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Soil and vegetation survey of Antelope Pasture, Curlew Grazing Allotment, Oneida County, ID

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Introduction

Antelope Pasture, located in the Black Pine Valley of Oneida County, Idaho, is a 1500-acre portion of the Curlew Grazing Allotment, managed by the Pocatello Field Office of the BLM (Figure 1). The pasture is heavily invaded with exotic annuals such as cheatgrass (*Bromus tectorum*), halogeton (*Halogeton glomeratus*), and clasping pepperweed (*Lepidium perfoliatum*), and grazing is temporarily discontinued. Land-use history of the pasture includes livestock grazing, possible homesteading and cultivation of *Agropyron cristatum* (crested wheatgrass).

Land use history

A patent search was conducted within the Bureau of Land Management (BLM) General Land Office Records for township sections within and around Antelope Pasture (Figure 2) to determine land-use history. Two records were found for sections 27 and 23 (the pasture's southern half and northeastern corner) (Department of Interior 2018). Those patents reveal that the odd-numbered sections were once under the ownership of the Central Pacific Railroad and included in a 400,000 acre ranch managed by railroad baron Charles Crocker. In 1909, the ranch was purchased in its entirety by the Promontory-Curlew Land Company to be resold in small parcels (Bullen Jr. 1966a; Francaviglia 2008). Advertisements produced in 1917 (Figure 3) indicate that neither the odd-numbered sections of Antelope Pasture nor any of the sections elsewhere in Black Pine Valley had sold by that time (Bullen Jr. 1966b). Ultimately patent record show these sections were acquired by the federal government under the Bankhead Jones Act of 1937, which allowed the federal government to purchase degraded land for rehabilitation (Department of Interior 2018).

No patents were found for sections 22 (the majority of the pasture's northern half) and 26 (the southeastern corner). If they were homesteaded, the settlers did not fulfill the requirements to "prove up," or file a claim. There is some visual evidence to suggest settlement in the northwest corner of Section 22, including artifacts such as pots and bed frames were found on the ground. The general area underwent a dry farming "boom and bust" in the early 1900's, due to the Enlarged Homestead Act of 1909 and the efforts of companies such as the Promontory-Curlew Land Co to sell land to wheat farmers. Many farms quickly failed and were abandoned by the 1920's (Morris et al. 2011).

Other than the possibility of a brief homestead, it is likely that the main land use history of Antelope Pasture was livestock grazing, from at least the time of Crocker's ownership and possibly earlier. Until the Taylor Grazing Act of 1937, public land was grazed on a first-come, first serve basis (Svejcar 2015), and Crocker's grazing of a checkerboard of odd-numbered sections would have ensured that cattle wandered freely across the neighboring sections if they were unfenced. In the Great Basin, extensive and unregulated grazing at the turn of the century is considered a main contributor to the invasion of cheatgrass and halogeton. Depletion of the native bunchgrasses and resulting soil erosion left the system open to invasion (Knapp 1996; Tisdale and Zappetini 1953). Great Basin valleys lowest in elevation and precipitation, such as the location of Antelope Pasture, have been identified as among the most susceptible to degradation from novel disturbance (such as inappropriate grazing practices) and the least resilient. This is attributable to factors such as low and variable precipitation, low cover of native grasses, low productivity, and low or episodic plant recruitment (Chambers et al. 2007).

Once incorporated in the BLM, Antelope Pasture was included in early attempts at controlling halogeton and soil erosion in alkali soils (Department of Interior 1953; Department of Interior 1960; Young 1988). In 1952, over 10,000 acres within Black Pine Valley were seeded with crested wheatgrass and *Melilotus officinalis* (yellow sweet clover). The project was described as a seeding of areas of "questionable rainfall," "heavily infested with jack rabbits" (Department of Interior 1960) for the control of halogeton. Seedbed preparation involved chaining or light harrow dragging, plowing and fertilizer application (Department of Interior 1953). Only the center swath of Antelope Pasture was included in this seeding (Figure 4).

Grazing standards and pasture divisions set in 1997 for the Curlew Grazing Allotment put Antelope Pasture on a fall/spring/rest rotation. A 2013 Land Health Assessment found that available forage in the pasture was far below allocated rates, and that the situation was similar for surrounding pastures in the 8-12" precipitation zone. Antelope Pasture was determined to have failed Standard 5 (Seeding) and Standard 8 (Threatened and Endangered Plants and Animals) (Department of Interior 2015a). In 2015, the Grazing Permit Renewal for the Curlew Allotment proposed that the stocking rate for Antelope Pasture be reduced, that only fall grazing be allowed, or that the pasture be rested until a restoration plan could be developed (Department of Interior 2015b).

