drive 1.5 miles (total from last triangle junction), go through fence and turn left (south). Road will follow fenceline for ~1.25 miles until it reaches another triangle junction, take right fork, which will spit you out going west on new road after 1.35 total miles from last junction. After 0.1 miles, take left fork. In 0.3 miles you will reach another fork (with a large patch of *Oenothera cespitosa*). Go left and park at top of hill to walk down and sample N. Harper South, go right, drive 0.4 miles west, and park to sample N. Harper North. Follow USGS 7.5" topo carefully. Not necessary.

APPENDIX FIGURE 8. NORTH HARPER OVERVIEW.



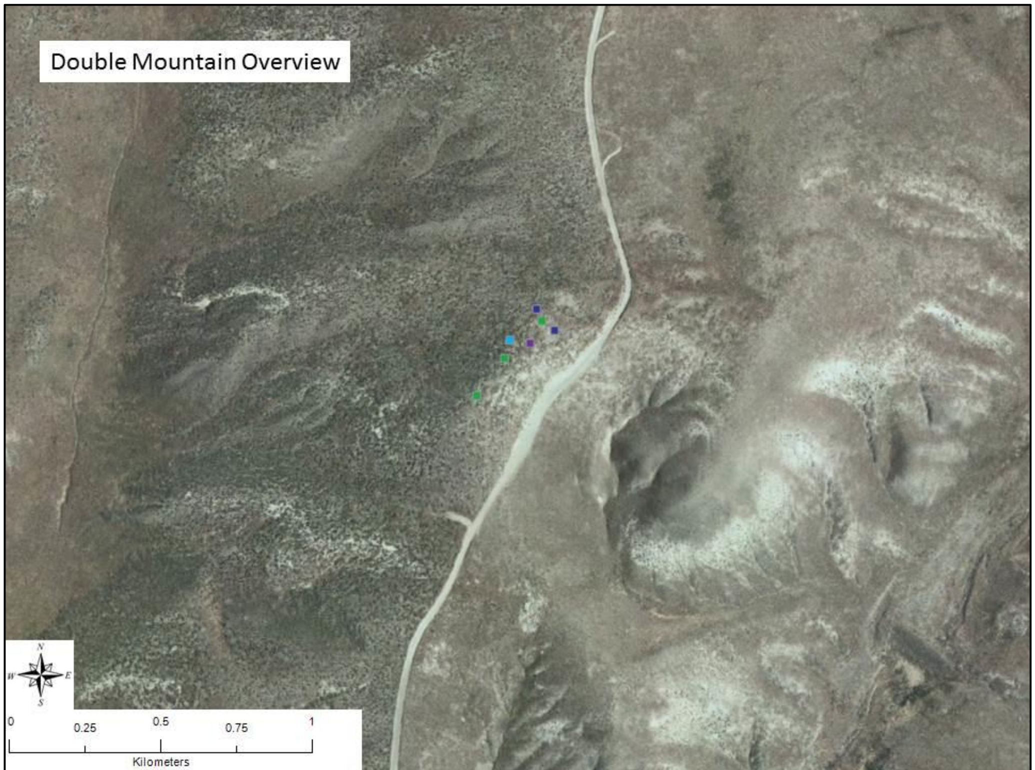
APPENDIX FIGURE 9. NORTH HARPER NORTH (TOP) AND SOUTH (BOTTOM) PLOT LOCATIONS.



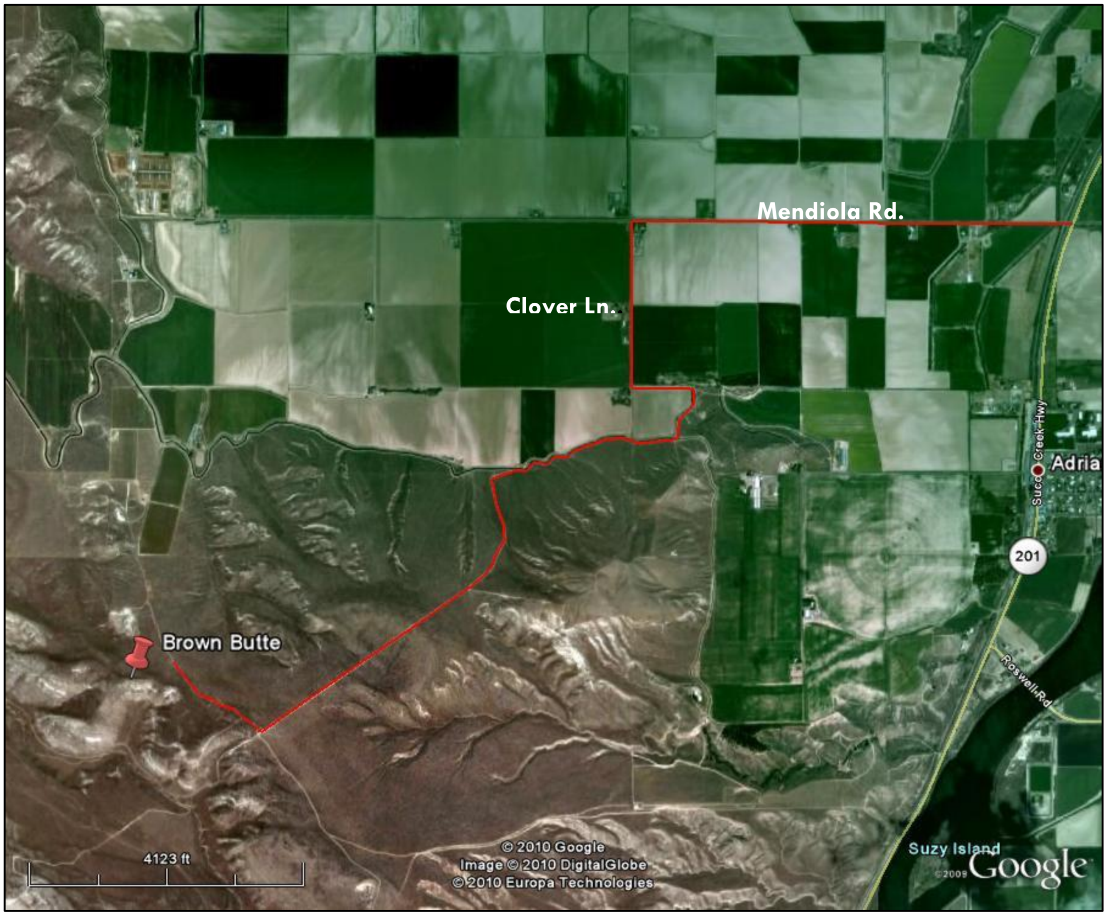
APPENDIX FIGURE 10. DOUBLE MOUNTAIN SITE AND DRIVING ROUTE.

