Astragalus mulfordiae: Population dynamics and the effect of cattle grazing in the Vale District, BLM

2018

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

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PREFACE

This project was coordinated by the Institute for Applied Ecology (IAE) and is funded by the Bureau of Land Management. 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 photograph: Mulford's milkvetch (*Astragalus mulfordiae*) habitat and monitoring plots at North Harper North, 2018.

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EXECUTIVE SUMMARY

This document summarizes the monitoring of *Astragalus mulfordiae* (Mulford's milkvetch) on land managed by the BLM Vale District. In 2018, we revisited permanent plots testing for the effects of herbivory on *A. mulfordiae,* along with permanent transects looking at long-term population trends and plant community composition in *A. mulfordiae* habitat.

- In 2018 we observed a decrease in number of *A. mulfordiae*. We counted a total of 103 plants, 49 in caged plots and 54 in uncaged plots, compared to 242 found in 2017. Only nine new plants were observed. Despite there being over a two-fold increase from 2014 to 2017, the total number of plants remained at about one third of the numbers observed in 2008-2010.
- Thirty-two plots that were originally established in high densities of *A. mulfordiae* no longer contained the species, almost doubling the number of empty plots found in 2017. No previously-empty plots were re-populated.
- We found that the size (diameter) of *A. mulfordiae* plants differed by treatment at Snively and South Alkali in 2018, but when averaged across all observed plants, neither treatment nor site was associated with a significant difference in plant size.
- Reproductive effort was variable across sites, with Brown Butte, North Harper North, and Snively having the fewest reproductive plants (three, two, and two, respectively) and South Alkali having the most (21). North Harper South had the highest average number of fruits per reproductive plant (39), but there was no significant difference between sites or treatments.
- Focusing on plots established in 2008, we observed a decrease in total number of plants from 2017 to 2018. Due to seedling die-off, the increase in *A. mulfordiae* observed in 2017 did not lead to significant population growth in 2018. The long-term decreasing trend in population size exhibited from 2008-2014 across all plots and sites appeared to resume in 2018.
- Along population monitoring transects, the number of *A. mulfordiae* decreased from 134 to 46 in 2018. Despite a pulse of seedlings in 2017, the total number of plants still lies far below that observed in 2010 (178 plants total), mirroring observations from the herbivory plots.
- In 2018, 65% of plants observed along transects were reproductive, an increase from 2017 (19% reproductive). Seedlings accounted for 28%, similar to levels observed in 2016, prior to the 2017 increase.
- Plant communities at these sites have varied from 2010 to 2018 with a general trend of increasing exotic species cover, primarily due to the presence of *Bromus tectorum* (cheatgrass). In 2018, however, only Brown Butte and Snively were dominated by exotic species.
- We found little evidence that cattle grazing has had consistent effects on the populations of *A. mulfordiae* at these sites.
- Continued monitoring and immediate attention may be necessary to mitigate any future losses of this rare species.

Astragalus mulfordiae: Population dynamics and the effect of cattle grazing in the Vale District, BLM

REPORT TO THE USDI, BUREAU OF LAND MANAGEMENT, VALE DISTRICT

INTRODUCTION

Astragalus mulfordiae (Fabaceae, Mulford's milkvetch; Figure 1) is listed as a Sensitive Plant Species by the USDI Bureau of Land Management, 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* provide evidence for 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 exotic plant species, particularly *A. desertorum*, *Chondrilla juncea* (rush skeletonweed), 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.

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 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 years of sequential 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, six *A. mulfordiae* populations were chosen for plot establishment: Brown Butte, Double Mountain, North Harper North, North Harper South, South Alkali ACEC, and Snively (Table 1, Appendix B).

Table 1. Site characteristics including total # of plots present in 2018.

Site (location of GPS pt)	Location (Nad83, Zone11)	Fire history	Grazing	# plots
South Alkali #1 (plot 648)	0484252E 4878746N	unknown	fall cattle grazing	3 caged 3 uncaged
South Alkali #2 (plot 653)	0486054E 4878989N	unknown	fall cattle grazing	3 caged 4 uncaged
South Alkali #3 (transect start)	0485982E 4877837N	unknown	fall cattle grazing	4 caged 4 uncaged
Brown Butte (transect start)	0489997E 4842103N	Fire: late 90's	summer cattle grazing	6 caged 5 uncaged
Snively (transect start)	0484372E 4840786N	unknown	spring cattle grazing	5 caged 4 uncaged
Double Mountain (transect start)	0476635E 4853382N	Fire: 2005	not grazed	5 caged 3 uncaged
North Harper North (transect start)	0481055E 4857204N	unknown	summer cattle grazing	5 caged 5 uncaged
North Harper South (plot 675)	0481446E 4856682N	unknown	summer cattle grazing	6 caged 6 uncaged

Herbivory Study

FIGURE 2. *ASTRAGALUS MULFORDIAE* CONTROL (UNCAGED) MONITORING PLOT. CORNERS ARE MARKED WITH 10" NAILS.

In 2008, we established 10-15 plots at each study site to determine the effect of ungulates (primarily sheep and cattle) on *A. mulfordiae* and to track individual plants over time (Table 1). Plot locations were systematically selected to maximize the number of individuals within a 1m^2 area. Half of the plots were uncaged (Figure 2), the other half were caged. 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 to data 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 0.3 m 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 2012-2018.

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 2). 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 C).

Within each monitoring plot, we mapped all *A. mulfordiae* individuals using a grid system so that recruitment, mortality, and overall trends in the plants' growth can be ascertained over time (Appendix A). We also measured the maximum diameter (cm), length of longest stem (cm), number of fruits, and evidence of insect and large ungulate grazing (yes/no) 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).

Population and Community Monitoring

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. 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 3). A 1-m^2 quadrat frame was placed flush against the tape beginning at the 0-m 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 information to help relocate transects.

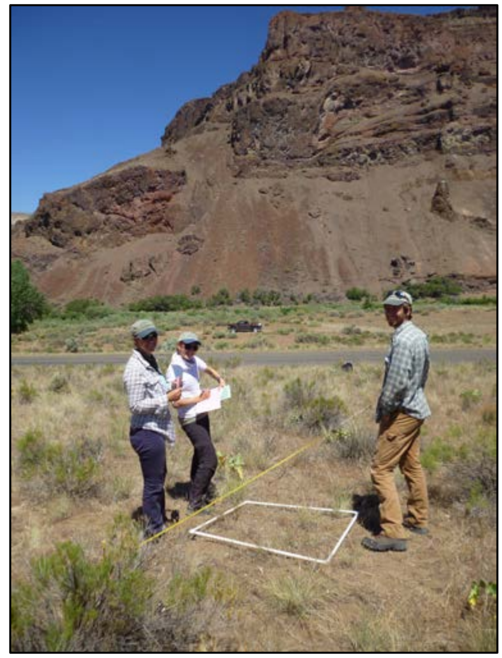

FIGURE 3. *ASTRAGALUS MULFORDIAE* POPULATION AND COMMUNITY MONITORING AT SNIVELY, 2013.

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

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

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

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

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 3 cm 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.

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 4). 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.

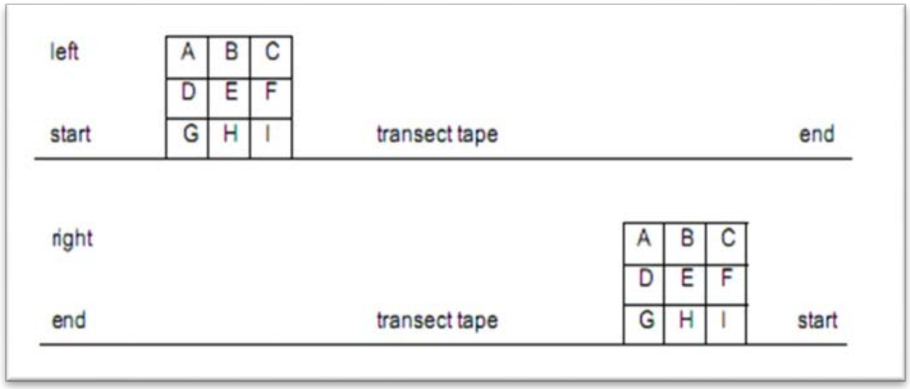

FIGURE 4. TRANSECT DESIGN FOR *A. MULFORDIAE* POPULATION AND COMMUNITY MONITORING.

The cover of each native and exotic plant species (shrubs, graminoids, and forbs) rooted 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 (Table 3). 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 3 m behind the origin rebar looking towards the end spike, and a sixth photo standing 3 m 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).

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 3.4.2 (R Core Team 2017).

TABLE 3. COVER CLASSES USED WHEN MONITORING PLANT SPECIES, GROUND COVER, AND SURFACE DISTURBANCES IN *A. MULFORDIAE* PLOTS.

Cover class	Percent cover range (%)	Midpoint for conversion (%)
0	0	0.0
1	<1 (trace)	0.5
2	1-4.9	3.0
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	85.0
8	95-100	97.5

The effect of caging on plant performance (plant size and reproduction) was tested using data from 2018 (all plots). We used an ANOVA to test for the responses of size of *A. mulfordiae* (diameter), using site and treatment (caged vs. uncaged) as fixed factors for data from 2018. To test for the response of number of inflorescences (count data), we used a general linear model with a quasipoisson distribution, using site and treatment as predictors. We considered $p < 0.05$ to be significant.

We acquired grazing information from 2008-2013 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 correlated with number of plants in uncaged plots in 2010, 2012, and 2013 to explore the relationship between stocking rates and population dynamics.

Climate data at North Harper North (monthly precipitation (in) and monthly maximum temperature (°F)) from 2011- 2018, and normals for 1971-2000, were acquired from the PRISM climate group (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.

RESULTS AND DISCUSSION

Herbivory Study

2018 Demography

In 2018, a total of 103 *A. mulfordiae* plants were encountered in 71 experimental plots (37 caged plots and 34 uncaged); 49 plants were found in caged plots and 54 in uncaged. This was a substantial decrease from 2017 when 242 live plants were observed (78 in caged plots, 164 in uncaged). Despite the more than two-fold increase in plant numbers from 2014 to 2017, total number of plants this season fell back to levels observed in 2014 and remained far below observations from 2008 to 2010 (Table 4).

TABLE 4. LIVE PLANTS, MORTALITY, AND NUMBER OF NEW PLANTS FOUND FROM 2008 TO 2018, INCLUDING PLOTS ESTABLISHED IN BOTH 2008 AND 2012. THE 2008-2010 COLUMN REPRESENTS THE MEAN VALUE OF LIVE PLANTS FROM THOSE THREE YEARS.

	Year					
	2008-2010	2014	2015	2016	2017	2018
Live Plants	301	109	164	164	242	103
Total Mortality	--	34	26	62	55	140
New Plants	--	8	78	62	124	9

Mortality in 2018 was the highest on record, primarily due to the disappearance of many new plants that were observed in 2017. Plants died at all sites in both caged and uncaged plots, with the highest mortality at North Harper South (91 plants total, 76 in uncaged plots and 15 in caged; Table 5). The high mortality at North Harper South was consistent with observations from 2016 and 2017, suggesting active turnover at this site (seedling establishment and subsequent failure). Contrary to prior years, the total number of live plants in 2018 was less than total mortality (103 and 140, respectively), with only nine new plants observed. The total number of new plants found in 2018 was nearly equal to that in 2014, and much smaller than in 2015, 2016, and 2017. Double Mountain had the most new plants (three), all found in caged plots, while North Harper North had no new plants. Across all sites, four new plants were found in caged plots and five in uncaged.

TABLE 5. LIVE PLANTS, MORTALITY, AND NEW PLANT TOTALS FOR EACH SITE IN 2018, INCLUDING PLOTS ESTABLISHED IN BOTH 2008 AND 2012, SEPARATED BY TREATMENT.

	Brown Butte	Double Mountain	North Harper North	North Harper South	Snively	South Alkali
Live	7	16	3	26	7	39
Caged	1	13	2	5	3	25
Uncaged	6	3	1	21	4	19
Mortality	13	8	16	91	4	8
Caged	5	3	1	15	1	4
Uncaged	8	5	15	76	3	4
New	1	3	0	2	2	1
Caged	0	3	0	0	0	1
Uncaged	1	0	0	2	2	0

The total number of *A. mulfordiae* per plot ranged from zero to 10 across all sites in 2018. Thirty-two plots had no living *A. mulfordiae*, an increase from 18 found in 2017, and two of these were unoccupied for the first time in our monitoring effort. A total of seven plots were newly empty after containing living specimens in both 2016 and 2017, and no empty plots from prior years gained new plants.

We compared plant size (plants > 5 cm diameter) between caged and uncaged plots and found that in 2018, size differed significantly between treatments within sites (site X treatment interaction, two-way ANOVA, $F = 4.5$, $p = 0.001$). There was no evidence for a significant difference in plant size between treatments across all sites ($F = 0.4$, $p = 0.55$), or between sites ($F = 2.2$, $p = 0.066$) (Figure 5, Appendix E). Plants ranged from five to 59 cm in diameter in 2018, and no significant differences were present between years. The effect of caging on plant size was variable and no consistent pattern has emerged year to year. In 2018, plants were significantly larger in caged plots at Snively ($p = 0.012$), but significantly smaller in caged plots at South Alkali ($p = 0.042$) (Figure 5, Appendix E), highlighting the variability in size differences between treatments and across space. Significant differences discussed in previous reports included plants < 5 cm in diameter, skewing results with many seedlings towards the smaller end of the size spectrum. We have updated all historical size data to include only plants > 5 cm in diameter.