Climate

Antelope Pasture has a cold semi-arid climate. Monthly normals for the 30-year period of 1981-2010 were obtained from the PRISM Climate Group, Oregon State University (Figure 5). Mean annual precipitation for the 1981-2010 is 11.95 inches (303.5 mm), and mean annual temperature is 47.7 °F (8.72 °C) (PRISM, accessed April 2018). Precipitation is typically highest in May and then drops drastically as the temperature climbs during the summer months. The warmest months of July and August are also the driest, creating a short growing season and summer drought. The bulk of precipitation comes as spring rain or winter snowfall.

Geologic History

Black Pine Valley was covered by pluvial Lake Bonneville during the late Pleistocene epoch. At 4500-4400 ft (1372-1341 m) elevation, Antelope Pasture was inundated with fresh water during the Bonneville and Provo high stands. The geology of the surrounding ranges is predominantly sedimentary rocks and includes an abundance of Permian and Pennsylvanian limestone, a highly calcareous rock derived from marine sediment (Long and Link 2007). Lake Bonneville caught the weathering products of surrounding ranges transported in alluvial systems, and deposited them in deep layers of lacustrine sediment. As Lake Bonneville receded below the Provo high stand and dropped below its natural outlet at Red Rock Pass, solutes such as calcium and sodium concentrated as the lake evaporated. Concentrated salt deposits are a cause of saline soils in the low valleys of the Great Basin (Chronic 1990; Stokes 1986).

Aerial photography of the valley shows that as the lake receded, remnant shorelines left terraces ringing the valley. Two visible terraces pass through Antelope Pasture; one crosses the northern end and one runs through the middle (Figures 1&2).

Current Soil Classification and Ecological Site Descriptions

The U.S Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) mapped the majority of Antelope Pasture as Mellor-Freedom complex, 0 to 2 percent slopes. According to the map unit description, 50% is Mellor series and similar soils, and 35% is Freedom series and similar soils; a complex is typically mapped when the main components of a map unit cannot be represented at 1:24,000 scale. A small area in the southeastern corner is mapped as Bayhook silt loam, 0 to 2 percent slopes (Figure 6). Soil classification changes at the Utah/Idaho border (the pasture's southern boundary). South of the pasture, soils have been classified as Thiokol silt loam, low rainfall, 0 to 1 percent slopes (Soil Survey Staff 2018c).

The Mellor series has been associated with two Ecological Site Descriptions -- Alkali Flat (Black Greasewood) R028AY004UT, and Semidesert Alkali Loam (Black Greasewood) R028AY202UT. The Alkali Flat description is a greasewood/shadscale community with saline and sodium-affected soils. Halophytic plant species and warm-season grasses are present. The semidesert alkali loam description is an ecotone between greasewood/shadscale Wyoming big sagebrush communities. Soils are salt-affected with sodium as the dominant component (Soil Survey Staff, 2018a).

The Freedom and Bayhook series have been associated with the Semidesert Loam (Wyoming Big Sagebrush) R028AY220UT Ecological Site Description. This vegetation community is co-dominated by Wyoming big sagebrush and *Pseudoroegneria spicata* (bluebunch wheatgrass). (Soil Survey Staff, 2018a). Soils are neither saline nor sodic (Soil Survey Staff, 2018a).

Study Objectives

Although the existing information on Antelope Pasture outlined above provides general information about the soils and vegetation of the area, detailed site-specific information is required for successful management of the pasture. To that end, in 2017, the Pocatello BLM Office partnered with Utah State University to provide detailed soil and vegetation maps of Antelope Pasture, determine plant-soil relationships and incorporate these results into a series of experiments on revegetation approaches. This report's focus is the soil and vegetation mapping and plant-soil relationships.

Methods

A survey of the soil and vegetation of Antelope Pasture was conducted in the summer of 2017. Vegetation sampling took place in May and early June, and soil sampling in June and July. Vegetation sample points were distributed systematically along a grid, for a total of 282 points (Figure 7). A subset of 58 points, located 300 m apart (Figure 7), were designated for soil sample collection as well as vegetation measurements. In the westernmost column, sampling points were laid out 100 meters apart, but after this the grid was expanded to 150 meters for remainder of the survey. At each sample point, a 1 x 3 meter vegetation sampling plot (Figure 8) was set up to the east. Soil samples were taken from the center of the 1 x 3 meter plot.

Vegetation Mapping

Along both long sides of the 1 x 3-meter plot, plant and soil surface cover were measured using the line-point intercept method (Herrick et al. 2005), dropping a pin every 30 cm for a total of 10 points per transect and 20 points per plot. Any interception of live vegetation, dead vegetation attached to the root crown of a living plant, or standing dead annual species from the current growth year was recorded as an intercept of a live plant species. Interceptions of standing dead annual plant species from previous growth years were recorded as "dead herbaceous," to provide a measurement of the standing dead litter created by invasive annual plants. Detached litter was considered an intercept rather than a soil surface code. To obtain data on species of low or sporadic cover, presence of all additional species with canopy cover within the 1 x 3-meter plot, but not intercepting the 3-meter transects, were recorded. Together, these methods provided cover and frequency measurements and captured the presence of rarer species that would otherwise have been missed. Waypoints were taken for incidental sightings of species not found within any plots to provide additional data on rare species and facilitate future monitoring.