Double Mountain Field Site (Double Mountain quad)

From the BLM office, turn right out of the BLM visitor's parking lot. Turn left onto 14th street. Turn right onto Hope Street. Turn left onto 17th street. Turn right onto Washington (20W). Take 20W past Vale. Turn left onto Russell Rd. Go 2 miles and turn left onto Dry Creek. 2.2 stay right, 2.6 stay left through gate, and 2.7 stay right. 4.6 cattle-guard, 6.5 and 6.9 cattle-guard. Park at 8.6 and hike uphill on the right to reach the site.



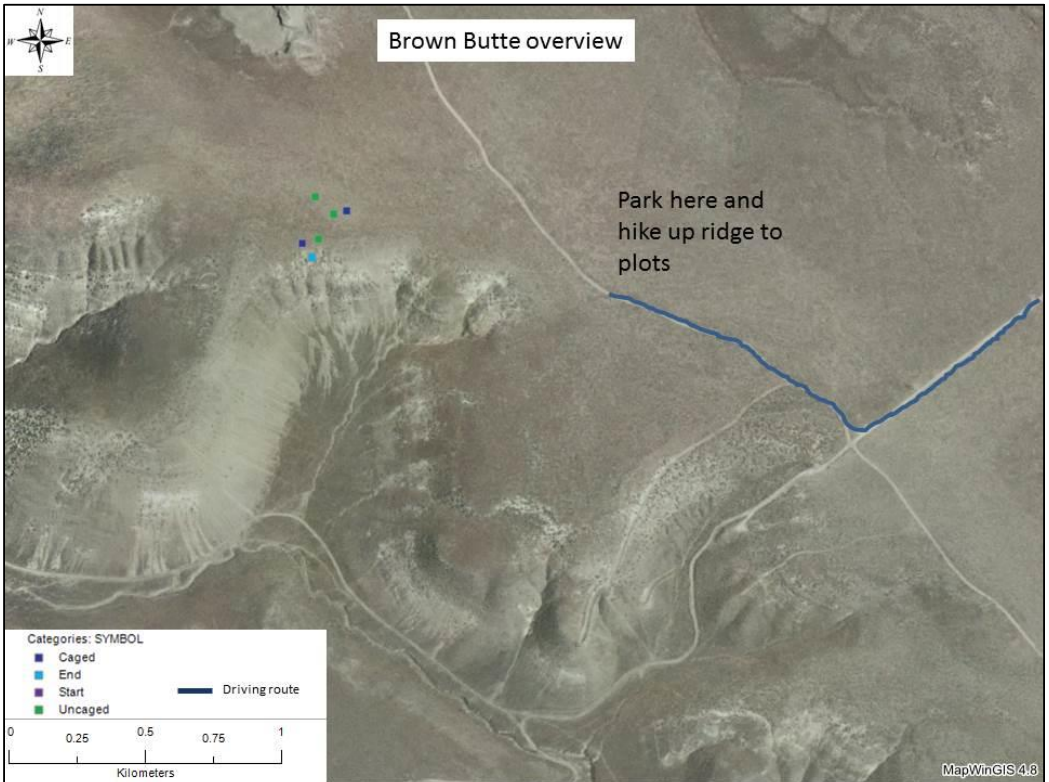
APPENDIX FIGURE 11. DOUBLE MOUNTAIN OVERVIEW (TOP) AND PLOT LOCATIONS (BOTTOM).



APPENDIX FIGURE 12. BROWN BUTTE SITE AND DRIVING ROUTE.

Brown Butte/Blackjack Field Site (Adrian quad)

Follow Lytle BLVD south out of Vale towards Adrian (about 13.8 miles). Take a sharp left on Janeta Ave, a sharp right on Jefferson Ave, and another sharp left on Owyhee Ave. Follow briefly (little over a mile) and then take a right onto HWY 201. Turn right onto Mendiola Road and reset odometer. At 1.2, turn left onto Clover Lane (will see stand of trees); where pavement ends (1.7), turn left on far side of irrigation ditch; cross canal and make a hard right turn (onto Road E). At 2.1 bear right, drive along base of butte, next to canal; cross over cattle guard at 2.6, make a right turn at intersection with power lines (~3.2) and follow road until you can park and hike uphill to plots (use GPS).