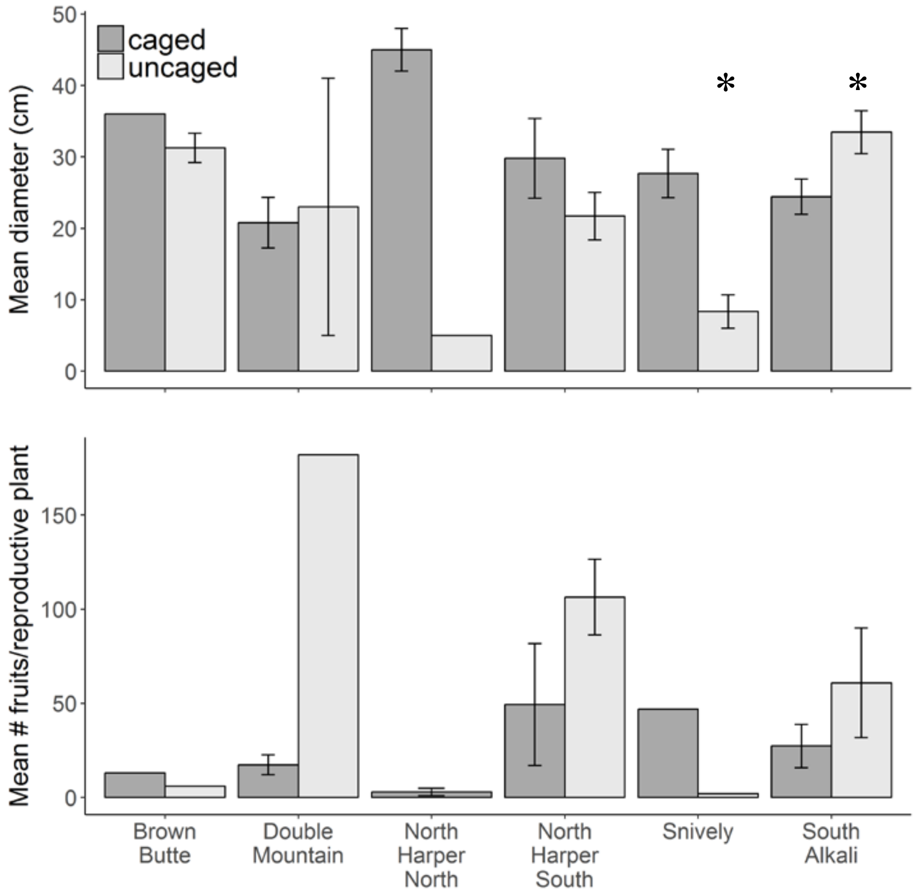

FIGURE 5. MEAN DIAMETER (TOP) AND MEAN NUMBER OF FRUITS PER REPRODUCTIVE *A. MULFORDIAE* PLANT (BOTTOM) IN CAGED AND UNCAGED PLOTS IN 2018 (PLOTS ESTABLISHED IN 2008 AND 2012). ERROR BARS ARE ± 1 S.E. AND ASTERISKS REPRESENT SIGNIFICANT DIFFERENCES (P < 0.05). MEANS WITHOUT ERROR BARS REPRESENT SAMPLES WITH N=1. NO UNCAGED REPRODUCTIVE INDIVIDUALS WERE OBSERVED AT NORTH HARPER NORTH.

Like plant size, the number of fruits per reproductive plant was variable across sites, with North Harper North and Brown Butte at the low end (ranging from zero to 20 fruits per plant) and Double Mountain at the high end (a single plant with > 150 fruits) (Figure 5). Neither treatment nor site showed correlation with the number of fruits per reproductive individual (quasipoisson GLM, $p > 0.3$, Appendix E). The proportion of live, reproductive plants was higher than observed in 2017 at three of our five sites, ranging from 28.6% at Snively to 66.7% at North Harper North (Table 6). The lower proportion of reproductive plants in 2017 was in part due to the high counts of non-reproductive seedlings, especially at North Harper.

TABLE 6. PROPORTION OF REPRODUCTIVE PLANTS BY SITE IN 2017 AND 2018 (INCLUDING ALL PLOTS).

Site	2017	2018
Brown Butte	35.0	42.9
Double Mountain	20.8	53.8
North Harper North	10.5	66.7
North Harper South	11.2	57.7
Snively	90.9	28.6
South Alkali	73.1	47.7
mean	*40.3*	*49.6*

Presence of insect herbivory varied greatly between years and between sites. In 2018, insect herbivory ranged from affecting 0% to 43% of plants at each site, with the most occurring at Snively and South Alkali. Insect herbivory rates were much lower than observed in 2017, but paralleled the patterns seen between sites; Snively had the highest proportion of grazed individuals, while the North Harper sites experienced little-to-no herbivory. Mammal herbivory was uncommon and documented at only three sites, Double Mountain (6.3% affected), North Harper South (3.9%), and South Alkali (4.6%) (Table 7).

TABLE 7. PROPORTION OF *A. MULFORDIAE* PLANTS WITH EVIDENCE OF HERBIVORY IN 2018 (INCLUDING ALL PLOTS).

Site	Insect	Mammal
Brown Butte	28.6	0
Double Mountain	12.5	6.3
North Harper North	0	0
North Harper South	23.1	3.8
Snively	42.9	0
South Alkali	34.1	4.5
mean	*23.5*	*2.4*

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 (Table 8). 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.

TABLE 8. GRAZING DATA FOR SITES 2008-2013, PROVIDED BY THE BLM.

			Stocking rate (# of cows*days/# acres)					
ASMU site	**Allotment**	**Season**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Brown Butte	Black Jack	summer	0.94	0.94	0.95	0.92	0.95	1.43
Double Mountain	Dry Creek		0.00	0.00	0.00	0.00	0.00	0.00
North Harper	North Harper	summer	0.79	0.33	1.00	0.92	0.73	0.43
Snively	Nyssa	spring	3.36	3.05	3.36	3.16	2.24	3.05
South Alkali 1-3	South Alkali	winter	5.86	6.73	6.95	6.73	6.08	6.81

Trends over time

This discussion is limited to data from plots established in 2008. The total number of *A. mulfordiae* in 2018 was lower than observed in recent years (2015-2017) and 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 South had the largest decrease in number of plants from the previous year, indicating the die-off of seedlings found in 2017 (Figure 6). Though each site shows some variability from year to year, this declining trend is consistent across all sites and is likely indicative of climate variability and potential threats from other disturbance such as invasion by exotic plant species.

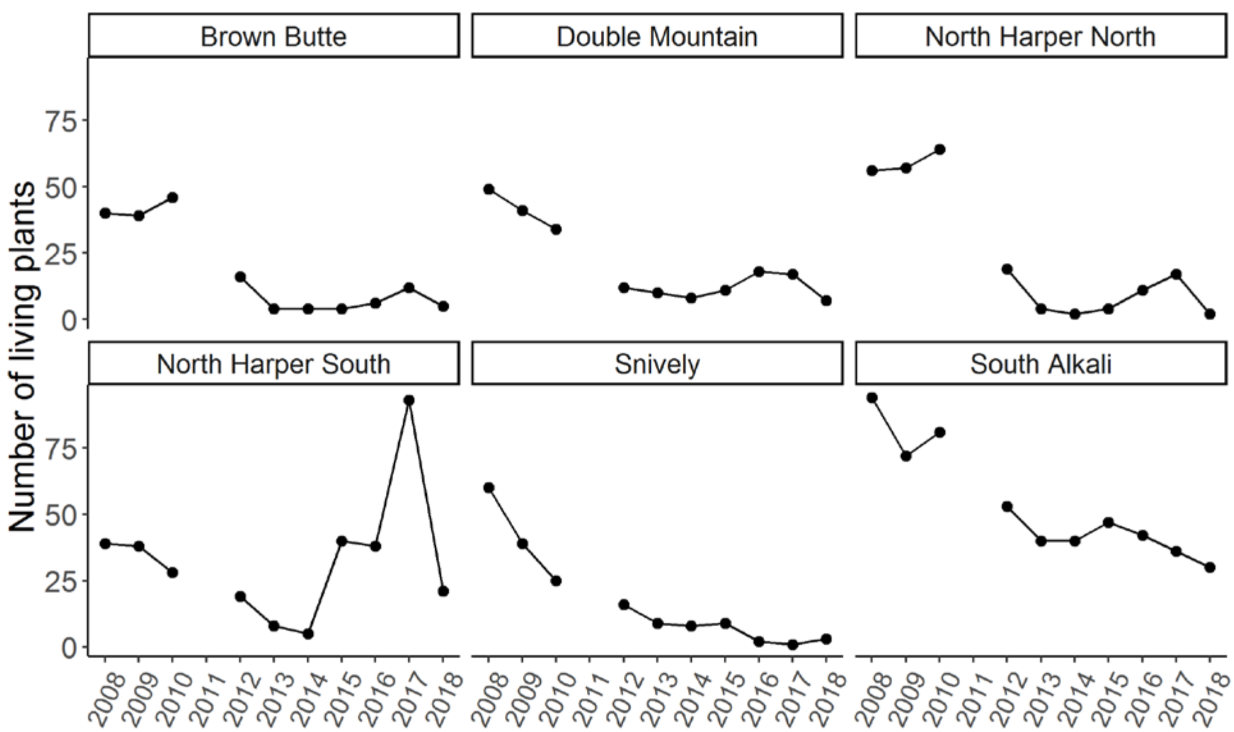

FIGURE 6. TOTAL *A. MULFORDIAE* IN MONITORING PLOTS FROM 2008 TO 2018 (PLOTS ESTABLISHED IN 2008 ONLY), SEPARATED BY SITE. PLANTS < 5 CM IN DIAMETER WERE INCLUDED IN THIS ANALYSIS, AND NO DATA WERE COLLECTED IN 2011.

TABLE 9. MEAN DIAMETER, MEAN NUMBER OF FRUITS PER REPRODUCTIVE PLANT, AND TOTAL NUMBER OF REPRODUCTIVE PLANTS IN CAGED (C) AND UNCAGED (U) STUDY PLOTS FROM 2010 TO 2018 (PLOTS ESTABLISHED IN 2008 ONLY).

Mean diameter (cm)

	2010		2012		2013		2014		2015		2016		2017		2018	
Site	C	U	C	U	C	U	C	U	C	U	C	U	C	U	C	U
Brown Butte	35.2	35.1	10.0	18.6	N/A	21.5	N/A	29.8	N/A	39.0	N/A	37.0	N/A	28.6	N/A	31.7
Double Mountain	18.7	16.2	11.2	6.5	20.2	9.0	17.7	16.0	12.8	22.0	33.5	14.0	30.5	11.5	21.3	23.0
N. Harper North	30.4	20.5	10.0	10.8	16.0	21.0	22.0	44.0	28.0	15.0	51.0	19.0	42.0	7.0	48.0	5.0
N. Harper South	27.7	33.4	11.2	14.7	12.0	9.5	9.0	10.0	16.5	9.3	36.0	15.9	13.2	16.5	34.0	20.1
Snively	22.9	29.8	14.8	15.1	19.0	16.0	25.3	26.8	19.0	27.4	40.0	N/A	43.0	N/A	32.0	6.0
South Alkali	27.2	33.8	23.1	22.9	31.2	32.9	35.1	29.8	26.3	28.4	21.2	43.0	23.8	34.7	22.1	38.8

Mean number of fruits per reproductive plant

	2010		2012		2013		2014		2015		2016		2017		2018	
Site	C	U	C	U	C	U	C	U	C	U	C	U	C	U	C	U
Brown Butte	23	19	N/A	N/A	N/A	2	N/A	27	N/A	27	N/A	95	N/A	14	N/A	1
Double Mountain	13	11	N/A	N/A	9	N/A	16	5	1	38	26	45	7	4	9	61
N. Harper North	21	15	N/A	N/A	N/A	4	N/A	3	N/A	N/A	69	222	5	1	5	0
N. Harper South	23	19	1	6	N/A	N/A	N/A	N/A	8	N/A	119	32	98	74	18	40
Snively	17	25	1	16	11	5	55	85	14	116	280	N/A	81	N/A	47	0
South Alkali	22	17	57	75	108	66	122	89	76	56	66	93	34	128	9	83

Total number of reproductive plants

	2010		2012		2013		2014		2015		2016		2017		2018	
Site	C	U	C	U	C	U	C	U	C	U	C	U	C	U	C	U
Brown Butte	21	24	0	0	0	1	0	1	0	4	0	4	0	2	1	2
Double Mountain	17	17	0	0	4	0	2	2	1	1	2	1	2	2	6	1
N. Harper North	36	28	0	0	0	1	0	1	0	0	1	1	1	1	2	0
N. Harper South	11	17	1	4	0	0	0	0	1	0	1	6	1	8	5	10
Snively	20	5	2	2	1	1	3	3	3	3	2	0	1	0	1	1
South Alkali	39	42	25	12	18	13	20	12	12	6	16	6	17	8	9	12

Plant size has not changed significantly over time, as earlier reports suggested (previous years included plants < 5 cm diameter in these analyses). At many sites plant size in both caged and uncaged plots increased slightly since 2012. In 2018, mean plant size across all sites was similar to that observed in 2010, but measurements and sample sizes have varied widely over time (Table 9).

In 2018, there were reproductive plants at all sites, and 50% of total plants were reproductive compared to 83.5% of plants in 2008, and 24% in 2017. The total number of reproductive plants was similar to observations from 2017, but was higher at all sites except South Alkali. Number of fruits per reproductive plant decreased across all sites except North Harper North (no change) and Double Mountain (increase from five to 31 fruits per plant). North Harper South had the highest mean number of fruits per reproductive plant (39 fruits/plant). Differences between caging treatments were not apparent for number of fruits per reproductive plant across all sites. These results were consistent with past comparisons indicating that the caging treatment does not yield consistent differences in plant size or reproductive ability of *A. mulfordiae* across sites.

While there tended to be some differences between size and reproductive effort between caged and uncaged plots across the years of this study, the lack of consistent trends suggests that other factors might have a greater effect on plant population dynamics than large mammal herbivory. The extreme variability experienced across all sites and years is in part an artifact of our limited sampling size, but is also likely related to variability in climate and site-specific factors such as invasive species presence. Annual population fluctuations have also been documented in other parts of *A. mulfordiae*'s range (Idaho Conservation Data Center 2008).

Maximum and minimum temperature have followed somewhat similar trends to long-term normals (1971-2000, PRISM climate group) over our study period, but maximum temperatures in 2015 and 2016 were greater than long-term normals across all seasons (Figure 7, top). In 2018, maximum temperatures were higher than long-term normals in winter, spring, and fall. Mean precipitation by season has varied greatly from 2010-2018. The winters of 2010 and 2011 were relatively wet in comparison to long-term normals, while 2012-2014 all had lower than normal precipitation (Figure 7, bottom). The winter of 2015 had precipitation levels similar to long-term normals, while the winters of 2016 and 2017 experienced precipitation levels higher than long-term normals, and the winter of 2018 experienced only half the amount of the long-term normal. While the climate monitoring site experienced a wet spring in 2011, spring precipitation was less than long-term normals from 2013-2016 and in 2018 (Figure 7, bottom). However, in 2017 spring precipitation was again higher than long-term normals. The increase in number of plants in 2015-2017 could be the result of these wet winters occurring after numerous years of drier conditions. Recent summer precipitation has remained lower than long-term normals with the exception of summer of 2010.