To depict cover of individual species and functional groups, maps were created in ArcMap 10.4.1 software (Environmental Systems Research Institute, Redlands, CA) using dot density symbology, which distributes dots randomly within a set polygon. This entailed creating a grid of 5.5-acre (300 x 300 m) polygons across Antelope Pasture, centered on our vegetation sample points. Then, within each polygon, the cover value of a species or functional group (measured in the field at the sample point) was represented as a series of randomly distributed dots, with each dot representing 5% cover and all dots summing to the total % cover. For example, to represent 50% cover of a species in a given polygon, ten dots would have been randomly distributed throughout the polygon. This approach was used to display percentage cover of all plant species intercepted in the 2017 survey and introduced annual cover overlaid on presence/absence of shrubs and crested wheatgrass.

Spearman rank correlation tests were performed on vegetation cover data to analyze pairwise relationships. Pearson's chi-square tests were performed on presence/absence data to test for independence between species or functional groups. To explore multivariate relationships among species, principal components analysis (PCA) was performed on vegetation cover data. After each PCA, variables that did not have a loading value of 0.3 or above for at least one of the first three principal components were eliminated, until a final solution was reached (Hirsch-Shantz et al. 2014). To examine the effect of crested wheatgrass on invasive annual species, we subset cheatgrass and introduced annual forbs into populations with and without the presence of crested wheatgrass. Population distributions with and without crested wheatgrass were visualized with boxplots and compared using Wilcoxon rank sum tests. This same process was performed on population subsets of cheatgrass and introduced annual forbs with and without the presence of shrubs. Analyses were conducted in JMP v. 13. (SAS Institute Inc., Cary, NC) and R v. 3.4.2 (R Core Development Team 2017).

Soil Sampling, Analysis, and Mapping

At each sample point, the soil pedon was excavated to a depth of 150 cm with a bucket auger, laid out along a tarp according to depth, and divided into genetic horizons. For each horizon, we recorded soil color (dry and moist), texture, consistence, pH, effervescence, roots, and ped and void surface features. For surface horizons we also assessed soil structure and horizon boundary. We followed National Cooperative Soil Survey soil pedon description and sampling protocols

(Schoeneberger et al. 2012; Soil Science Division Staff 2017; Soil Survey Staff 2012). Soil pH was measured in the field using phenol red and thymol blue colorimetric indicator solutions, and effervescence class was determined using 1M hydrochloric acid.

Soil pH was used as a proxy measurement for sodium during the classification process. Soil pH has been shown to have a positive correlation with exchangeable sodium in aridic soils (Bhargava and Abrol 1978), and sodic soils will generally have a pH of 8.5 or greater in carbonate-rich soils. The pH, electrical conductivity (EC), and sodium adsorption ration (SAR) was determined on a subset of 12 soil samples by USU Analytical Laboratory (USUAL). Soil horizons chosen for analysis included several strongly alkaline (pH 8.5 to 9.0) horizons with and without evidence of clay illuviation and one slightly alkaline (pH 7.4 to 7.8) horizon with evidence of clay illuviation. To provide enough soil for lab sampling, each sample consisted of two adjacent horizons from each pedon. Only horizons of similar clay content and pH were combined. Simple linear regression was performed to test for relationships among SAR, EC and pH. Response variables were square root transformed to improve normality.

Principal components analysis (PCA) was used to examine relationships among a chosen set of soil variables. These variables included percent clay, pH, effervescence and depth of A1 horizons, pH and percent clay at 30 cm (a depth at which all but three natric horizons are intercepted), and maximum percent clay within each pedon. Variables also included depth to, pedon weighted average of, and maximum within a genetic horizon of the following ped and void surface features: redox depletions, carbonate concentrations, silica concentrations and redo concentrations. Concentrations and depletions were reported as the percent of the visible soil surface area occupied within a horizon. The pedon weighted average was calculated by multiplying the amount for each horizon by the horizon thickness (cm), summed, and divided by 150 cm. We created maps in ArcMap to show the spatial distribution, depth and amount of soil ped and void features for each pedon, using ArcMap multiple attribute symbology.

For PCA, the soil variables described above each were standardized by subtracting the mean and dividing by the standard deviation for that variable. This method of standardization placed all variables on a common scale, with a mean of zero (0) and a standard deviation of one (1). During analysis, variables that did not have a loading value of 0.3 or above for at least one of the first three principal components were eliminated until a final solution was reached (Hirsch-Shantz et al. 2014). In the final graph, if variables derived from the same soil attribute (such as maximum silica concentrations and weighted average of silica concentrations) co-varied strongly, the variable with the lesser eigenvector was eliminated. We repeated this PCA process for the 12 pedons sampled for SAR and EC, again standardizing these two variables as described above. PCA analysis used the FactoMineR package (Le et al. 2008).