APPENDIX FIGURE 13. BROWN BUTTE OVERVIEW (TOP) AND PLOT LOCATIONS (BOTTOM).

Written directions

Last updated 8/16 MP + SC

DO NOT assume directions, especially mileages, are precise. You can use the Google maps (above) and a compass to ensure you are always basically going in the right direction. Leave all gates as you find them (open or closed)!

To Bully Creek Reservoir (camping)
From Vale → take Graham west for ~5.7 miles. Turn right (north) onto Bully Creek Road and travel for 3.7 miles to campground and reservoir. 2475 Bully Creek Road, (541) 473-2969, cash or check only.

South Alkali Field Site (Henry Gulch quad) - NOTE: While in the past we have completed this as a circuit, there looked like there was a washout in 2013. After South Alkali 3, it is safer to backtrack rather than making a circle.

From the BLM office, turn right onto Hwy 26/12th St/Glenn St. N and then left onto Hope St. E/Railroad Avenue E. After two blocks turn left onto 10th St. After one block, 10th curves to the right and turns into Lagoon Dr. Lagoon parallels railroad tracks until it dead ends, go left (north) onto Foothill Dr. At intersection, Foothill turns right, stay straight, road changes to Vale View Rd---RESET your odometer. After 0.5 miles Vale View will turn to the left (west)—don't do this. At this turn in the road, there will be a gravel road with a stop sign (may look like a driveway) → take this road. Go past Netcher Ln (on your right after ~0.1) and continue on this road (Right at the Y-intersection at 0.9) to a total of 1.2 miles where you will see a large gate with two tall rock columns. Go through this gate!

Follow the road to the right along the dyke and go through a gate that has two rock columns. Reset odometer—you are about to begin a 9 mile circuit of the ridge in front of you, following around the edge of the watershed/basin to your right. Reference a topo and/or aerial map of the area if you need help navigating. Continue on this road to the left (by Jordan Water Hole). The road goes up into the hills, along a ridge, with the valley on your right. At 0.4 → stay right. Stay Right at 1 mile. At 3.3 park at S. Alkali 1. At 4.7 go through gate and turn right. At 5.2 pass through a green gate. At 5.4 park at S. Alkali 2. At 6.2 park at S. Alkali 3. When finished, turn around and go back the way you came. [OLD DIRECTIONS TO COMPLETE CIRCUIT: At 9.2 go through gate (this gate was on your right when you first started the loop). At 9.25 pass thorough gate with two rock columns—you have completed a 9.25 mile circuit along the ridge line.]

Double Mountain Field Site (Double Mountain quad)

From the BLM office, turn right out of the BLM visitor's parking lot. Turn left onto 14th street. Turn right onto Hope Street. Turn left onto 17th street. Turn right onto Washington (20W). Take 20W past Vale. Turn left onto Russell Rd. Go 2 miles and turn left onto Dry Creek. 2.2 stay right, 2.6 stay left through gate, and 2.7 stay right. 4.6 cattle-guard, 6.5 and 6.9 cattle-guard. Park at 8.6 and hike uphill on the right to reach the site.

Brown Butte/Blackjack Field Site (Adrian quad)

Follow Lytle BLVD south out of Vale towards Adrian (about 13.8 miles). Take a sharp left on Janeta Ave, a sharp right on Jefferson Ave, and another sharp left on Owyhee Ave. Follow briefly (little over a mile) and then take a right onto HWY 201. Turn right onto Mendiola Road and reset odometer. At 1.2, turn left onto Clover Lane (will see stand of trees); where pavement ends (1.7), turn left on far side of irrigation ditch; cross canal and make a hard right turn (onto Road E). At 2.1 bear right, drive along base of butte, next to canal; cross over cattle guard at 2.6, make a right turn at intersection with power lines (~3.2) and follow road until you can park and hike uphill to plots (use GPS).

North Harper (North and South) (Mitchell Butte quad) ** **Do S first, then continue up road to N****
<u>-From Cow Hollow** [USE THESE]</u>
From Vale, take 20 west. Turn left onto Russell Rd ~4miles out of town. Turn left onto Dry Creek/Twin Spring (Cow Hollow) → reset odometer. R at 0.1, after 4.5mi, turn left onto 2 track. At 5.2 stay straight and beware of large washout on right. At 5.7 go past cattle station (road goes through big thicket of Russian thistle, kind of invisible). Go through the gate on left (6.1) and continue to drive along the road. In 2015 the road was full of thistle! Follow the road to the left and up into the hills (along a drainage)—this has become increasingly hairy since 2012. This road will take you directly to the site-Park at 6.9. Stay on the road, continuing up the hill. For North Harper North, at the T in the road, go left and park ~7.3. ASMU is in the road. ****NOTE: In 2015, the road is getting increasingly sketchy/sandy from the cattle area to NHS → park below where it is flat and hike into both sites [bring plenty of food/water].**