The high temperatures seen over the course of this study relative to long-term normals may have an effect on population trends. Precipitation has been variable over time and in recent years mean values have remained mostly less than long-term normals, which could be a factor in the decline of this species, particularly given that rainfall is limiting in these systems. 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). Despite the increases seen in 2015-2017, the rapid decline in *A. mulfordiae* population numbers observed in the preceding years and

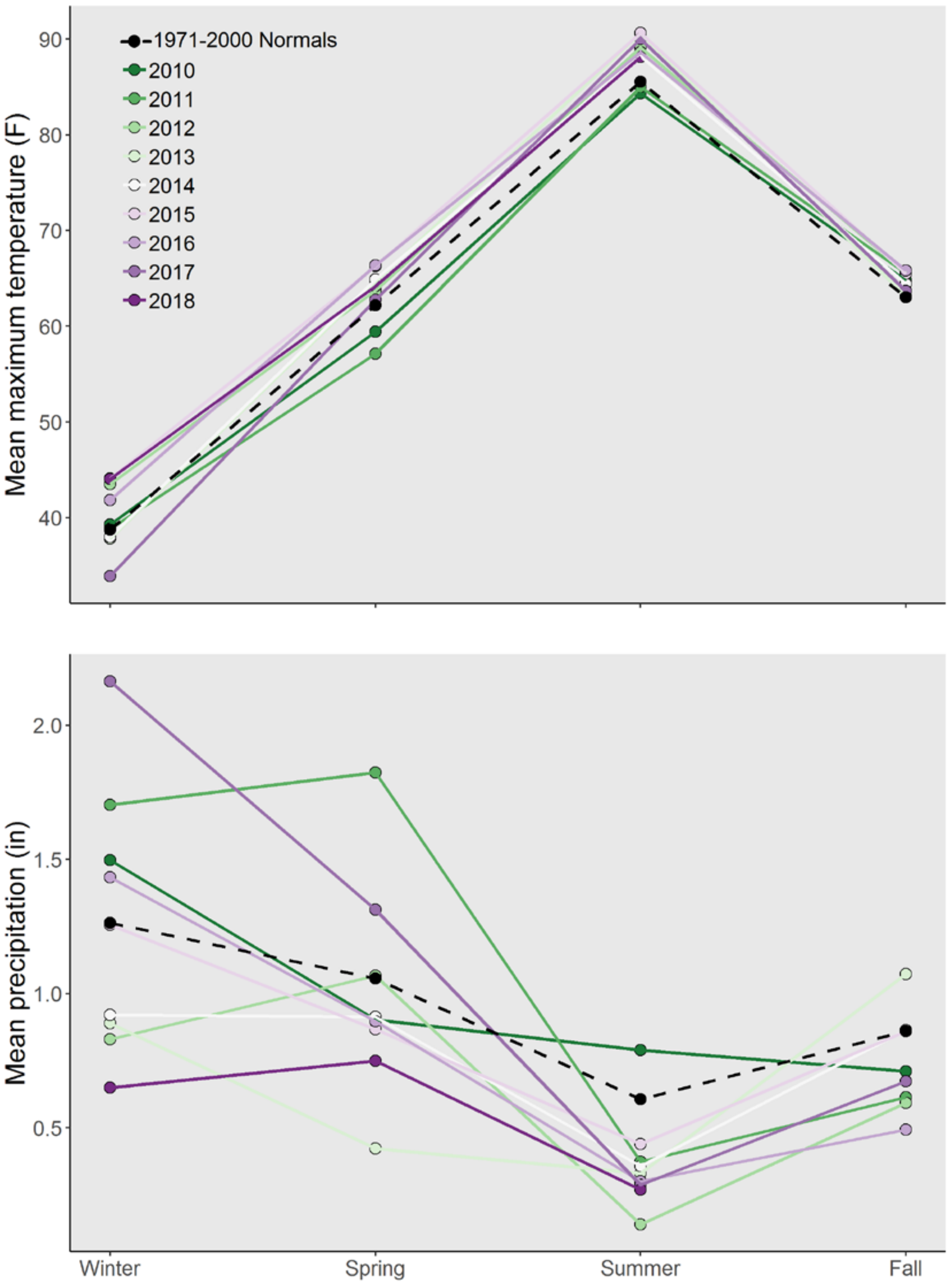

FIGURE 7. MEAN MAXIMUM TEMPERATURE AND MEAN PRECIPITATION FROM 2010 TO 2018 ALONG WITH LONG-TERM CLIMATE NORMALS AT NORTH HARPER NORTH (PRISM CLIMATE GROUP 2018).

in 2018, coupled with the decrease in their size and variability in reproductive effort over the course of this study, suggest that continued monitoring of this rare species will be essential for managing for its persistence, especially in the face of current and ongoing climate changes.

Population and Community Monitoring

In 2018, a total of 46 *A. mulfordiae* plants were observed along five community monitoring transects, less than a third of those observed in 2017 (134) and a quarter of our highest count from 2010 (178). The majority of the plants in 2018 occurred along the transect at South Alkali (27). Seedlings accounted for 28% of the total across all sites, similar to levels seen prior to the increase in 2017. Reproductive plants accounted for 65% of total plants observed, within the range observed from 2013 to 2016 (40-76% reproductive plants). Non-reproductive plants (> 4 cm tall) constituted only 6% (Figure 8).

In comparison to 2010, cover of *A. mulfordiae* declined at all sites except for South Alkali. South Alkali experienced an increase in cover in 2013 and 2014, followed by a decline in 2015 to the lowest value observed during this study. Cover of *A. mulfordiae* increased again at South Alkali in 2016 and 2017 but little change in cover was observed in 2018 (Figure 9). The decline in *A. mulfordiae* at most sites may be associated with the increase in cover of *B. tectorum* over the years of this study, which ranged from 2-16% cover across the sites in 2010 and from 22-49% in 2017. *Bromus tectorum* is known to compete with native vegetation and to fill in the spaces between native perennial bunchgrasses (Knapp 1996), where *A. mulfordiae* also tends to grow. In 2018 we saw a large decrease in *B. tectorum* cover, not associated with an increase in *A. mulfordiae* cover. 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. The next several years of monitoring will be crucial to discern any persistent patterns.

Plant community composition along transects also changed from 2010 to 2018. Exotic species cover (as percent of total cover) generally increased from 2010 to 2018 but was variable at North Harper North, South Alkali, and Double Mountain. Proportions of native species declined from 2010 to 2018, at all sites except North Harper North and South Alkali (Figure 10). In 2010, all sites were native-dominated except for South Alkali, but by 2015 all sites were exotic-dominated. In 2017 and 2018, both North Harper North and South Alkali sites reverted to higher proportions of native species.

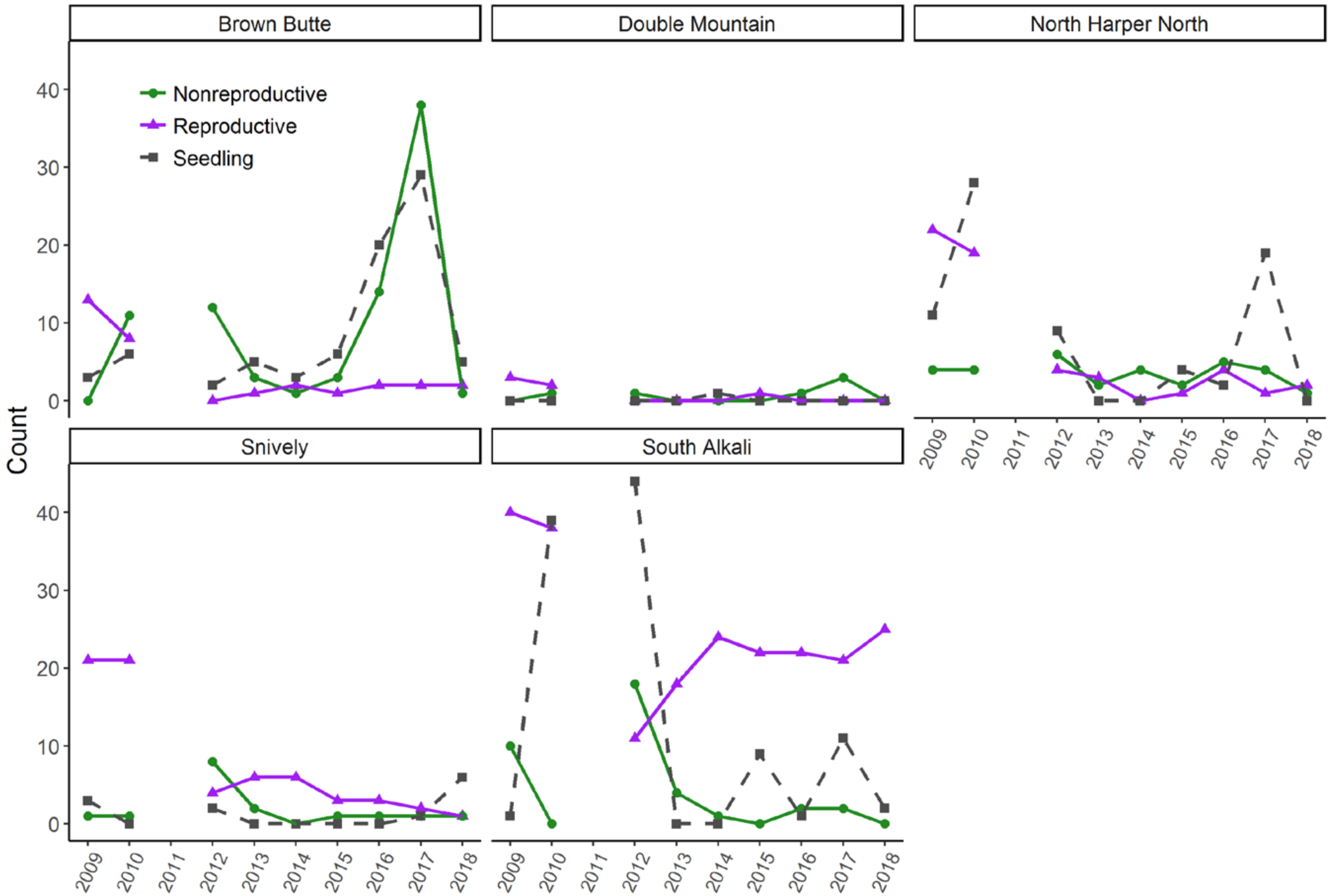

FIGURE 8. CHANGES IN *A. MULFORDIAE* COUNTS OVER TIME, SEPARATED BY REPRODUCTIVE STAGE AND SITE. NO DATA WERE COLLECTED IN 2011.

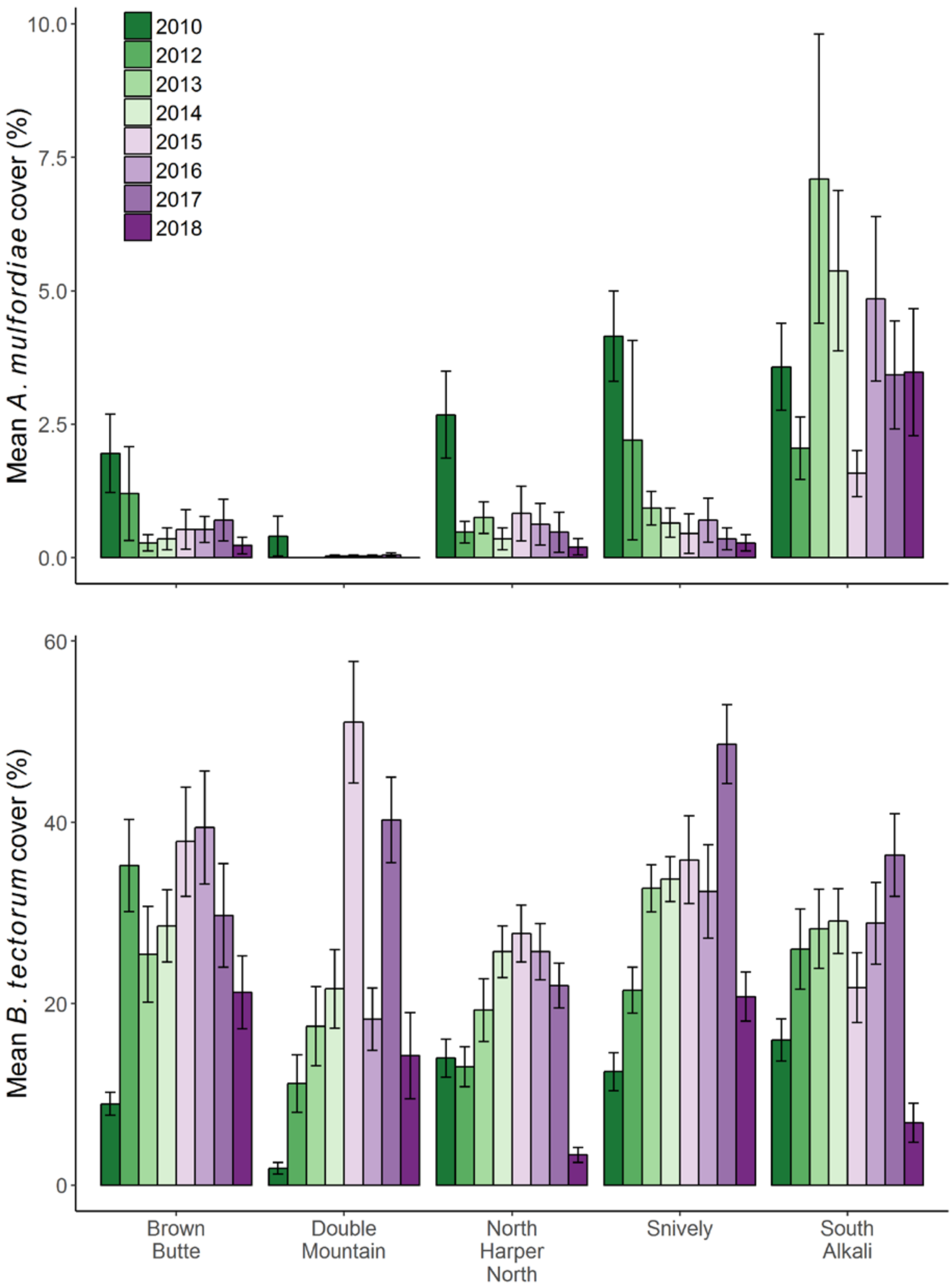

FIGURE 9. MEAN *A. MULFORDIAE* (ABOVE) AND *B. TECTORUM* (BELOW) COVER (%) IN COMMUNITY MONITORING TRANSECTS FROM 2010 TO 2018. ERROR BARS ARE ± 1 S.E. NOTE THE DIFFERENCE IN Y-AXIS SCALE.