Kruskal-Wallis rank sum tests were performed on the same set of soil variables to test for significant differences between soil families and subgroups. All analyses were conducted in R v. 3.4.2 (R Core Development Team 2017).

We classified all soil pedons to order, suborder, great group, subgroup, and family following the Keys to Soil Taxonomy, 12th edition (Soil Survey Staff 2014). We prepared descriptions of representative soils. We assessed spatial patterns in topography using a Digital Elevation Model

(USGS 10-meter DEM, Figure 9). We correlated the soil pedons described and sampled to an established soil series. We delineated boundaries between soil types based on soil morphology, soil classification, and topography.

Soil-Vegetation Relationships

Spearman rank correlation tests were performed to analyze one-to-one relationships between soil surface categories and dominant plants species and/or functional groups. Data from plots sampled for both soil and vegetation were subset based on soil family, subgroup, great group and hypothesized disturbance history (hypotheses included possible fire or plowing). Kruskal-Wallis rank sum tests were then performed on both soil and vegetation data to identify significant differences between categories. Constrained Correspondence Analysis (CCA) was performed on cover data for key species, using the set of soil variables described above. Plant species were chosen based on PCA analyses of vegetation data, and CCA analyses were run on each explanatory variable separately, with an alpha of 0.05 set as criteria for inclusion in our final model (Draper and Smith 1981). All analyses were conducted in R v. 3.4.2 (R Core Development Team 2017). CCA analysis used the Vegan package (Oksanen et al. 2013).

Results and Discussion

Vegetation

We found a total of 42 plant species at Antelope Pasture, 26 of which are native to the region (Appendix Table 1-1). However, species of the highest cover and frequency were introduced annuals such as *Bromus tectorum* (cheatgrass), *Lepidium perfoliatum* (clasping pepperweed), *Descurainia pinnata* (flixweed) and *Ranunculus testiculatus* (burr buttercup), as well as the seeded perennial *Agropyron cristatum* (crested wheatgrass) (Appendix Tables 1-2 thru 1-4; Figures 10-14). Introduced annual forbs, as a functional group, had a lower mean cover value than cheatgrass (39% compared to 63%) but were similar in frequency (93% forbs, 94% cheatgrass). The dominant grasses were *Elymus elymoides* (bottlebrush squirreltail) and *Poa secunda* (Sandberg bluegrass) (Figure 14). Bottlebrush squirreltail was the most common native herbaceous species. Shrub cover was highest in the northwest corner of the pasture, where *Sarcobatus vermiculatus* (Greasewood) and *Artemisia tridentata* (sagebrush) were intermixed, and in the southeast corner, where sagebrush predominated (Figure 15).

Spearman rank correlation tests performed on vegetation cover data show significant, but relatively weak correlations between species, especially those of native origin (Figure 20). Principal components analysis confirmed that invasive annual species drive the dominant relationships within the current vegetation (Figure 21, Table 1), consistent with displacement of native species by invasive annuals and a lack of intact native communities. Native perennial grasses did show weak associations with shrubs, such as the positive correlation between squirreltail and sagebrush (Figure 20). As a functional group, native perennial grasses co-occurred with shrubs in 30% of plots, and shrub presence was significantly associated with native perennial grass presence ($X^2 = 52.18$, $p < 0.01$).

Cheatgrass tended to show negative relationships with other plant species and co-varied with "dead herbaceous," defined in our survey as standing dead herbaceous plant matter from previous growth years (Figures 20-21; Table 1). From this we inferred that cheatgrass has reduced species diversity and has created a fuel load of standing dead litter. Open patches of cheatgrass, many greater than 1 acre in size, are distributed throughout much of the pasture (M. Owen, personal observation). These patches can be identified by examining patterns of shrub cover (Figure 15); median cheatgrass cover was higher when shrubs were absent (presence of shrub =62.5%, absence of shrubs=90%; W=6371, $p<0.001$; Figure 22), and shrubless patches are often located where cheatgrass cover is highest (Figure 18). Dense patches of cheatgrass are visible in NAIP aerial imagery; a comparison of field results in Figure 11 to imagery in Figure 2 shows that, in 2017, reddish or pinkish coloration in the aerial imagery coincide with field-mapped cheatgrass populations. The size and lack of plant biodiversity within these patches provide an opportunity for herbicide treatment and reseeding. The litter load should be taken into consideration during these treatments. Litter acts as a positive feedback for cheatgrass, not only by shortening the fire regime (Brooks et al. 2004) but by promoting cheatgrass germination through moderated soil surface temperatures and reduced evapotranspiration (Young et al 1972). Experiments done in nearby Park Valley have shown that cheatgrass suppression is more effective and longer-lasting when treatments that remove litter, such as prescribed fire, are used (Hirsch-Schantz et al. 2014).