<u>-From Lytle Blvd. (**Use only as backup- Follow Cow Hollow directions**)</u>
Turn right onto dirt road (if coming from Vale) that cuts to northwest and goes behind ridge paralleling road. If you pass the dump, you went too far. Keep on dirt road for ~2.5 miles (always going ±NW) until you come to a triangle junction, turn left (towards water tower). Road runs ~SW for 0.9 miles before turning WNW (near the water tower). Drive 1.5 miles (total from last triangle junction), go through fence and turn left (south). Road will follow fenceline for ~1.25 miles until it reaches another triangle junction, take right fork, which will spit you out going west on new road after 1.35 total miles from last junction. After 0.1 miles, take left fork. In 0.3 miles you will reach another fork (with a large patch of *Oenothera cespitosa*). Go left and park at top of hill to walk down and sample N. Harper South, go right, drive 0.4 miles west, and park to sample N. Harper North. Follow USGS 7.5" topo carefully. Not necessary.

Snively Field Site (Owyhee Dam site)

From Vale: Follow Lytle BLVD south out of Vale towards Adrian. Take a sharp left on Janeta Ave, a sharp right on Jefferson Ave, and turn right onto Owyhee Avenue. Turn left onto Owyhee Lake Road. Follow past Snively Hot Springs, field site is across the road from a pull-out with cottonwoods.

SC 8/16: There is a shortcut between BB and Snively. Leaving BB, get back on Clover Ave. Pass Mendiola and Clover becomes Locust. Follow until it T's at Overstreet. Turn left on Overstreet. Follow until it T's on Owyhee Lake Rd, after crossing the Owyhee River. Turn left on Owyhee Lake Rd. Follow along river, pass Snively Hot Spring and keep an eye on the left hand side for a big pull-out. If you have access to google maps it will show up at Snively Gulch Rd. From the Owyhee River crossing to the pullout is ~4.6 miles.

APPENDIX B: HERBIVORY PLOT STATUS

APPENDIX TABLE 2. HERBIVORY PLOT STATUS. "Y" INDICATES YES.

Site	Trt	Plot #	New in 2012	Empty in 2013	Empty in 2014	Empty in 2015	Empty in 2016	Empty in 2017	Empty in 2018	Empty in 2019
Brown Butte	caged	86	y							
	caged	88	y							
	caged	538		y	y	y	y	y	y	y
	caged	541		y	y	y	y			
	caged	543		y	y	y	y	y	y	y
	caged	545		y	y	y	y	y	y	y
	uncaged	87	y		y	y				
	uncaged	537								
	uncaged	540								
	uncaged	544								
	uncaged	546								
Double Mountain	caged	269	y	y	y					
	caged	270	y					y	y	y
	caged	679								
	caged	680		y	y	y	y	y	y	y
	caged	683		y	y	y	y			
	uncaged	268	y		y	y	y	y	y	y
	uncaged	272	y	y	y	y	y	y	y	y
	uncaged	678								
North Harper North	caged	528		y	y	y	y	y	y	y
	caged	530		y	y	y	y	y	y	y
	caged	532			y	y	y			y
	caged	534								
	caged	79	y							
	uncaged	78	y		y	y				y
	uncaged	527			y	y	y			
North Harper	uncaged	529			y					
	uncaged	533			y	y	y			y

Site	Trt	Plot #	New in 2012	Empty in 2013	Empty in 2014	Empty in 2015	Empty in 2016	Empty in 2017	Empty in 2018	Empty in 2019
North (cont.)	uncaged	535								y
North Harper South	caged	73		y		y				
	caged	667			y	y	y	y		
	caged	669			y	y				y
	caged	670								
	caged	672	y			y	y	not monitored		y
	caged	74		y						
	uncaged	75		y						
	uncaged	76/576		y		y	y	y		y
	uncaged	666								
	uncaged	671				y				
	uncaged	674				y	y			
	uncaged	675	y			y	y			
Snively	caged	69		y					y	y
	caged	71		y			y	y	y	y
	caged	72		y						
	caged	547			y	y	y	y	y	y
	caged	553								
	uncaged	70		y					y	
	uncaged	550						y	y	y
	uncaged	552						y		
	uncaged	554				y	y	y	y	
South Alkali 1	caged	646								
	caged	649								
	caged	650								
	uncaged	647								
	uncaged	648						y	y	y
	uncaged	651								

Site	Trt	Plot #	New in 2012	Empty in 2013	Empty in 2014	Empty in 2015	Empty in 2016	Empty in 2017	Empty in 2018	Empty in 2019
South Alkali 2	caged	80		y						y
	caged	83		y					y	y
	caged	652								
	uncaged	81		y						
	uncaged	655	y		y					
	uncaged	82		y						
	uncaged	84		y				y	y	y
South Alkali 3	caged	659								
	caged	660			y	y				
	caged	663								
	caged	665			y	y			y	y
	uncaged	85		y						
	uncaged	658				y		y	y	
	uncaged	662				y				
	uncaged	664							y	y

APPENDIX C. VASCULAR PLANT SPECIES COVER 2019

APPENDIX TABLE 3. MEAN PERCENT COVER (± 95% C.I.) FOR ALL VASCULAR PLANT SPECIES RECORDED AT FIVE TRANSECTS IN 2019. PLANTS ARE ORGANIZED BY GROWTH HABIT AND NATIVE STATUS (I = NON-NATIVE, N = NATIVE).