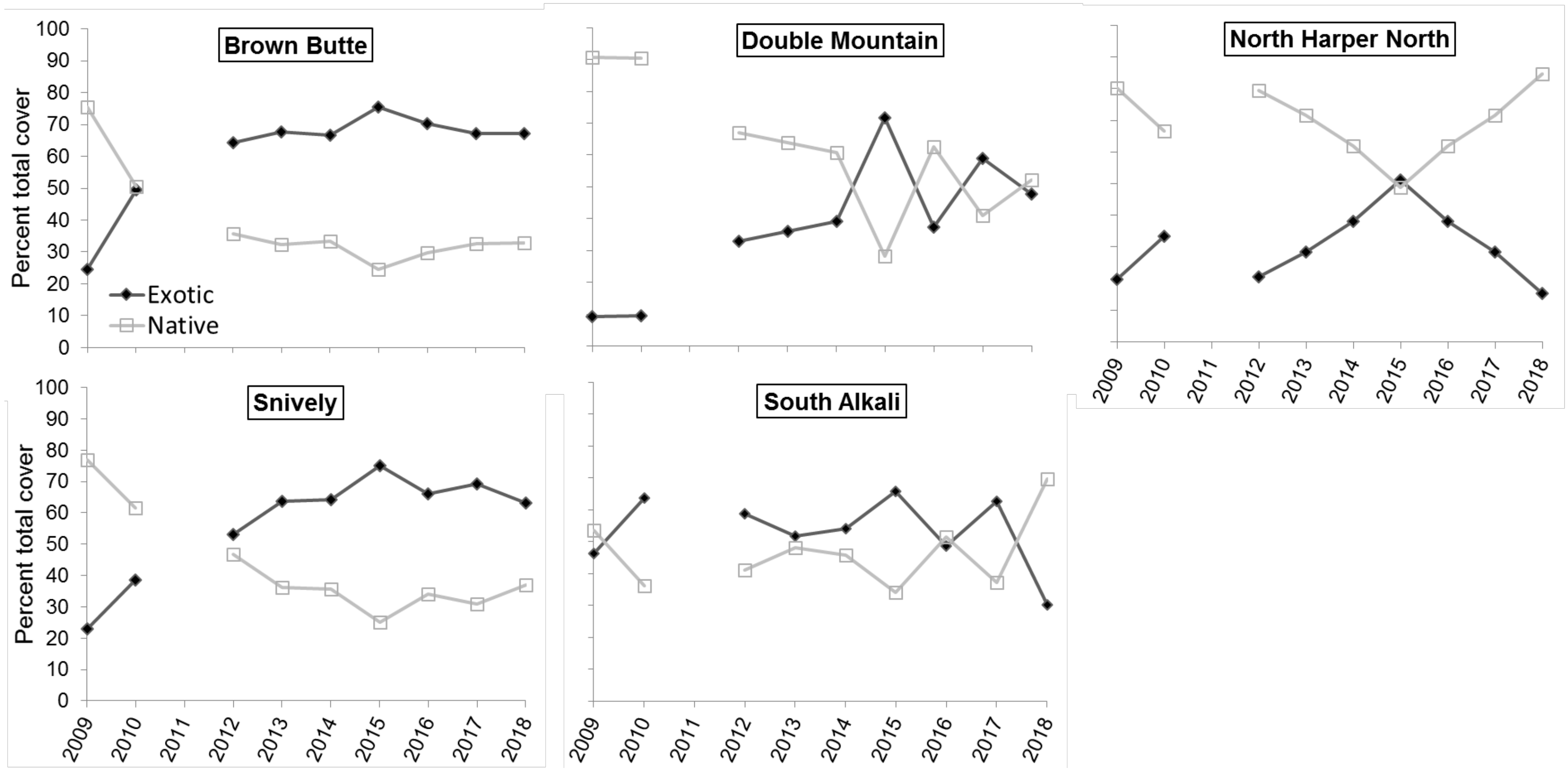

FIGURE 10. PERCENT (%) OF TOTAL COVER OF NATIVE AND EXOTIC SPECIES, BY SITE, FROM 2009 TO 2018.

Of the eight exotic species recorded along transects in 2018, three were graminoids and five were forbs (Appendix D). *Bromus tectorum* dominated exotic species cover ranging from an average of 3.3% to 20.8% cover across all transects, and composing 91.7-100% of total exotic species cover. Other exotic species included *Erodium cicutarium, Alyssum desertorum, Bromus hordeaceus, Lactuca serriola, Salsola tragus, Sisymbrium altissimum*, and *Poa bulbosa*. Though these other exotic species were present, their total cover was minimal, suggesting that without the invasion of *B. tectorum* at these sites, the plant community would have remained native-dominated. The most abundant native species present along transects were perennial bunchgrasses *Achnatherum hymenoides, Poa secunda,* and *Hesperostipa comata,* and the perennial forb *Balsamorhiza sagittata. Chrysothamnus viscidiflorus* was the primary shrub present in all transects. Mean cover of *A. mulfordiae* ranged from 0-3.8%, with South Alkali having the highest cover and Double Mountain the lowest.

The non-vegetated ground surface was composed largely of bare ground accounting for 40% of mean cover. Litter cover increased over three-fold between 2010 (19%) and 2017 (61%), but fell again in 2018 to 37%; these changes are likely 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, biological crust, and basal vegetation were also present (Table 10).

TABLE 10. MEAN COVER OF GROUND SURFACE CATEGORIES BY SITE IN 2018.

	Brown Butte	Double Mountain	North Harper North	Snively	South Alkali	*Site mean*
Basal veg (cut off at ground)	28.5	27.4	22.8	29.3	18.8	25.3
Bare ground	48.2	42.6	52.9	21.8	34.5	40.0
Biological crust	2.1	0.1	0.4	0.5	0.5	0.7
Rock/gravel (≥ 2mm)	0.5	0.5	0.0	2.6	0.3	0.8
Litter (< 2mm), including scats	37.0	33.3	28.8	36.6	50.0	37.1
Completely dead shrub, attached	6.4	1.9	1.6	1.1	3.0	2.8
Wood (≥ 2mm), not attached -- must be wood from shrub/tree	0.4	1.2	1.1	0.4	0.4	0.7

The loose, sandy substrate characterizing *A. mulfordiae* habitat leaves evidence of many physical disturbances. Disturbances recorded in 2018 varied by site, but overall were higher than observed in 2017. Brown Butte experienced the most 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 cattle and human footprints, divots, cattle feces, and insect burrows (erosion rills occurred only at Brown Butte) (Table 11). The invasion of these areas by *B. tectorum* could be influenced by disturbances occurring at these sites. Though non-researcher anthropogenic disturbances were relatively uncommon in 2018, increased disturbance could act as a conduit to further invasion at these sites. Along transects, herbivory and trampling damage to *A. mulfordiae* occurred on 21 plants, lower than in 2017 but higher than the five plants affected in 2016. Insect damage and disease occurred on only two plants, lower than in both 2017 and 2016.

TABLE 11. TOTAL COVER (%) OF DISTURBANCES OBSERVED ALONG TRANSECTS IN 2018.

Disturbance Category	Brown Butte	Double Mountain	North Harper North	Snively	South Alkali	*Total Cover*
Anthill	0	0.5	6	0	0	6.5
Burrow	0	12	9	1	0	22
Cattle feces-older (>1 yr)	0	0	20.5	10.5	26.5	57.5
Cattle prints	160	7.5	66	16.5	0	250
Deer prints	0	0	4	0	0	4
Divot	15	15	9	28.5	6	73.5
Human footprints (researcher)	35	47.5	56	16.5	19	174
Insect burrow (diameter < 1 cm)	6.5	19.5	14	41.5	1.5	43
Lizard prints	0	0.5	0	0	0	0.5
Medium sized rodents (pocket gopher, kangaroo rat, ground squirrel)	15	0	0	0	0	15
Rills (erosion)	130	0	0	0	0	130
Shotgun shell(s), human trash	0	0	0	0	0.5	0.5
Unknown animal prints	0	0.5	13.5	0	0	14
Total ground disturbance	361.5	103	198	114.5	61.5	

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 years of consistent data we will be able to make comparisons between population dynamics and climate variability at the Oregon occurrences.

CONCLUSIONS

Over the course of this study, we have observed a decline in *A. mulfordiae* at all of our study sites. In 2014, the density of *A. mulfordiae* was the lowest observed since 2008, with pronounced declines observed from 2012 to 2013. Despite increases over the previous three years (2015-2017), the number of *A. mulfordiae* plants declined in 2018. This year, the number of plants that died was much higher than the number of new plants found, seven plots were found empty that had *A. mulfordiae* present in the past two years, and no plots had new individuals, all consistent with the long-term trend of population decline. Densities have remained so low that while re-establishing plots in 2012, it was difficult to find suitable habitat that had two or more plants within a 1-m^2 area. Since then we have not attempted to establish new monitoring plots. Despite the increase in plants noted from 2015 to 2017, the overall decline observed across recent years is cause for alarm, particularly in conjunction with the documented increase of *B. tectorum* and the variable climate experienced in recent years. Though population dynamics were difficult to discern in prior studies (Newton et al. 2010), the consistent decline across all sites indicates that this species might be sensitive to climate variability and other factors such as competition from invasive plant species.

Plant size and reproductive effort of *A. mulfordiae* have varied over the years and across treatments. Though the caging treatment has shown significant differences in plant characteristics on a site by site or year by year basis, we do not have consistent evidence that grazing by livestock (cattle and/or sheep) directly affects *A. mulfordiae* population size and/or reproductive success. We also found no 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. Insect herbivory was present across all sites, and we did not see differences between caged and uncaged plots, and herbivory was less common than observed in 2017. 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.

Invasive plant species were present in all *A. mulfordiae* sampling plots, and have increased over time. Between 2010 and 2018, plant community composition has varied, but some sites have transitioned from a native-dominated community to one dominated by exotic species. In 2018, plant communities at all sites were dominated by the ubiquitous *B. tectorum*, even though total cover of this species was lower than seen 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.

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. 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 exotic 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*.

Given declines observed in recent years across all sites, we recommend continued monitoring in order to determine long-term population trends and to describe areas where populations are particularly vulnerable or changes are occurring rapidly. Although there were increases in the number of *A. mulfordiae* observed over the past four years, numbers declined again in 2018 to one third of the total observed at the beginning of this study. To mitigate for future loss, we recommend efforts focused on seed collection for 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. DATASHEET FOR *ASTRAGALUS MULFORDIAE* MONITORING.

Astragalus mulfordiae demographic monitoring plot

Site: ______________________________

Plot #: ________ Caged or Uncaged

Date: ______________________________

Name: ______________________________

Note location of rebar posts and compass bearing to top of page

Compass bearing:

							Herbivory			
	X-coord	Y-coord	Diam (cm)	longest stem (cm)	#Infl.		Insect		Deer / Cattle	Notes
Plant #										

APPENDIX B. GPS COORDINATES FOR ALL PLOT AND TRANSECT LOCATIONS.

Set Datum to "NAD83"

Set Position Format to "hddd.ddddd"

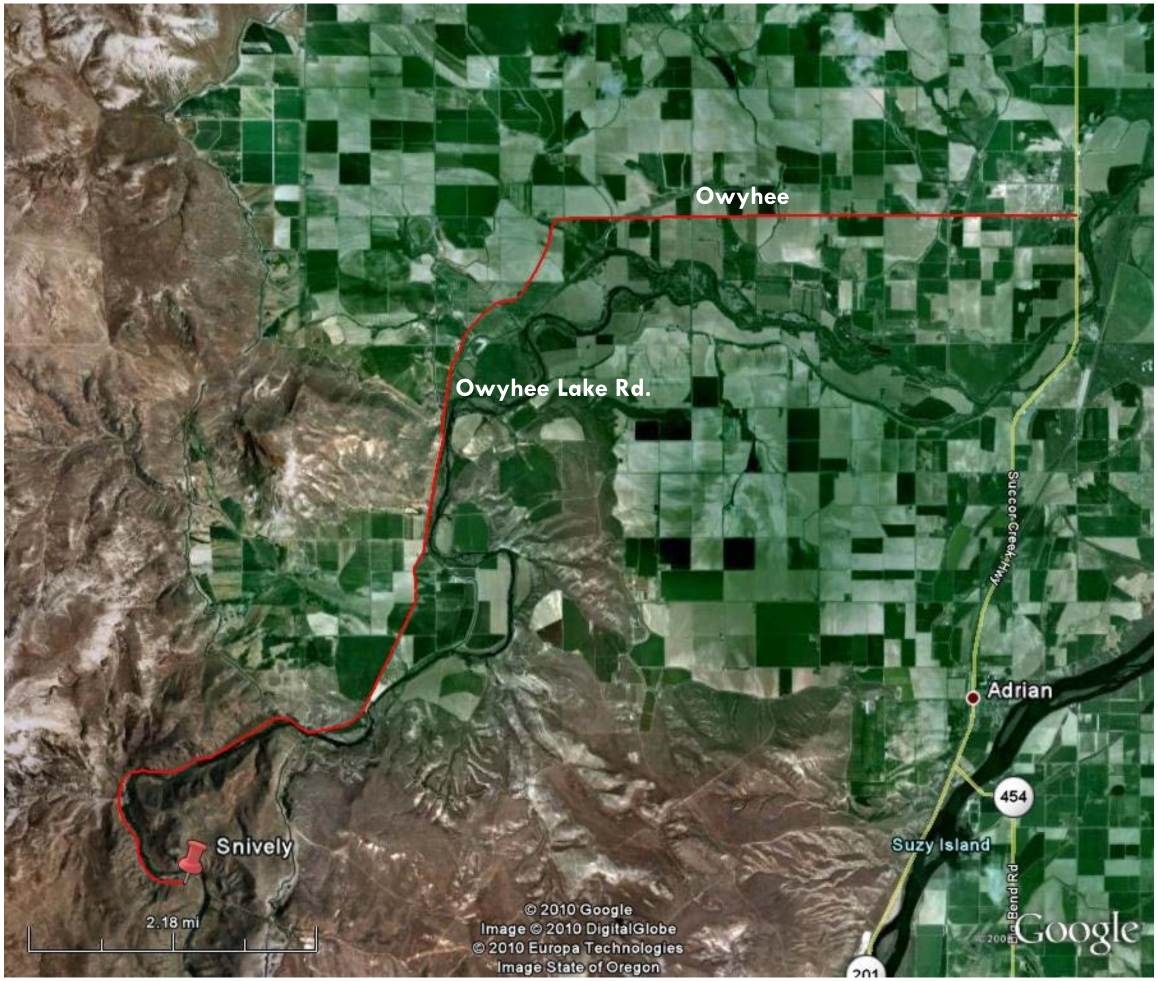
						Notes			
Site	**Sub-site**	**Plot #**	**Treatment**	**LAT**	**LONG**	**2012**	**2013**	**2014**	**2015**
Brown Butte		End	Transect	43.73173	-117.12424				
Brown Butte		Start	Transect	43.73190	-117.12421				
Brown Butte		86	Caged	43.73237	-117.12403	New			
Brown Butte		88	Caged	43.73187	-117.12437	New			
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	New			
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	New			
Double Mountain		270	Caged	43.83346	-117.29051	New			
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	New			
Double Mountain		272	Uncaged	43.83269	-117.29130	New			
Double Mountain		678	Uncaged	43.83326	-117.29034				
Double Mountain		682	Uncaged	43.83302	-117.29093			Plot missing	Plot missing