Results also suggest that introduced annual forb species found during our survey (clasping pepperweed and burr buttercup) were more adept at invading shrub canopies than at competing with cheatgrass in open areas (Figures 19). Introduced annual forb cover was higher when shrubs were present (presence of shrubs=40%, absence of shrubs=20%, W=12400, $p<0.001$; Figure 22). Introduced annual forbs tended to co-occur with specific shrub species (Figure 21, Table 1). This pattern was most apparent in the northwest corner of the pasture, where clasping pepperweed and burr buttercup have invaded an intact canopy of greasewood and sagebrush but cheatgrass was limited or absent (Figures 10-13, 19). The northwest corner of the pasture is distinctive due to its lack of cheatgrass, intact shrub community, and other factors such as high biological soil crust development (Figures 15-16). We hypothesize that this pattern is due, in part, to a difference in disturbance history; while the portions of the pasture with fragmented shrub cover, open cheatgrass patches and low biological soil crust were mostly likely affected by fire or cultivation, this corner was not. In this area of the pasture, invasive annual forbs dominate the understory and perennial grasses are depleted, but we believe this is more likely due to inappropriate grazing practices rather than fire or soil disturbance.

Crested wheatgrass was the dominant species over much of the area where it was seeded in 1952 (Figures 4 & 14). The central portion of the seeding appears to have been unsuccessful and has been invaded with cheatgrass (Figure 18). In plots where it was present, mean cover was 40% and median 45%, and plants were healthy and robust. Crested wheatgrass appeared to have a suppressive effect on introduced annual species cover (Figures 18-19, 22). Crested wheatgrass presence reduced median cheatgrass by 82% (presence of CWG=15%, absence of CWG=85%; W=3667, $p<0.001$). Although the 1952 seeding has continued to thrive and suppress populations of invasive annual plant species, vegetation cover data shows that these stands have also excluded native species and limited biodiversity.

Due to the degraded nature of the vegetation communities within the pasture, many species were rare and only encountered incidentally, outside of any sampling plots (Appendix Tables 1-2 thru 1-4). This was the case for the majority of native, perennial forbs, but also for many warm-season, introduced annuals. In particular, during our sampling period the distribution of the introduced annual *Halogeton glomeratus* (halogeton) was limited to ruderal zones or areas with soil disturbance, such as ditches and a few animal mounds near to the central two-track (M. Owen, personal observation). Halogeton populations were small enough to be feasibly controlled by spot-spray herbicide treatments along dirt roads, ditches running north/south in the northeast corner, and the prominent ditch beginning in the northwest corner and running diagonally through the pasture (M. Owen, pers. obs.). Other warm-season, introduced annuals such as *Atriplex rosea* (tumbling saltbush), *Salsola tragus* (Russian thistle) and *Kochia scoparia* (kochia) were either found incidentally or were limited in abundance, but were dispersed throughout the pasture (Figure 11). It is possible that these species have had a wider distribution in years when patterns in precipitation favored warm-season invasive annuals over cold-season. The diversity and number of introduced, annual forb species within the pasture creates the risk that cheatgrass control will result in dominance by a different invasive annual. The best way to mitigate this risk will be to plant competitive, perennial grasses following weed control.

In conclusion, the current vegetation of Antelope Pasture is a mosaic of introduced annual species, seeded perennial species (crested wheatgrass) and remaining fragments of the original salt-desert shrub community. We conclude that due to the co-dominant and intermixed sagebrush and greasewood, the lack of bluebunch wheatgrass and the limited number of halophytic species or warm season grasses, the site is best described by the Semi-Desert Alkali Loam R028AY202UT NRCS Ecological Site Description (Soil Survey Staff, 2018a). This ESD describes the reference state as a broad ecotone between Wyoming big sagebrush and greasewood/shadscale communities, with bottlebrush squirreltail, Sandberg bluegrass and Indian rice grass as the primary grasses. Shrubs are the dominant vegetation component, with cover in the reference state estimated at 50%. Grass and forb cover in the reference state are 35% and 10%, respectively. Current native species cover and diversity are well below these levels and are not likely to improve on their own. State and transition models developed for the Semi-Desert Alkali Loam ESD depict the Shrub-Dominated/Invasive Annual and Invasive Annual States as stable alternatives to the reference condition (Soil Survey Staff, 2018a). Without active restoration, transitions from shrub-dominated to annual-dominated communities are likely to continue.

Soils

The primary diagnostic features for Antelope Pasture soils were shallow accumulations of exchangeable sodium and calcium carbonate, resulting in natric and calcic horizons. Pasture soils also displayed thin, pale surface horizons (ochric epipedons) indicative of low organic matter and fertility. Pedons with diagnostic subsurface horizon(s) and an aridic soil moisture regimes were classified in the soil order of Aridisols, in agreement with NRCS classification for the Idaho portion of the valley floor. Aridisols share a soil moisture regime in which evaporation exceeds precipitation for the majority of the year and soils are often deficient in water. The shallow calcic and natric horizons within the pasture indicate that percolation of water into the soil has often been limited to the uppermost horizons, though the average depth of wetting would have increased during seasons of high precipitation (Buol et al. 2011).