Code	Current classification	Common name	Habit	Nativity	Brown Butte	Double Mountain	North Harper	Snively	South Alkali
ALYDES	*Alyssum desertorum*	desert madwort	F	I					0.5 (0)
AMSTES	*Amsinckia tessellata*	bristly fiddleneck	F	N	0.2 (0.3)				
ASTMUL	*Astragalus mulfordiae*	Mulford's milkvetch	F	N	0.3 (0.3)	0.2 (0.3)	0.3 (0.4)	0.6 (0.5)	5.0 (2.9)
BALSAG	*Balsamorhiza sagittata*	arrowleaf balsamroot	F	N	0.4 (0.7)	1.7 (1.8)	10.8 (5.8)	1.3 (1.7)	1.5 (1.8)
CHADOU	*Chaenactis douglasii*	Douglas' dustymaiden	F	N					0.03 (0.05)
CHAMAC	*Chamaesyce maculata*	spotted sandmat	F	N	0.3 (0.1)			0.2 (0.1)	0.2 (0.1)
COMUMB	*Comandra umbellata*	bastard toadflax	F	N	0.5 (0.5)				
CREPIS	*Crepis* sp.	hawksbeard sp.	F	NA			0.6 (0.5)		1.5 (1.2)
CRYPTANTHA	*Cryptantha* sp.	borage	F	NA	0.2 (0.3)				
DESPIN	*Descurainia pinnata*	western tansymustard	F	N		0.5 (0)		0.1 (0.1)	
EPIBRA	*Epilobium brachycarpum*	tall willowherb	F	N			0.1 (0.1)	0.03 (0.05)	
EPILO	*Epilobium* sp.	willowherb	F	NA					0.2 (0.1)
ERIPUM	*Erigeron pumilus*	shaggy fleabane	F	N					0.8 (0.6)
ERIOGO-PER	*Eriogonum* sp. (perennial)	buckwheat	F	NA				2.3 (3.7)	
EROCIC	*Erodium cicutarium*	redstem stork's bill	F	I	1.8 (0.8)				0.1 (0.1)
FRIPUD	*Fritillaria pudica*	yellowbells	F	N				0.2 (0.1)	
GLYMAR	*Glyptopleura marginata*	carveseed	F	N	0.03 (0.05)				
LACSER	*Lactuca serriola*	prickly lettuce	F	I	0.03 (0.05)	0.3 (0.1)			0.03 (0.05)
MACCAN	*Machaeranthera canescens*	hoary tansyaster	F	N			0.03 (0.05)	0.1 (0.1)	0.3 (0.3)
NAMARE	*Nama aretioides*	ground nama	F	N		0.1 (0.1)			
OENPAL	*Oenothera pallida*	pale evening primrose	F	N			0.2 (0.3)		0.9 (0.8)
OPUPOL	*Opuntia polyacantha*	plains prickly pear	F	N			0.4 (0.7)		
PENACU	*Penstemon acuminatus*	sharplead penstemon	F	N			0.03 (0.05)		1.0 (0.9)
PHAHET	*Phacelia heterophylla*	varileaf phacelia	F	N				0.1 (0.1)	1.4 (1.7)
PHALIN	*Phacelia linearis*	threadleaf phacelia	F	N			1.9 (0.6)	0.2 (0.1)	0.03 (0.05)
SISALT	*Sisymbrium altissimum*	tall tumblemustard	F	I	0.4 (0.3)		0.4 (0.1)	0.1 (0.1)	
SPHGRO	*Sphaeralcea grossulariifolia*	gooseberryleaf globemallow	F	N	0.3 (0.3)				

Code	Current classification	Common name	Habit	Nativity	Brown Butte	Double Mountain	North Harper	Snively	South Alkali
TOXPAN	*Toxicoscordion paniculatum*	foothill deathcamas	F	N					0.03 (0.05)
TRADUB	*Tragopogon dubius*	yellow salsify	F	I			0.03 (0.05)		
UNKAST	unknown milky Asteraceae		F	NA		0.03 (0.05)			
ZIGVEN	*Zigadenus venenosus*	death camas	F	N				0.03 (0.05)	
ACHHYM	*Achnatherum hymenoides*	Indian ricegrass	G	N	1.0 (0.9)		0.3 (0.3)	0.03 (0.05)	
ACHTHU	*Achnatherum thurberianum*	Thurber's ricegrass	G	N		8.1 (4.2)			
BROTEC	*Bromus tectorum*	cheatgrass	G	I	9.1 (4.0)	7.5 (5.0)	3.2 (1.5)	8.1 (1.9)	1.1 (0.5)
ELYELYE	*Elymus elymoides* ssp. *elymoides*	squirreltail	G	N	0.03 (0.05)	0.7 (0.5)	0.1 (0.1)		1.6 (0.7)
HESCOMC	*Hesperostipa comata* ssp. *comata*	needle-and-thread grass	G	N	2.9 (2.4)	0.03 (0.05)	2.6 (0.9)	4.1 (1.7)	
PASSMI	*Pascopyrum smithii*	western wheatgrass	G	N			0.1 (0.1)	0.1 (0.1)	0.3 (0.3)
POABUL	*Poa bulbosa*	bulbous bluegrass	G	I			0.2 (0.3)	0.2 (0.1)	
POASEC	*Poa secunda*	Sandberg bluegrass	G	N	0.5 (0.5)		4.1 (2.4)	0.1 (0.07)	6.0 (2.0)
UNKGRA	unknown grass		G	NA	0.5 (0.5)				
UNK 3	Unknown Caryophyllaceae		NA	NA					0.2 (0.1)
UNK 5	unknown		NA	NA				0.03 (0.05)	0.1 (0.09)
VULPIA	*Vulpia* sp.	fescue	G	NA			1.1 (0.6)		0.03 (0.05)
ATRCON	*Atriplex confertifolia*	shadscale saltbush	S	N			0.03 (0.05)		
CHRVIS	*Chrysothamnus viscidiflorus*	green rabbitbrush	S	N	1.6 (1.9)	13.7 (6.1)	10.0 (5.1)	8.9 (5.2)	4.8 (5.0)
GRASPI	*Grayia spinosa*	spiny hopsage	S	N	0.8 (1.0)				
LINPUN	*Linanthus pungens*	granite prickly-phlox	S	N			0.6 (0.5)	0.03 (0.05)	