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	New			
North Harper	North	78	Uncaged	43.86760	-117.23532	New			
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	New			
North Harper	South	667	Caged	43.86389	-117.23113		Plot missing		
North Harper	South	669	Caged	43.86382	-117.23115		Plot missing		
North Harper	South	670	Caged	43.86317	-117.23102				
North Harper	South	672	Caged	43.86305	-117.23102	Plot missing	Plot missing		
North Harper	South	673	Caged	43.86269	-117.23064	Plot missing	Plot missing		
North Harper	South	74	Caged	43.86284	-117.23062	New			
North Harper	South	75	Uncaged	43.86292	-117.23095	New			
North Harper	South	576	Uncaged	43.86385	-117.23113	New			
North Harper	South	77	Uncaged	43.86381	-117.23113	New		Plot missing	Plot missing
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	Plot missing			

Snively		End	Transect	43.72012	-117.19399				
Snively		Start	Transect	43.71994	-117.19401				
Snively		69	Caged	43.72001	-117.19503	New			
Snively		71	Caged	43.71998	-117.19470	New			
Snively		72	Caged	43.72005	-117.19387	New			
Snively		547	Caged	43.71979	-117.19368				
Snively		553	Caged	43.71994	-117.19364				
Snively		70	Uncaged	43.72001	-117.19506	New			
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	New			
South Alkali	#2	83	Caged	44.06392	-117.17404	New			
South Alkali	#2	652	Caged	44.06392	-117.17407				
South Alkali	#2	81	Uncaged	44.06406	-117.17443	New			
South Alkali	#2	82	Uncaged	44.06408	-117.17443	New			
South Alkali	#2	84	Uncaged	44.06385	-117.17415	New			
South Alkali	#2	655	Uncaged	44.06407	-117.17423	Plot missing			

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				
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				

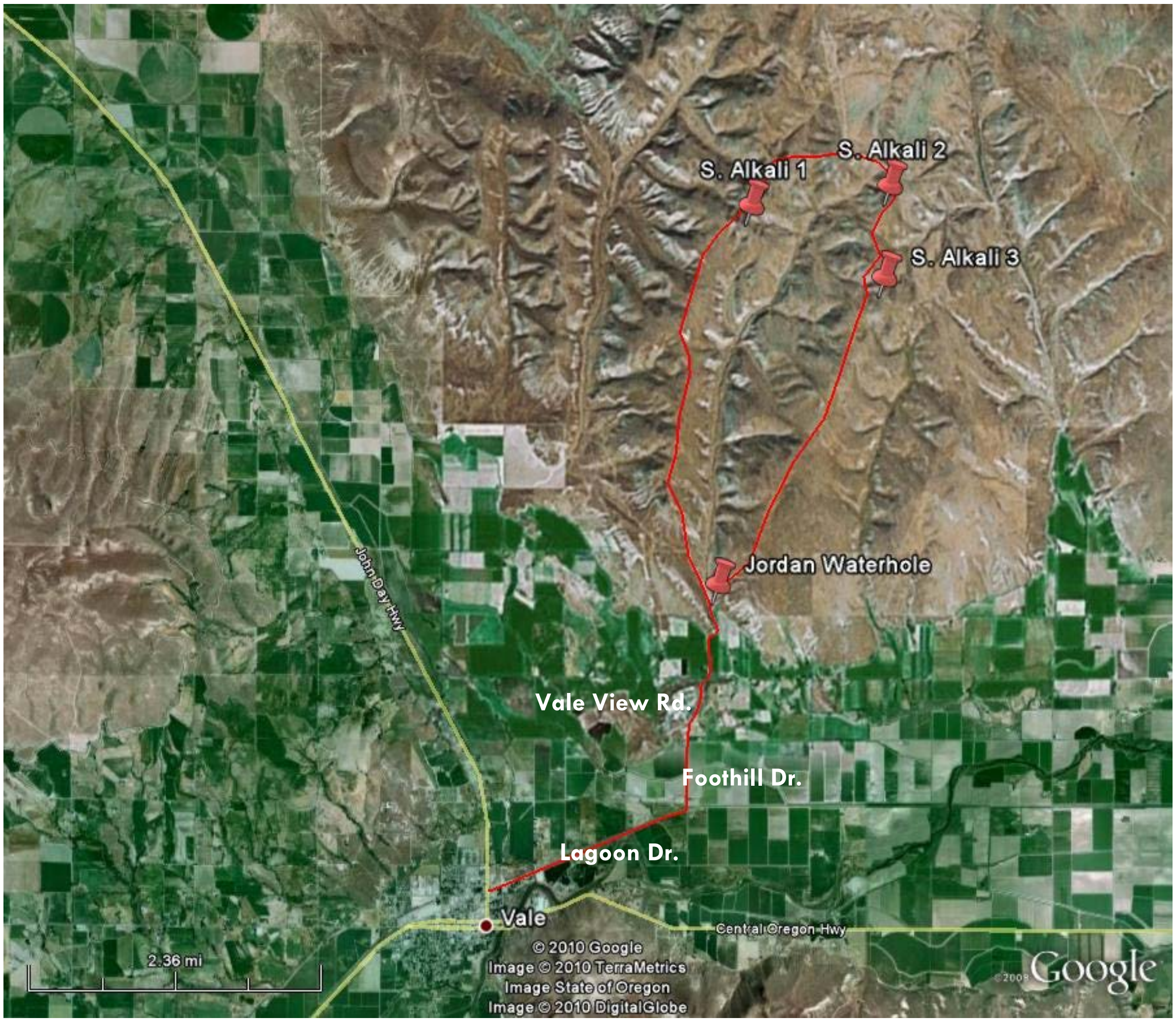
DRIVING DIRECTIONS TO SNIVELY



Driving route to Snively from State Route 201. Written driving directions can be found in Appendix C.

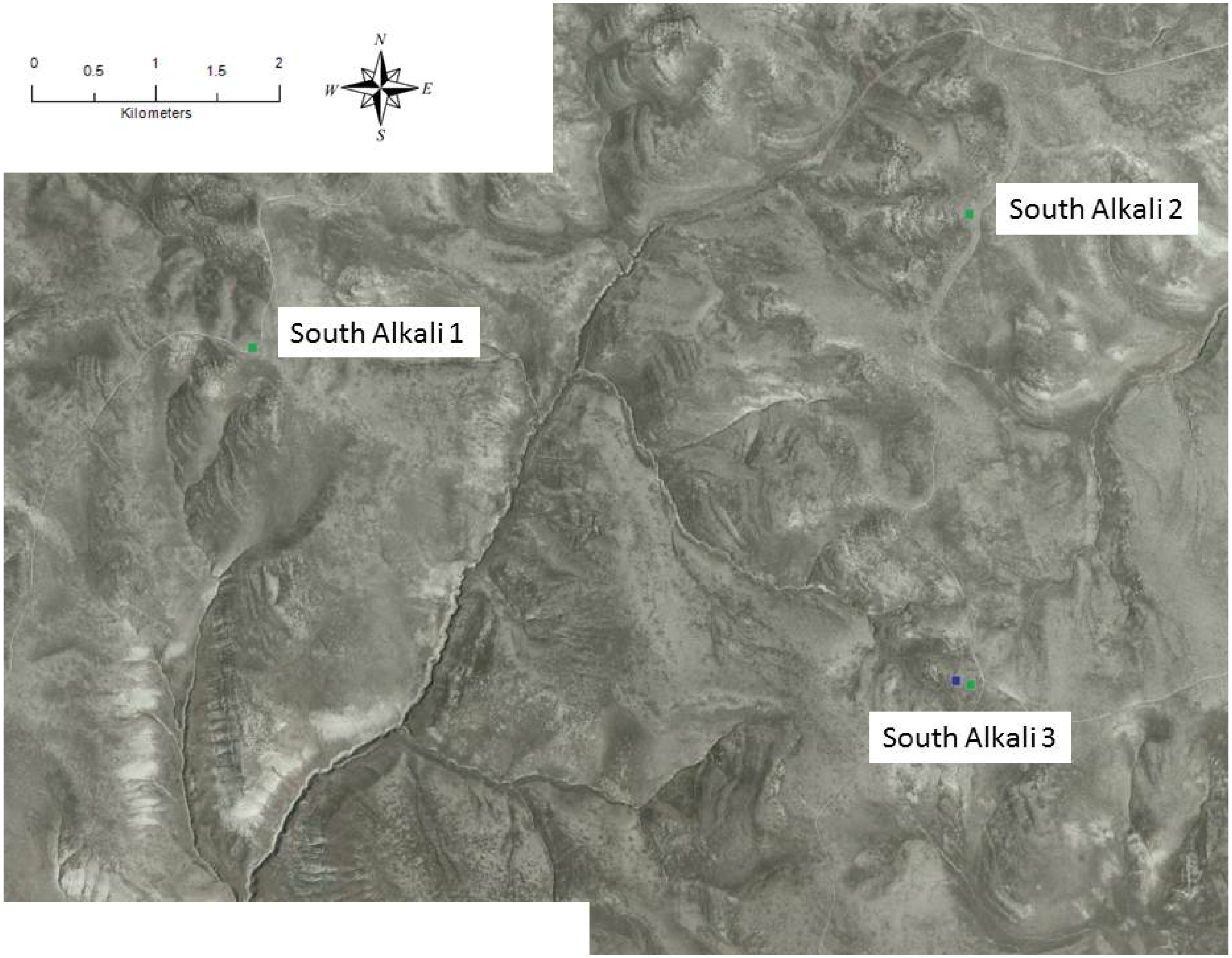

Snively overview

DETAILED MAP OF THE SNIVELY FIELD SITE.



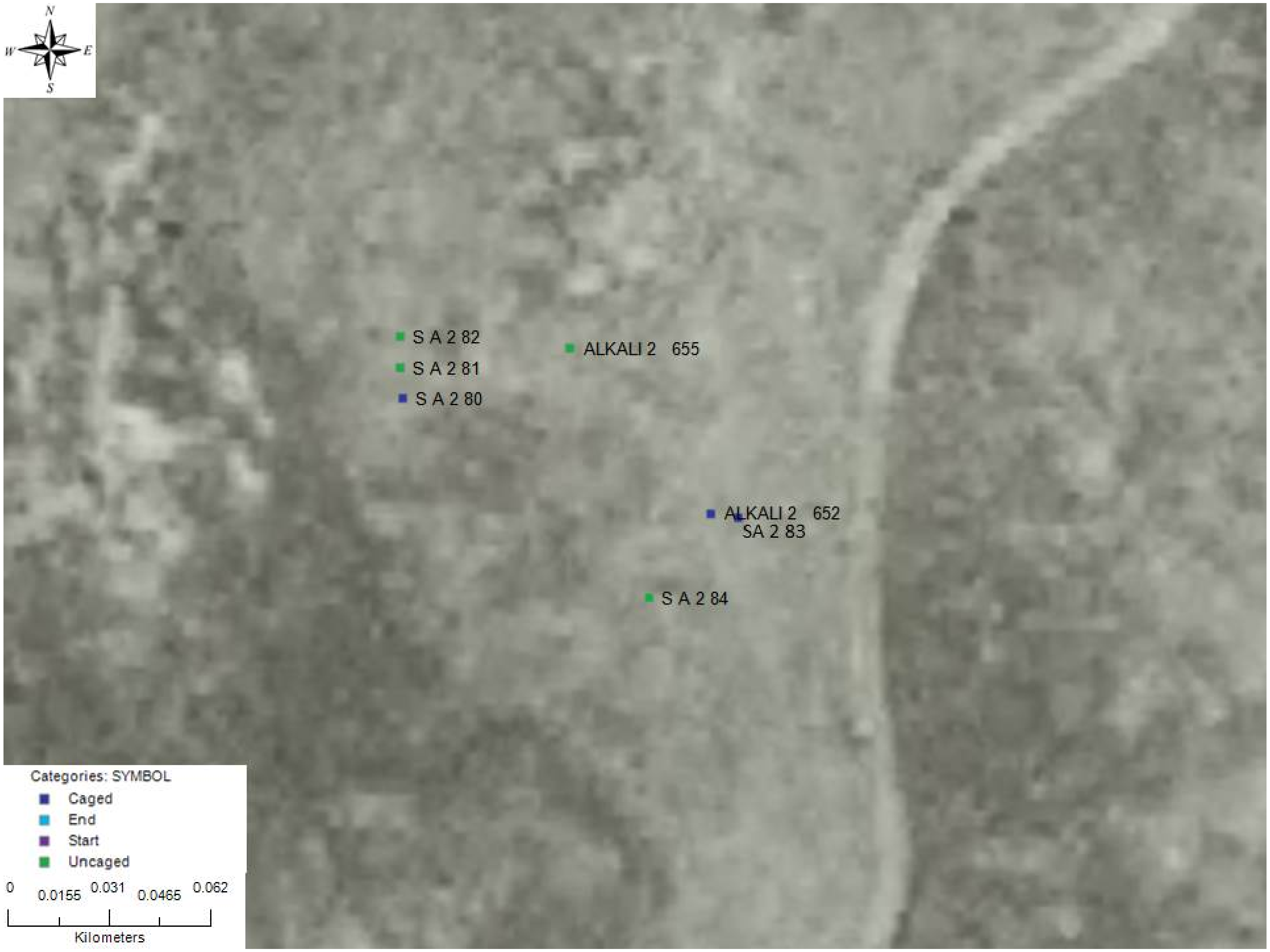
Driving route to South Alkali 1, 2, and 3. From Jordan Waterhole, it is advisable to drive clockwise around the loop, visiting S. Alkali 1 first. The road basically stays on top of a ridgeline all the way around this valley. Follow the 7.5" USGS topo map and written driving directions (Appendix C) carefully, especially once you are on Valley View Road. 11T 0485982E 4877837N (start of transect at population 3, Nad83). Note, large washout occurred at the base of the valley to the right. Safest is to travel clockwise from SA1 to SA3, then turn back and travel counter-clockwise around the valley.