We found 75% of pedons to have a natric horizon; these soils were classified into the Natrargids great group (Figures 23 & 29). To qualify as a natric horizon, horizons exhibited an increase in clay relative to overlying horizon(s), and the sodium adsorption ratio reached 13 or greater within 40 cm of the horizon upper boundary (Soil Survey Staff 2014). There was a positive relationship between SAR and pH ($F(1,9)=6.949$, $p=0.027$, $r^2=0.373$, after the removal of one outlier, soil sample 215). This provided evidence for our use of soil pH as a proxy measurement for SAR, though this relationship did not have a high predictive value. Soil pH, measured in the lab was generally lower than field pH.

Natric horizons were often near the soil surface; median depth to the upper boundary was 10 cm, with a maximum depth of 61 cm. As soil samples were collected by auger, structure could not be observed, but natric horizons have a blocky, compressed structure due to the detrimental effects of sodium and should be expected to display poor permeability and act as a root-restricting layer. Excessive tillage of such soils would further degrade the structure. Erosion or disturbance of the thin surface horizon above them would expose soils rich with sodium and clay and would likely cause surface crusting (Brady and Weil 2010).

The EC of soil samples (Table 3) ranged from less than 1 to 9 dS/m, while SAR ranged from 2 to 46 (soils with an EC greater than 4 dS/m are considered saline, and soils with an SAR greater than 13 are considered sodic) (Brady and Weil 2010). SAR was above 13 in strongly alkaline soils both with and without evidence of clay illuviation (Figure 25). Soils with SAR greater than 13 that did not meet the minimum clay increase for a natric horizon were classified into sodic subgroups of the Haplocalcids great group. Two pedons contained shallow, subsurface horizons with a high amount of accumulated clay but maintained a pH of 8.4 or below. The minimum clay increase was sufficient to meet the requirements for an argillic horizon, and the soils were classified into the Calciargids great group (Soil Survey Staff 2014).

All pedons showed evidence of calcification (the accumulation of calcium carbonates), whether through the presence of finely disseminated carbonates, light coloration, or effervescence in response to hydrochloric acid. Masses of secondary (i.e., translocated) calcium carbonates 2-20 mm in size were present in the subsurface horizons of all but a few samples (Figure 25), but cementation was not found to have proceeded past that stage in any of the sampled pedons. Subsoil horizons 15 cm thick or greater, with non-cemented accumulations of calcium carbonates were classified as calcic horizon. Soils with calcic horizons within 100 cm of the soil surface (and lacking natric horizons) were classified into the Haplocalcids (no argillic horizon) or Calciargids (with argillic horizon) great groups (Figures 24 & 29) (Soil Survey Staff 2014). There was no significant difference in depth, weighted average or maximum amount of calcium carbonate concentrations between soil families or subgroups. Calcic horizons typically occurred below any argillic or natric horizons; median depth to the upper boundary in pasture soils was 57 cm. Calcic horizons are not typically detrimental to native plant productivity, though calcium carbonate will neutralize soil acidity and affect the solubility of some nutrients (Buol et al. 2011).

Additional subsurface features present in pasture soils included redoximorphic features and silicate concentrations. These features were not present in sufficient amounts to affect classification and there were no significant differences in depth, weighted average or maximum amount of silica concentrations or redoximorphic features between soil families or subgroups. Silica masses and cementations (durinodes) 5-20 mm in size were found in nearly half of pedons and in all families except for fine-loamy Xeric Natrargids (Figure 26). Duric soils are common in arid or semi-arid soils and are distributed throughout the Great Basin, but are not generally detrimental to native plant productivity unless a cemented duripan is present (Bockheim 2014). Redox concentrations and depletions were present in the lower horizons of all but a few pedons (Figures 27-28). Reduction and depletion of iron oxides would have occurred under intermittent saturation and can indicate the depth of the water table, but these features can persist in soils for hundreds of years and may not reflect current conditions (James 2002). Our soil survey, conducted in June/July of 2017, found three saturated soils along the northern boundary of the pasture, at the base of a remnant lake terrace: samples 47, 50 and 53. Soil samples from these pedons were muddy below a depth of 80 cm.