APPENDIX D. STATISTICAL TESTING OUTPUT

APPENDIX TABLE 4. TWO-FACTOR ANALYSIS OF VARIANCE (ANOVA) FOR THE MEAN DIAMETER (CM) OF A. MULFORDIAE IN 2019 ONLY, BY TREATMENT (CAGED/UNCAGED) AND SITE. DATA WERE TESTED WITH NORTH HARPER AND SOUTH ALKALI SUBSITES CLUMPED (SITE DF = 4).

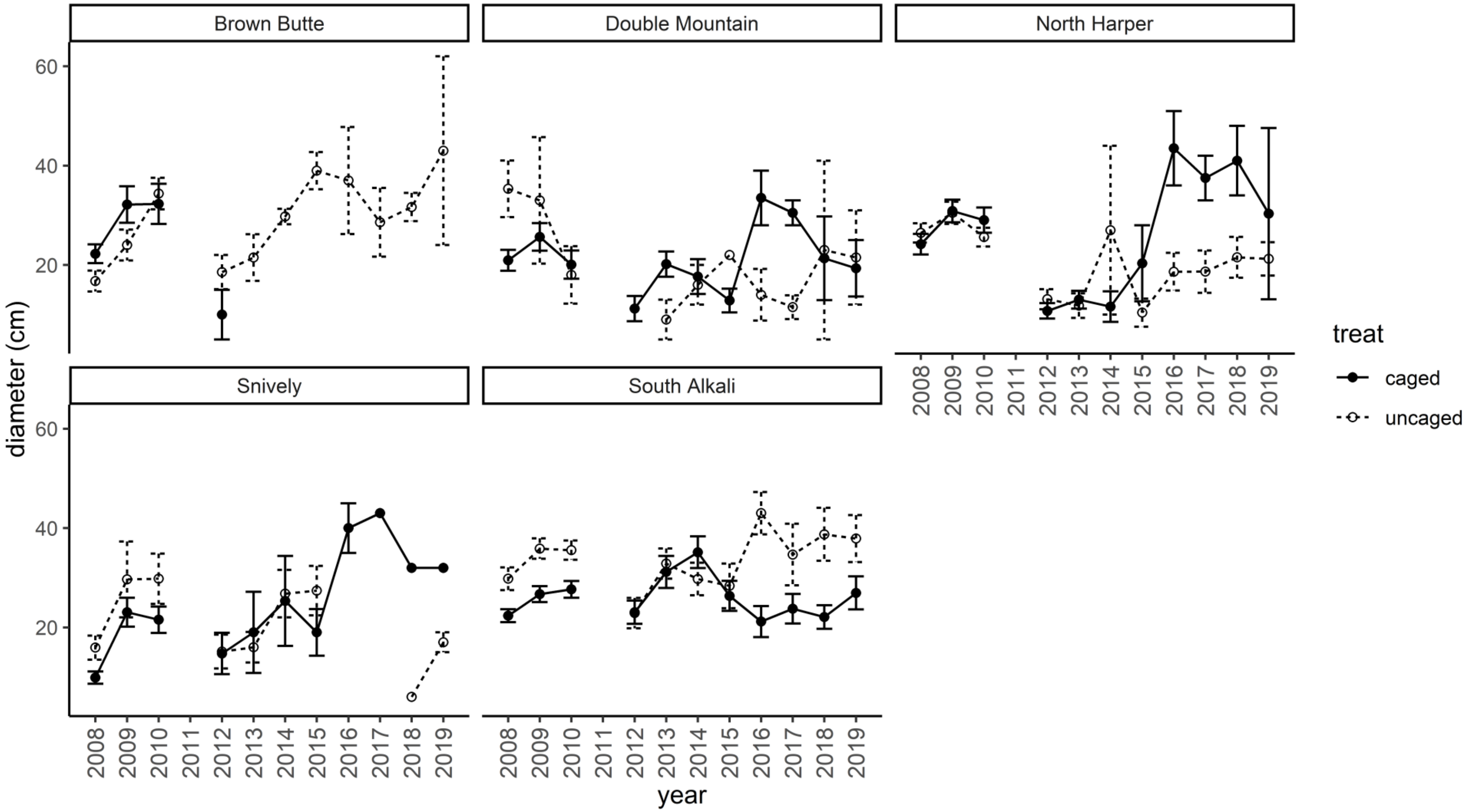
	Df	**SS**	**F value**	***P* value**
Treatment	1	215	1.1	0.288
Site	4	3794	5.0	**0.0009** ***
Treatment*Site	4	2293	3.0	**0.021** *
Residuals	109	20627		

APPENDIX TABLE 5. GENERALIZED LINEAR MODEL (GLM) RESULTS FOR NUMBER OF FRUITS PER REPRODUCTIVE PLANT IN 2019, BY PREDICTOR VARIABLES TREATMENT (CAGED/UNCAGED) AND SITE.