OVERVIEW OF SOUTH ALKALI



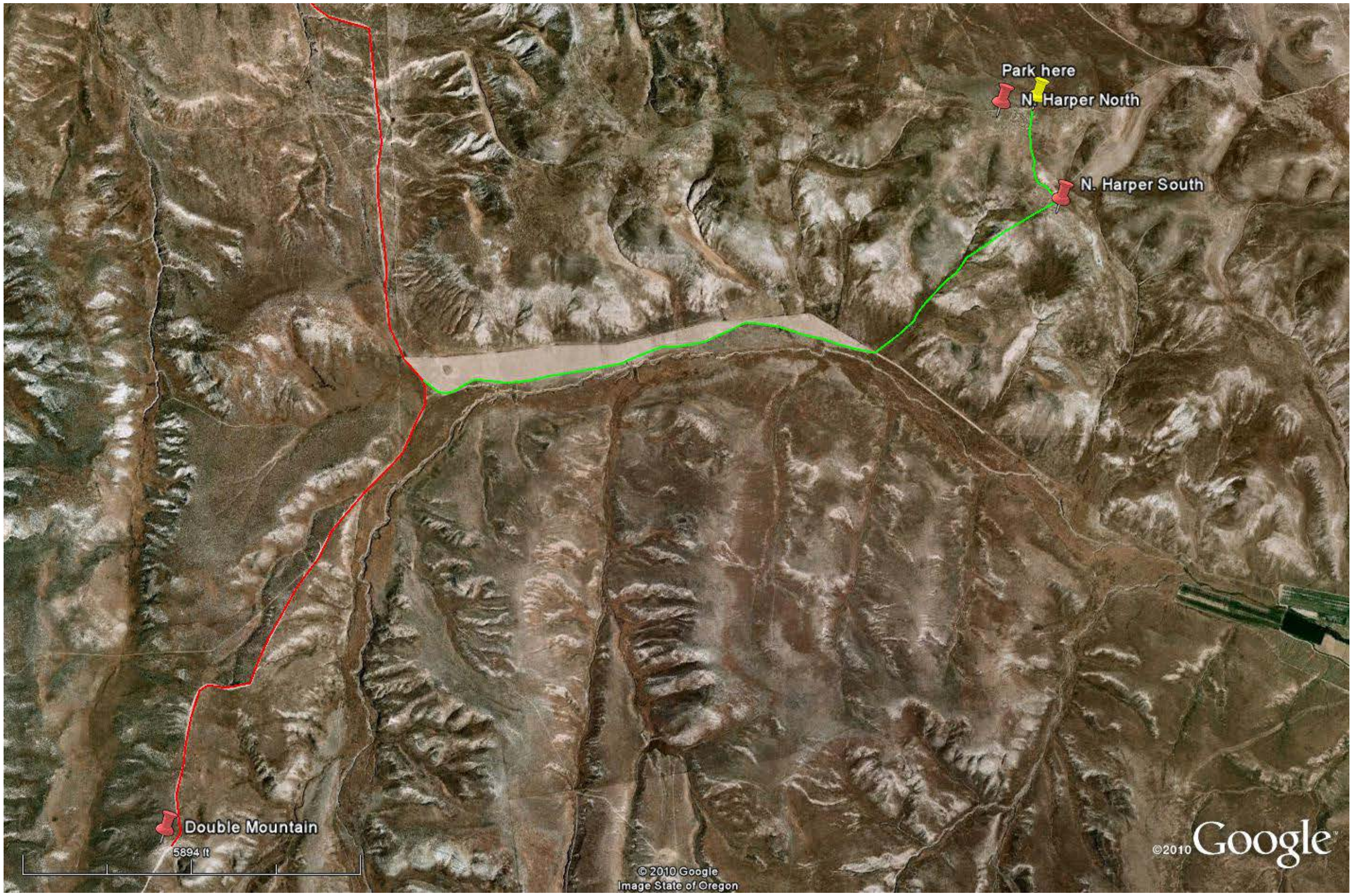
SOUTH ALKALI #1, DETAILED MAP

SOUTH ALKALI #2, DETAILED MAP



SOUTH ALKALI #3, DETAILED MAP

Driving Route to North Harper

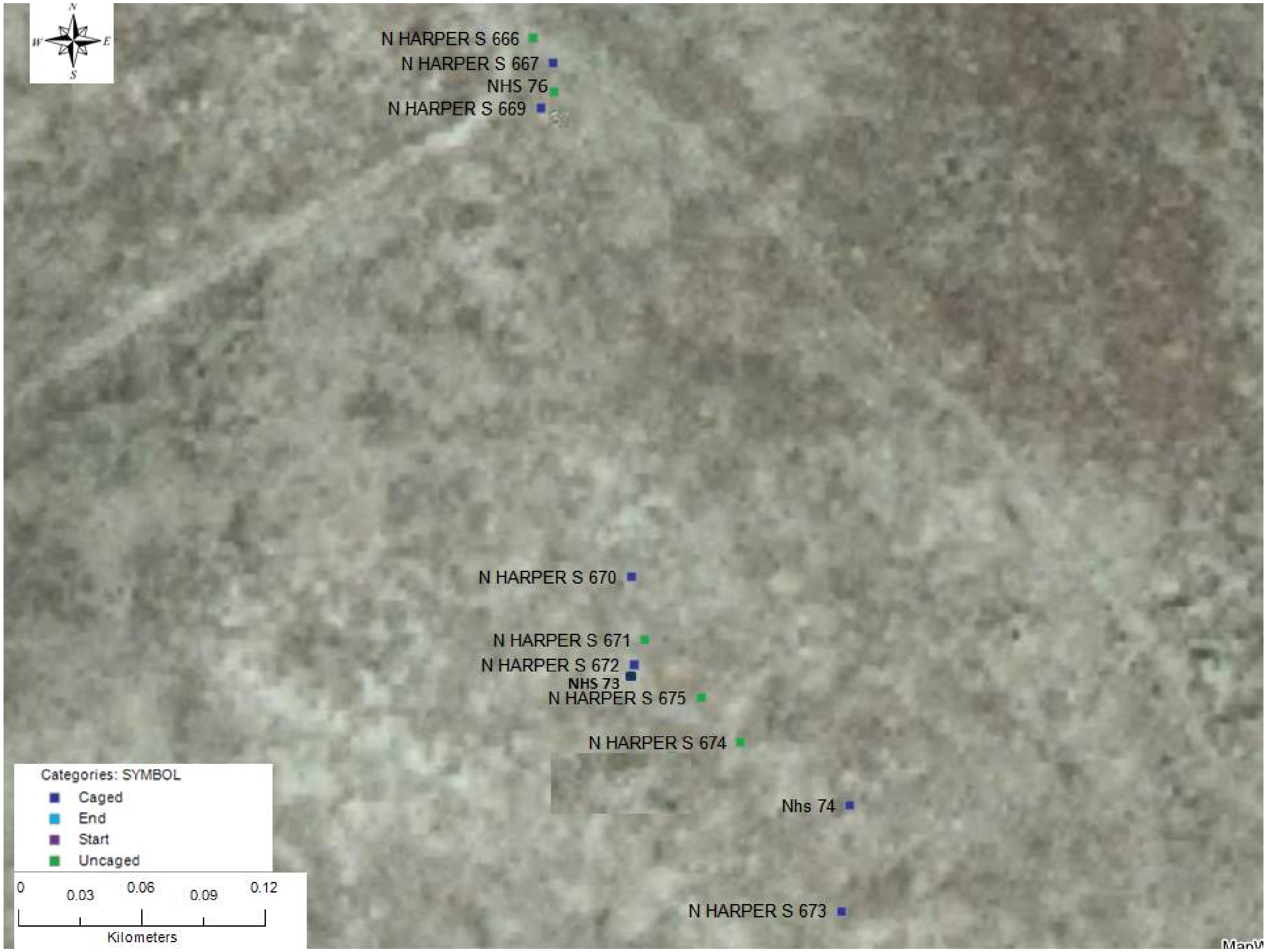


Driving directions to North Harper. Highway 20 is north on Russell Road. Follow the 7.5" USGS topo quad and written driving directions carefully (Appendix C).