As expected from NRCS soil maps (Figure 6), the majority of soils were classified into the Xeric Natrargids subgroup and were similar in morphology to the Mellor soil series. In our 2017 survey, soils at Antelope Pasture were found to fall into four families: fine-silty, mixed, superactive, mesic Xeric Natrargids; fine-loamy, mixed, superactive, mesic Xeric Natrargids; fine-silty, mixed, superactive, mesic Xeric Calciargids; and fine-silty, mixed, superactive, mesic Sodic Xeric Haplocalcids. Figure 29 shows these soil families at their sampling locations and Figure 30 delineates the boundaries of these families within the pasture. Descriptions of representative pedons are located in Appendix 2. Official Soil Series Descriptions and map unit descriptions for series mapped within Antelope Pasture are located online at USDA-NRCS websites <https://soilseries .sc.egov.usda.gov> and <https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx>, respectively.

The greatest discrepancies between NRCS and our 2017 field classifications came from differences in texture; the Mellor series is in the fine-silty family particle-size class and has a clay loam to silty clay loam natric horizon. Textures within our natric horizons ranged from silty clay loam to silt loam, and two pedons fell into the fine-loamy family texture class. We found Sodic Xeric Haplocalcids to be much more extensive across the pasture than expected. NRCS soil maps depict a Mellor-Freedom complex running through the center of Black Pine Valley, with the Bayhook series and other Sodic Xeric Haplocalcids encircling it (Figure 6). The Freedom series is fine-silty, mixed, superactive, mesic Xeric Haplocalcid and is not salt-affected, while our Haplocalcids classified into Sodic subgroups based on soil pH and the high sodium adsorption ratios. We would consider these Haplocalcids more similar to the Bayhook soil series, though again, there are differences in the family texture class: Bayhook is classified as coarse-silty rather than fine-silty. As we could not test all pedons for exchangeable sodium, it is possible that some are in fact more similar to the non-salt affected Freedom series.

Principal components analysis indicated calcium carbonate and silica concentrations to be prominent sources of variation within the data (Figure 31, Table 2). Silica concentrations and redoximorphic features varied independently of clay content, while solutes such as calcium carbonate displayed strong relationships to soil texture. This is likely due to the effect of texture on water infiltration or the presence of a seasonally high water table.

In conclusion, the soils of Antelope pasture are formed in medium- to fine-grained, lacustrine sediment and are primarily characterized by translocated accumulations of calcium carbonate and exchangeable sodium in the subsurface horizons. The primary differences among pedons were the presence or absence of natric horizons or silica masses. High SAR (>40 was found within the rooting zone of perennial grasses, shrubs and forbs. Excessive tillage is not recommended, and overgrazing can cause the erosion of the near-surface horizons, which may lead to soil crusting, formation of slick spots and continued decline in water infiltration. Proper grazing practices are necessary to maintain the health of these soils (Vecchio et al. 2018). Seedings of perennial grasses in the 1950's were largely successful within the pasture, including in areas with high pH as an indicator of SAR. If future seedings show a lack of success, soils could be tested for sodium to determine if that is a contributing factor. If so, application of gypsum or sulfuric acid has been shown to successfully amend sodic soils, but requires sufficient irrigation to leach sodium from the rooting zone (Qadir et al. 2001) and drainage of sodium-rich irrigation drainage water from the area.

Soil/Vegetation Relationships

The strongest relationships between soil and dominant vegetation were found in soil variables in proximity to or at the soil surface (Figure 32). Analyses did not uncover patterns in vegetation based on prominent subsurface features such as silica concentrations or redoximorphic features. Canonical correlation analysis showed weak patterns of covariance between vegetation and soil variables relating to texture, such as the depth of calcium carbonate concentrations and percent clay at a depth of 30 cm (Figure 33, Table 4). Greasewood cover was correlated with higher pH values in surface horizons, due to its ability to concentrate sodium oxalates and other solutes in its leaves (Rickard 1965), which are then shed each year onto the soil surface.

Introduced annuals such as cheatgrass and clasping pepperweed were more strongly associated with cover values for soil surface variables than for subsurface features (Figure 32). Native species were positively correlated with cover values for both moss and biological soil crust. Research in the Great Basin has previously identified a pattern of association between native vegetation and cryptogam-stabilized soils, and has suggested that these soils offer favorable microsites for plant establishment (Eckert Jr. et al. 1986; Belnap et al. 2001). In contrast, cheatgrass displayed a negative correlation with biological soil crust. The abundance of cheatgrass within the pasture and its continued persistence suggest that soil crusts are acting as a barrier to seed germination for this species. This pattern has also been identified in previous research within sagebrush ecosystems (Peterson 2013). Meanwhile, results for introduced annual forbs such as clasping pepperweed and *Ranunculus testiculatus* (burr buttercup) suggest these species do not have the same difficulty germinating in the presence of cryptogam or moss cover. This pattern is most apparent in the pasture's northwest corner, where soil crust and introduced annual forb cover are high and cheatgrass is largely absent (Figures 10-13, 16). Clasping pepperweed and bur buttercup are small-seeded species, and may be more adept at penetrating the physical barriers established by the presence of soil crusts.