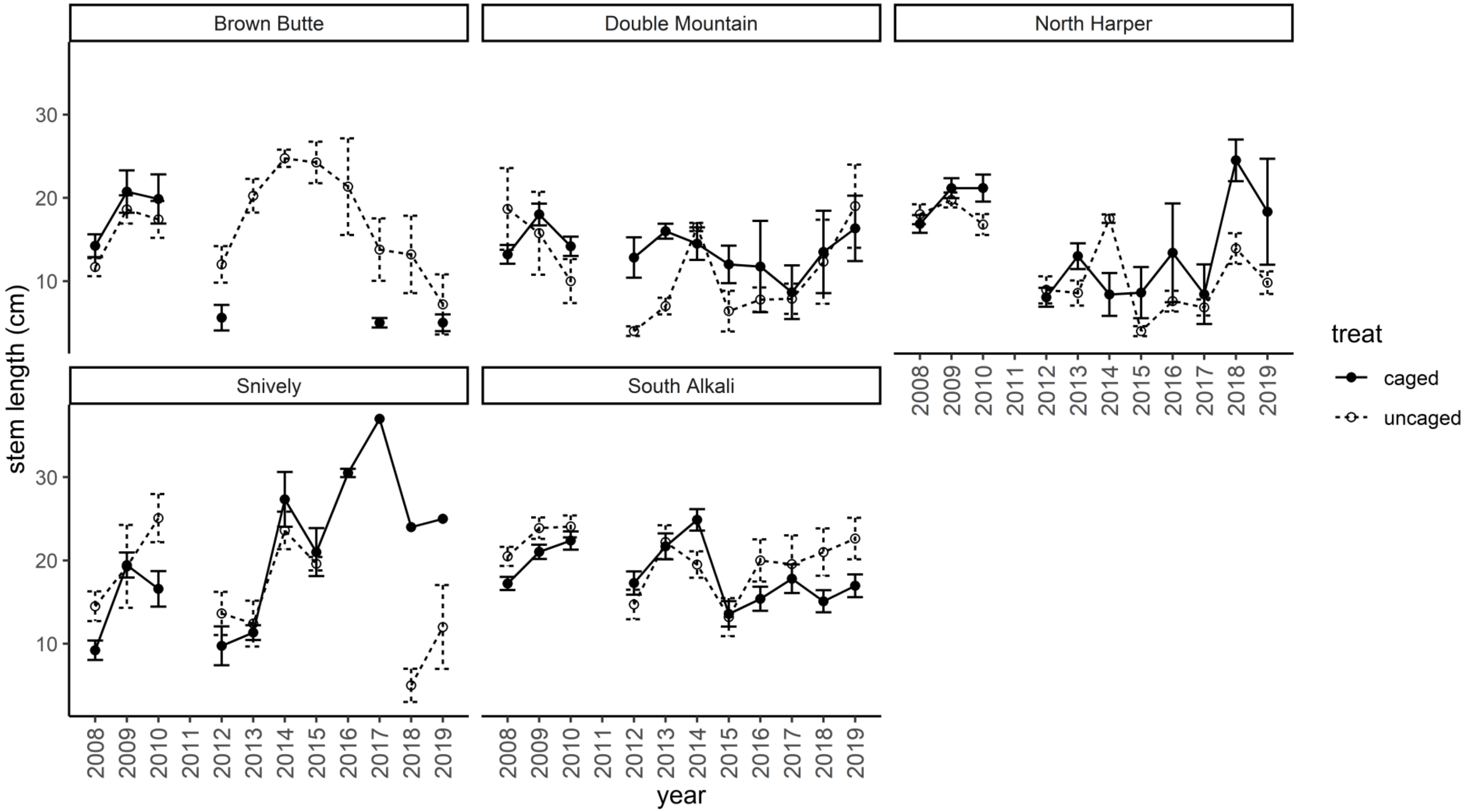
Coefficients:	Estimate	Std. Error	t value	P value
(Intercept)	3.4012	1.4374	2.366	**0.0167** *
Double Mountain	-0.3472	1.7988	-0.193	0.8438
North Harper	1.6857	1.4954	1.127	0.2446
Snively	1.1666	1.7100	0.682	0.4865
South Alkali	0.9084	1.4892	0.610	0.5338
uncaged	-0.8688	1.9257	-0.451	0.6452
Double Mountain: uncaged	1.0920	3.0913	0.353	0.7185
North Harper: uncaged	-0.9055	2.0028	-0.452	0.9932
Snively: uncaged	-2.7647	3.5832	-0.755	0.4416
South Alkali: uncaged	1.8701	1.9347	0.945	0.3353

Dispersion parameter for quasipoisson family taken to be 247.9427
Null deviance: 26877 on 163 degrees of freedom
Residual deviance: 17239 on 154 degrees of freedom