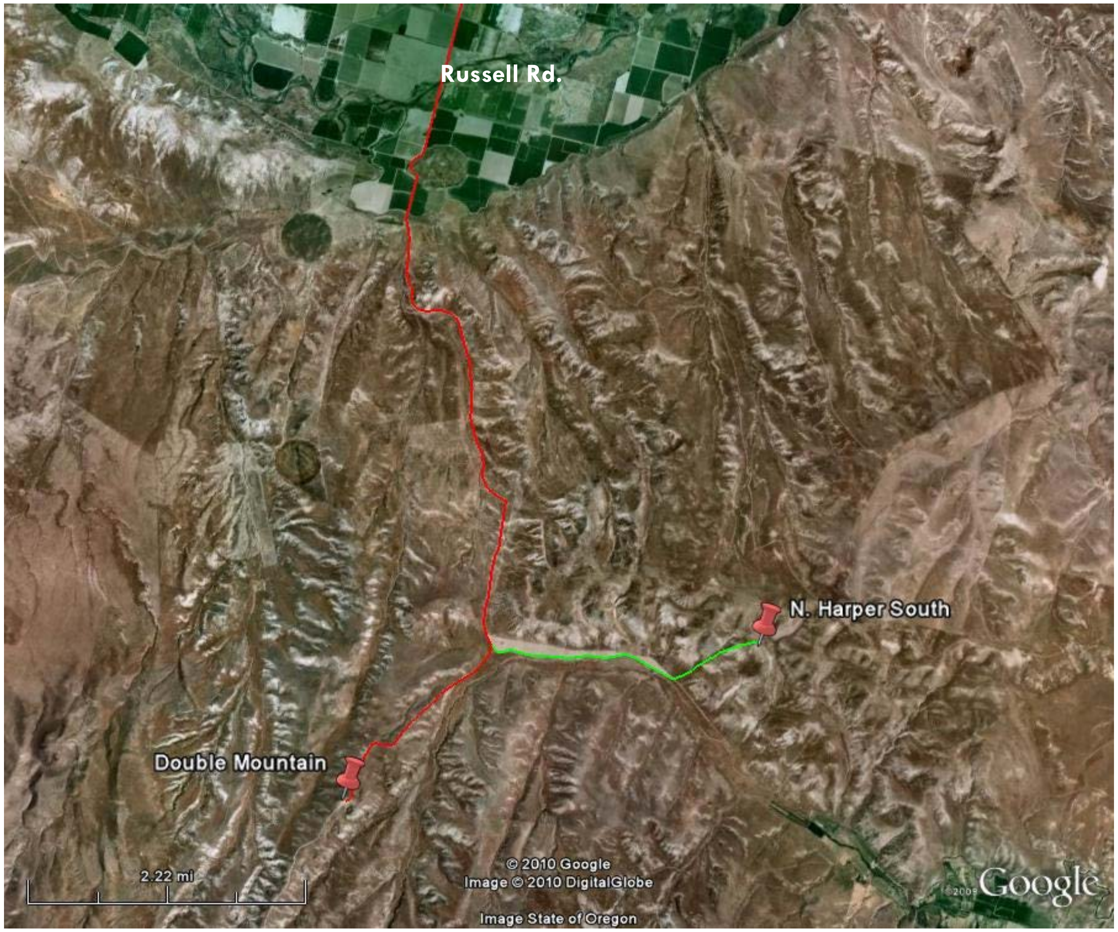
OVERVIEW OF NORTH HARPER FIELD SITES

NORTH HARPER NORTH, DETAILED MAP

NORTH HARPER SOUTH, DETAILED MAP

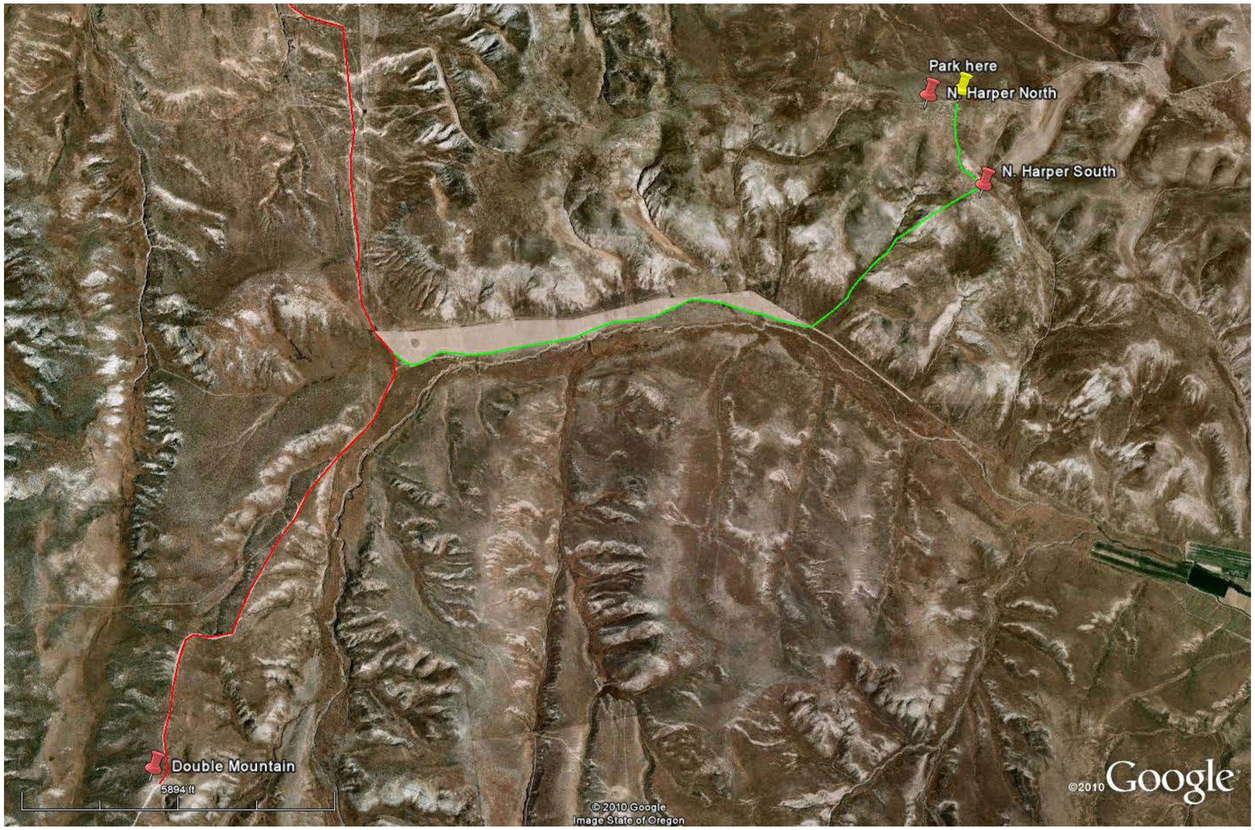


DRIVING ROUTE TO DOUBLE MOUNTAIN



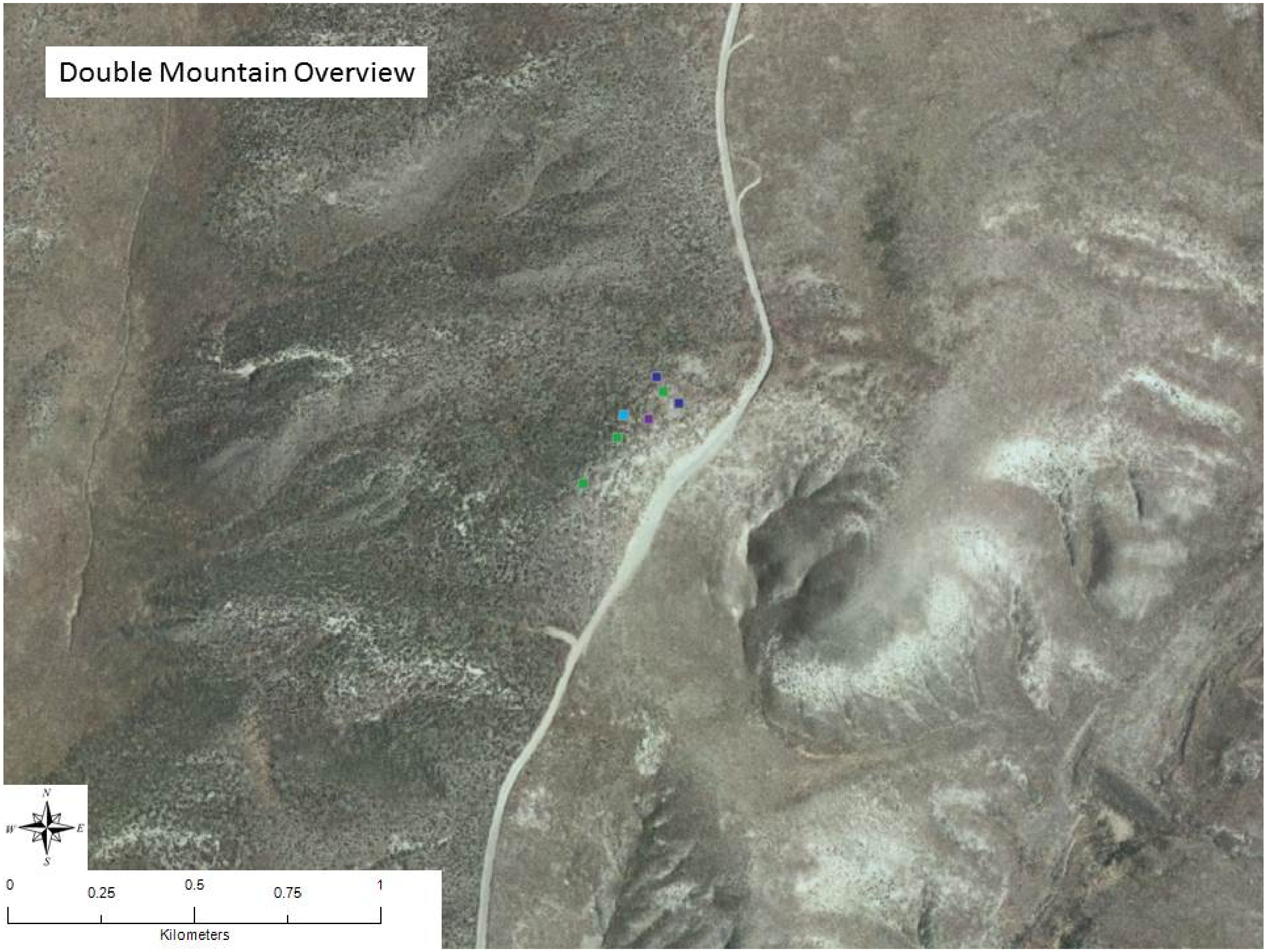
Driving route to Double Mountain (red) and alternative route to North Harper South (green). Highway 20 is north on Russell Road. Follow the 7.5" USGS topo quad and written driving directions carefully (Appendix C).

DRIVING ROUTE TO DOUBLE MOUNTAIN (ZOOM)

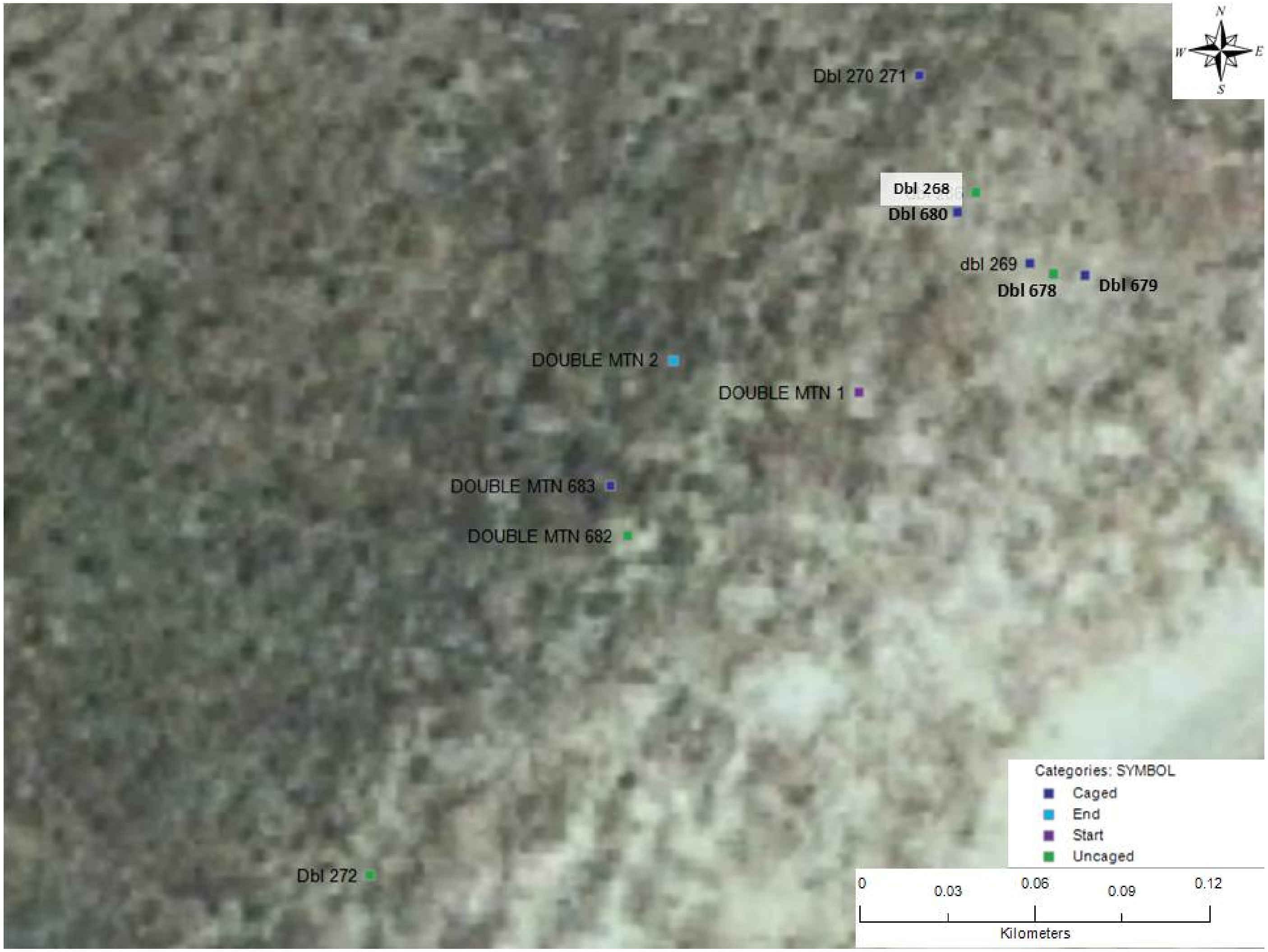


Driving route to Double Mountain (red) and alternate route to North Harper South and North (green). Highway 20 is north on Russell Rd. Follow the 7.5" USGS topo quad and written driving directions carefully (Appendix C).