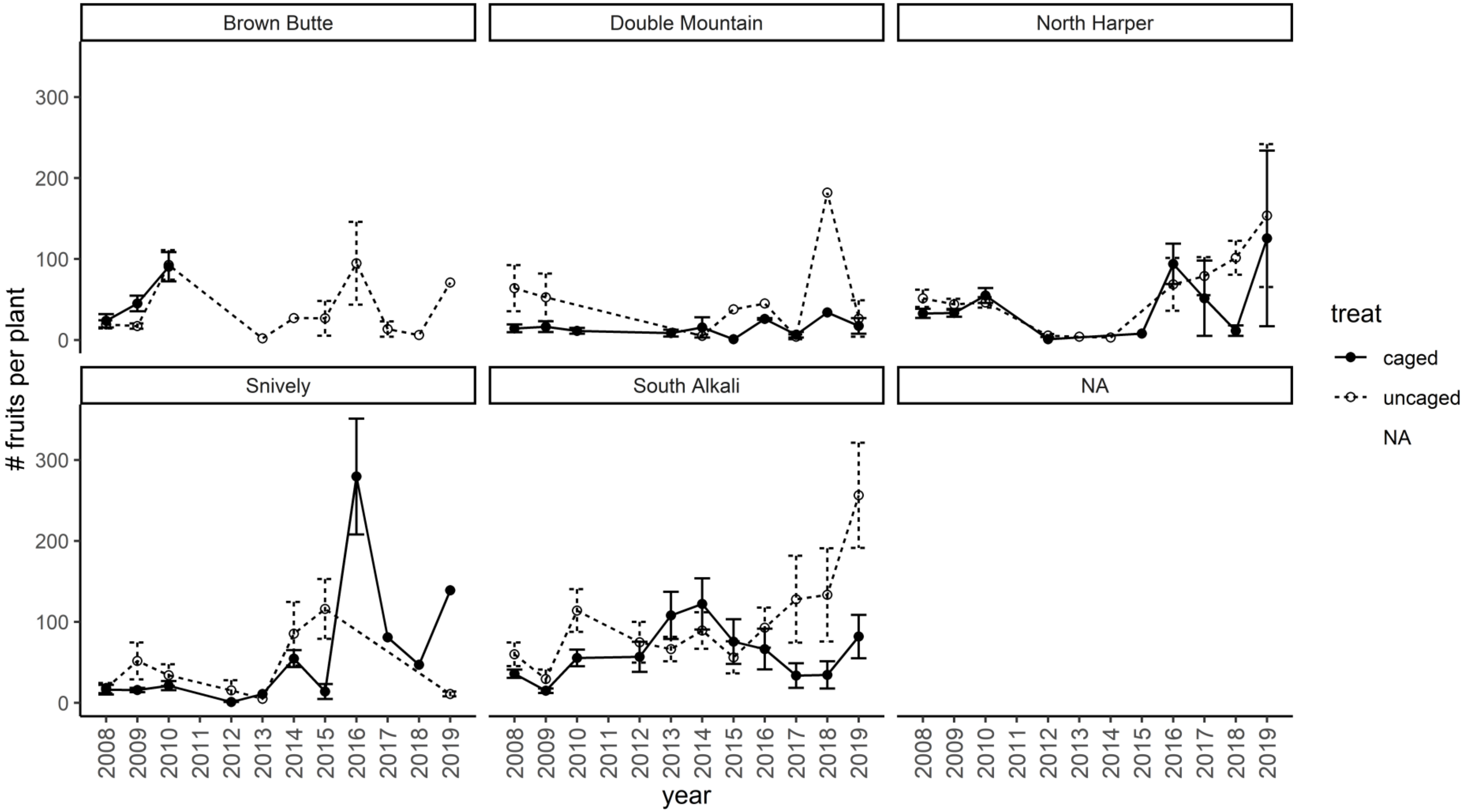
APPENDIX E. SUPPLEMENTAL FIGURES



APPENDIX FIGURE 14. AVERAGE DIAMETER FOR PLANTS > 5 CM DIAMETER IN CONTINUOUS PLOTS FROM 2008 TO 2019. SOLID LINES REPRESENT CAGED PLOTS, WHILE DASHED LINES REPRESENT UNCAGED PLOTS. ERROR BARS REPRESENT 1 STANDARD ERROR. POINTS WITH NO ERROR BARS HAVE ONLY A SINGLE OBSERVATION.



APPENDIX FIGURE 15. AVERAGE LONGEST STEM LENGTH FOR PLANTS IN CONTINUOUS PLOTS FROM 2008 TO 2019. SOLID LINES REPRESENT CAGED PLOTS, WHILE DASHED LINES REPRESENT UNCAGED PLOTS. ERROR BARS ARE 1 STANDARD ERROR. POINTS WITH NO ERROR BARS HAVE ONLY A SINGLE OBSERVATION IN THE YEAR SAMPLED.



APPENDIX FIGURE 16. AVERAGE NUMBER OF FRUITS PER REPRODUCTIVE PLANT IN CONTINUOUS PLOTS FROM 2008 TO 2019. SOLID LINES REPRESENT CAGED PLOTS, WHILE DASHED LINES REPRESENT UNCAGED PLOTS. ERROR BARS ARE 1 STANDARD ERROR. POINTS WITHOUT ERROR BARS HAVE ONLY ONE OBSERVATION.