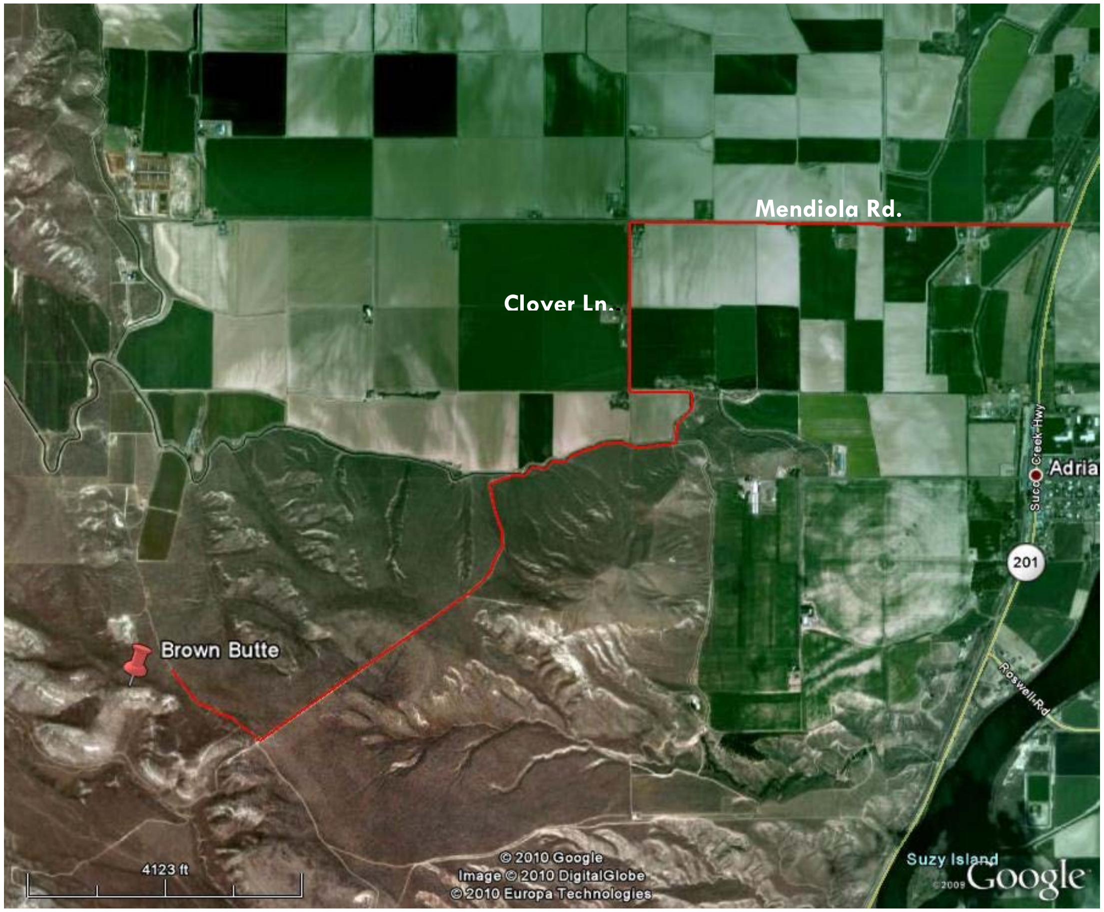
OVERVIEW OF THE DOUBLE MOUNTAIN FIELD SITE



DETAILED MAP OF THE DOUBLE MOUNTAIN FIELD SITE

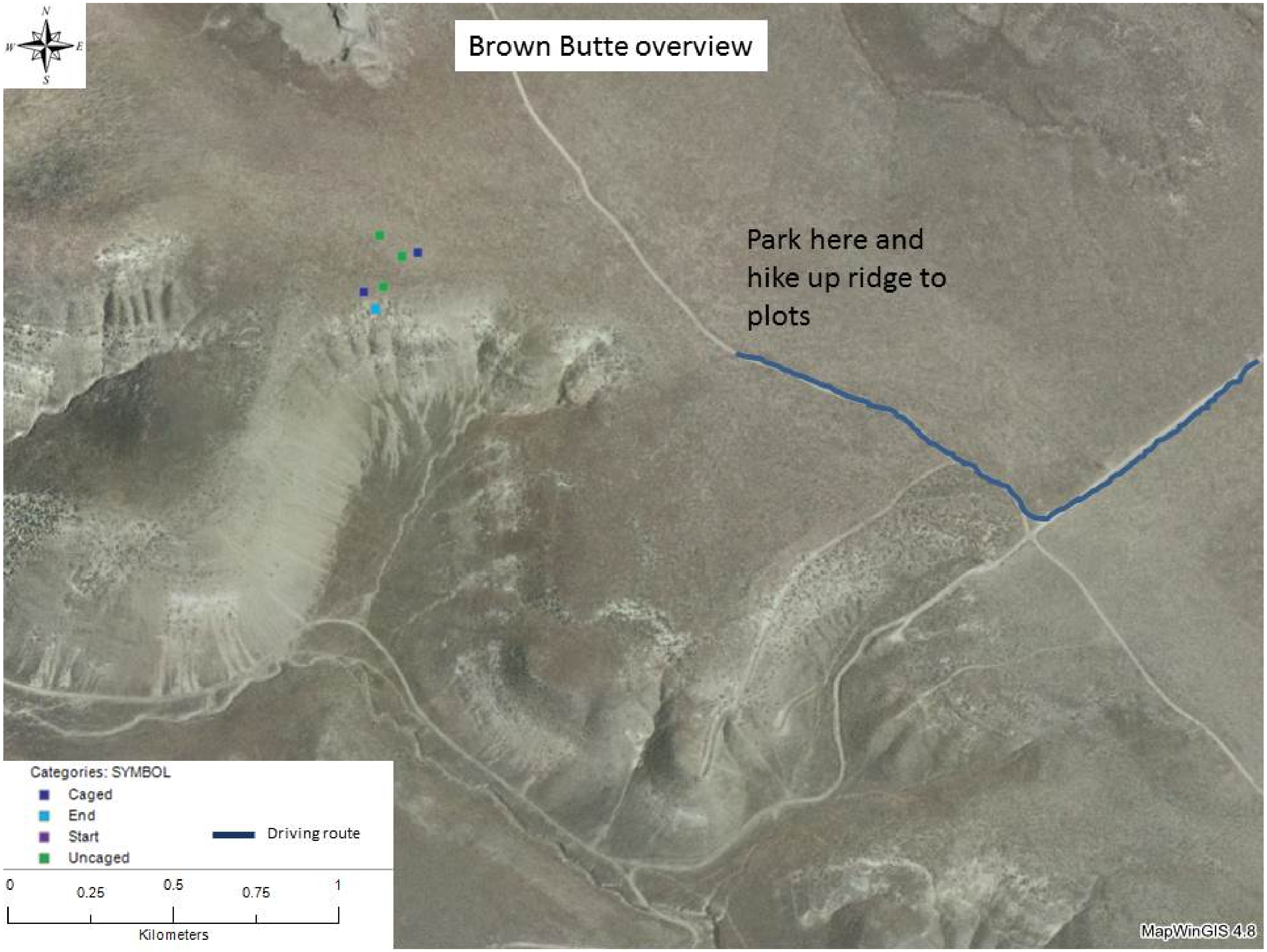


DRIVING ROUTE TO BROWN BUTTE

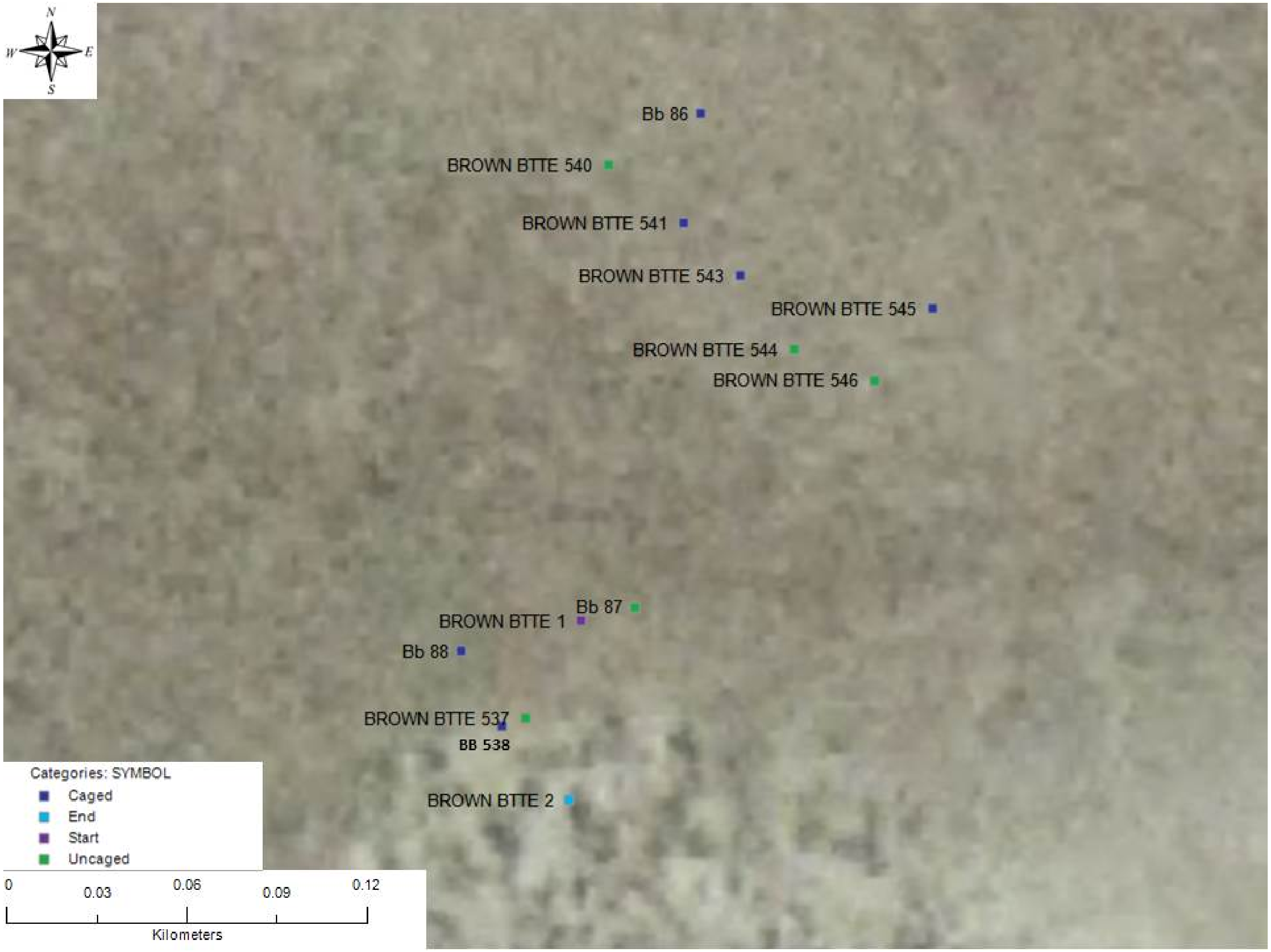


Driving route to Brown Butte sampling site from State Route 201. See Appendix C for written directions. After Clover Lane, follow the written directions carefully.

Overview of Brown Butte



DETAILED MAP OF BROWN BUTTE



Directions – Update directions as needed for future sampling. 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)!
Last updated 8/16 MP + SC

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****

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.

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 C. HERBIVORY PLOT INFORMATION.

New plots were added in 2012. “y” indicates yes.

Site	Treatment	Plot #	New in 2012?	Empty in 2013?	Empty in 2014?	Empty in 2015?	Empty in 2016?	Empty in 2017?	Empty in 2018?
Brown Butte	caged	86	y						
	caged	88	y						
	caged	538		y	y	y	y	y	y
	caged	541		y	y	y	y		
	caged	543		y	y	y	y	y	y
	caged	545		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
	caged	679							
	caged	680		y	y	y	y	y	y
	caged	683		y	y	y	y		
	uncaged	268	y		y	y	y	y	y
	uncaged	272	y	y	y	y	y	y	y
	uncaged	678							
North Harper North	caged	528		y	y	y	y	y	y
	caged	530		y	y	y	y	y	y
	caged	532			y	y	y		
	caged	534							
	caged	79	y						
	uncaged	78	y		y	y			
	uncaged	527			y	y	y		
	uncaged	529			y				
	uncaged	533			y	y	y		
	uncaged	535							

North Harper South	caged	73		y		y			
	caged	667			y	y	y	y	
	caged	669			y	y			
	caged	670							
	caged	672	y			y	y	not monitored	
	caged	74		y					
	uncaged	75		y					
	uncaged	76 [new tag #576]		y		y	y	y	
	uncaged	666							
	uncaged	671				y			
	uncaged	674				y	y		
	uncaged	675	y			y	y		
Snively	caged	69		y					y
	caged	71		y			y	y	y
	caged	72		y					
	caged	547			y	y	y	y	y
	caged	553							
	uncaged	70		y					y
	uncaged	550						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
	uncaged	651							
South Alkali 2	caged	80		y					
	caged	83		y					y
	caged	652							
	uncaged	81		y					
	uncaged	655	y		y				
	uncaged	82		y					
	uncaged	84		y				y	y
South Alkali 3	caged	659							
	caged	660			y	y			
	caged	663							

South Alkali 3 [CONT]	caged	665			y	y			y
	uncaged	85		y					
	uncaged	658				y		y	y
	uncaged	662				y			
	uncaged	664							y

APPENDIX D. AVERAGE PERCENT COVER OF ALL VASCULAR PLANT SPECIES

Recorded at five transects sampled in 2018. Plants are organized by native status and growth habit.

Abbreviations include: “N” = native, “I” = invasive, “F” = forb, “G” = graminoid, “S” = shrub.

Code	Current Name	Common name	Habit	Nativity	Brown Butte	Double Mtn	North Harper North	Snively	South Alkali
ACHHYM	*Achnatherum hymenoides*	Indian ricegrass	G	N	2.90	3.00	2.98	0.15	0.00
ALYDES	*Alyssum desertorum*	desert madwort	F	I	0.00	0.00	0.00	0.58	0.50
ASTMUL	*Astragalus mulfordiae*	Mulford's milkvetch	F	N	0.23	0.00	0.20	0.28	3.48
ASTPUR	*Astragalus purshii*	woollypod milkvetch	F	N	0.00	0.00	0.00	0.00	0.03
BALSAG	*Balsamorhiza sagittata*	arrowleaf balsamroot	F	N	0.15	2.45	6.75	1.01	2.13
BROTEC	*Bromus tectorum*	cheatgrass	G	I	21.25	14.28	3.33	20.78	6.88
CHADOU	*Chaenactis douglasii*	Douglas' dustymaiden	F	N	0.00	0.00	0.00	0.00	0.05
CHAMAC	*Chamaesyce maculata*	small spotted sandmat	F	N	0.28	0.00	0.00	0.35	0.15
CHRVIS	*Chrysothamnus viscidiflorus*	green rabbitbrush	S	N	1.93	8.70	5.45	4.30	3.23
COMUMB	*Comandra umbellata*	bastard toadflax	F	N	0.48	0.00	0.00	0.00	0.00
CREACU	*Crepis acuminata*	tapertip hawksbeard	F	N	0.00	0.00	0.08	0.00	0.98
DESINC	*Descurainia incana*	mountain tansymustard	F	N	0.00	0.00	0.00	0.08	0.00
DESPIN	*Descurainia pinnata*	western tansymustard	F	N	0.53	0.15	0.05	0.28	0.03
ELYELYE	*Elymus elymoides* ssp. *elymoides*	squirreltail	G	N	0.00	0.50	0.20	0.00	1.35
EPILO	*Epilobium* sp.		F	-	0.00	0.03	0.00	0.03	0.18
ERIPUM	*Erigeron pumilus*	shaggy fleabane	F	N	0.00	0.00	0.00	0.00	1.18
ERISPA	*Eriastrum sparsiflorum*	Great Basin woollystar	F	N	0.00	0.00	0.00	0.00	0.05
ERIOG	*Eriogonum* sp.	buckwheat	S	N	0.00	0.00	0.00	2.25	0.00
EROCIC	*Erodium cicutarium*	redstem stork's bill	F	I	0.58	0.00	0.00	0.00	0.08
GRASPI	*Grayia spinosa*	spiny hopsage	S	N	3.75	0.00	0.00	0.00	0.00
HESCOMC	*Hesperostipa comata* ssp. *comata*	needle-and-thread grass	G	N	0.00	0.00	0.20	3.38	0.00
LACSER	*Lactuca serriola*	prickly lettuce	F	I	0.10	0.10	0.00	0.00	0.00

Code	Current Name	Common name	Habit	Nativity	Brown Butte	Double Mtn	North Harper North	Snively	South Alkali
LINPUN	*Linanthus pungens*	granite prickly phlox	S	N	0.00	0.00	0.38	0.03	0.00
MACCAN	*Machaeranthera canescens*	hoary tansyaster	F	N	0.00	0.00	0.00	0.25	0.20
OENPAL	*Oenothera pallida*	pale evening primrose	F	N	0.00	0.00	0.00	0.00	0.53
OPUPOL	*Opuntia polyacantha*	plains prickly pear	F	N	0.00	0.00	0.15	0.00	0.00
PASSMI	*Pascopyrum smithii*	western wheatgrass	G	N	0.00	1.00	0.00	0.35	0.15
PENACU	*Penstemon acuminatus*	sharpleaf penstemon	F	N	0.00	0.00	0.03	0.00	0.50
PHAHET	*Phacelia heterophylla*	varileaf phacelia	F	N	0.00	0.00	0.03	0.00	0.35
PHALIN	*Phacelia linearis*	threadleaf phacelia	F	N	0.00	0.00	0.43	0.00	0.10
POABUL	*Poa bulbosa*	bulbous bluegrass	G	I	0.00	0.00	0.00	0.20	0.00
POASEC	*Poa secunda*	Sandberg bluegrass	G	N	0.35	0.05	1.53	0.05	2.85
SALTRA	*Salsola tragus*	prickly Russian thistle	F	I	0.10	0.18	0.00	0.43	0.00
SPHGRO	*Sphaeralcea grossulariifolia*	gooseberryleaf globemallow	F	N	0.18	0.00	0.00	0.00	0.00
TRADUB	*Tragopogon dubius*	yellow salsify	F	I	0.00	0.00	0.00	0.00	0.03
VULPIA	*Vulpia* sp.	fescue	G	-	0.00	0.00	0.78	0.00	0.03
ZIGVEN	*Zigadenus venenosus*	meadow deathcamas	F	N	0.00	0.00	0.03	0.00	0.00

APPENDIX E. OUTPUT FROM STATISTICAL ANALYSES IN 2018.

1. Two factor analysis of variance (ANOVA) for the mean diameter (cm; log-transformed) of *A. mulfordiae* in **2018 only,** by treatment (caged/uncaged) and site. Predictors with a *p*-value < 0.05 are in bold. Data were tested with South Alkali subsites clumped (Site df=5).

	Df	SS	MS	F value	*P* value
Treatment	1	0.119	0.1186	0.358	0.55151
Site	5	3.604	0.7209	2.175	0.06550
Treatment:Site	5	7.433	1.4866	4.485	**0.00122**
Residuals	87	25.523	0.3315		

2. Analysis of variance (ANOVA) table for the mean diameter (cm; log-transformed) of *A. mulfordiae* in **2010-2018**, by site, treatment, and year. Predictors with a *p*-value < 0.05 are in bold.

	Df	SS	MS	F value	*P* value
Treatment	1	0.33	0.326	1.026	0.311366
Site	5	43.82	8.765	27.622	**< 2.2e-16** ***
Year	7	29.25	4.178	13.168	**2.92e-16** ***
Treatment:Site	5	7.64	1.528	4.814	**0.000237** ***
Treatment:Year	7	3.89	0.555	1.751	0.093939
Site:Year	35	26.31	0.752	2.369	**1.72e-05** ***
Treatment:Site:Year	35	18.36	0.524	1.653	**0.010523** *
Residuals	945	299.86	0.317		

3. Analysis of variance (ANOVA) table for the mean diameter (cm) of *A. mulfordiae* at **South Alkali in 2018 only,** by treatment (caged/uncaged). Predictors with a *p*-value < 0.05 are in bold.

	Df	SS	MS	F value	*P* value
Treatment	1	1.198	1.1979	4.422	**0.0418** *
Residuals	40	10.836	0.2709		

4. Analysis of variance (ANOVA) table for the mean diameter (cm) of *A. mulfordiae* at **Snively in 2018 only,** by treatment (caged/uncaged). Predictors with a *p*-value < 0.05 are in bold.

	Df	SS	MS	F value	*P* value
Treatment	1	2.360	2.360	18.82	**0.0123** *
Residuals	4	0.5015	0.1254		

5. Generalized linear model (glm) results for number of fruits per reproductive plant in 2018, by predictor variables treatment (caged/uncaged) and site.

Coefficients:

	Estimate	**SE**	**t value**	**P value**
(Intercept)	2.5649	2.5837	0.993	0.324
Double Mountain	-0.2231	2.7405	-0.081	0.935
North Harper North	-1.4663	4.5978	-0.319	0.751
North Harper South	1.3350	2.6508	0.504	0.616
Snively	0.1866	2.9193	0.064	0.949
South Alkali	-0.2785	2.6511	-0.105	0.917
Uncaged	-2.5649	4.5978	-0.558	0.578
Double Mountain: uncaged	4.3285	4.7382	0.914	0.363
North Harper North: uncaged	-9.8362	1608.4183	-0.006	0.995
North Harper South: uncaged	2.6391	4.6446	0.568	0.571
Snively: uncaged	-0.8797	8.1472	-0.108	0.914
South Alkali: uncaged	3.9285	4.6488	0.845	0.400

Dispersion parameter for quasipoisson family: 86.78331
Null deviance: 7467.7 on 98 degrees of freedom
Residual deviance: 5711.0 on 87 degrees of freedom