No significant difference was found in the cover of dominant plant species (*Artemisia tridentata, Sarcobatus vermiculatus, Bromus tectorum* and *Lepidium perfoliatum*) between soils with natric horizons and without. Despite sodium's toxicity to plants (Abrol 1988), sodium adsorption ratio and electrical conductivity values (SAR and EC) did not show significant linear relationships with vegetation cover, and many species were present in abundance in soils with high SAR values within the rooting zone. For examples, *Agropyron cristatum* (crested wheatgrass) cover was 70% in plot 215, which had a sodium adsorption ratio of 26.5 at a depth of 11-44 cm below the soil surface.

We conclude that the strongest driving factor in relationships between pasture soils and vegetation identified through analyses was the presence or absence of a biological soil crust or moss cover. Because so few relationships were found between vegetation and soil variables, other factors, such as disturbance history, are more likely to be the central cause of variation in vegetation across the pasture.

Products

Antelope Pasture Geodatabase
We created a geodatabase with the following feature classes. The geodatabase uses the North American 1983 Datum (NAD83).

Vegetation Cover
This feature class includes vegetation, non-living plant matter and soil surface cover data for all 282 plots. Attribute fields include plot number, x and y coordinates in NAD83, sample date and cover (by plot) for all plant species, non-living plant matter and soil surface categories, labeled by species code (see Appendix Tables 1-1 thru 1-6 for species codes). A data dictionary is provided in the metadata.

Vegetation Presence
This feature class includes vegetation presence data for all 282 plots. Species are listed as present if they were intercepted along transect lines or located within the 3m plot. Attribute table fields include plot number, x and y coordinates in NAD83, sample date and presence (by plot) for all plant species, labeled by species code. A data dictionary is provided in the metadata.

Incidentals
This feature class includes data on incidental sightings of plant species, i.e., species that were only found outside of plots. Attribute table fields include x and y coordinates in NAD83 and species codes. A data dictionary is provided in the metadata.

Soil Data
This feature class includes soil data for all 58 soil samples. Attribute fields include plot number, x and y coordinates in NAD83, date sampled, soil subgroup/great group, pH and percent clay for the surface horizon (A1) and at a depth of 20 cm, 50 cm and 100 cm. Attributes also include EC and SAR lab results and maximum value for calcium carbonate, silicate and redoximorphic concentrations and redoximorphic depletions, given as a percent of the visible soil surface area occupied within a horizon. A data dictionary is provided in the metadata.

Family Polygons
This feature class delineates the extent of all soil families mapped within Antelope Pasture. Attribute table fields include family classification. A data dictionary is provided in the metadata.

Digital Images
We prepared a compilation of photos taken at each soil sampling point during the 2017 survey.

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Table 1. Principal component analysis factor loading values for vegetation data analysis. Included are two shrub species (ARTTRI and SARVER), one introduced annual grass (BROTEC), two introduced annual forbs (DESSOP and LEPPER) and standing dead herbaceous (DH). The accompanying PCA biplot is shown in Figure 20.

Species Code	**Species Name**	**Factor Loading Values: PCA1**	**Factor Loading Values: PCA2**	**Factor Loading Values: PCA3**
ARTTRI	*Artemisia tridentata*	-0.192	-0.154	**0.598**
BROTEC	*Bromus tectorum*	**0.512**	-0.156	-0.131
DESSOP	*Descurainia sophia*	-0.087	0.047	**0.432**
LEPPER	*Lepidium perfoliatum*	-0.204	**0.332**	-0.280
SARVER	*Sarcobatus vermiculatus*	-0.112	**0.994**	0.020
DH	Standing Dead Herbaceous	**0.984**	-0.054	-0.172

Table 2. Principal components analysis (PCA) factor loading values for soils data analysis. Values for concentrations and depletions were calculated as a percent of the visible soil surface area occupied within a soil horizon. The accompanying PCA biplot is shown in Figure 31.

Code	**Definition**	**Factor Loading Values: PCA1**	**Factor Loading Values: PCA2**	**Factor Loading Values: PCA3**
CaCO3.depth	Depth (cm) to calcium carbonate concentrations	-0.328	**0.535**	0.013
CaCO3.max	Maximum value of calcium carbonate concentrations within a horizon	0.428	**-0.445**	-0.032
Clay.max	Maximum percent clay within a horizon	**0.464**	-0.188	0.046
F3M.depth	Depth (cm) to redoximorphic concentrations	-0.172	-0.163	**-0.366**
F3M.max	Maximum value of redoximorphic concentrations within a horizon	**0.389**	0.200	0.441
FED.max	Maximum value of redoximorphic depletions within a horizon	0.182	0.348	**0.519**
Silica.depth	Depth (cm) to silica concentrations	-0.346	-0.400	**0.455**
Silica.max	Maximum value of silica concentrations within a horizon	0.400	0.364	**-0.437**

Table 3. Electrical conductivity (EC), sodium adsorption ratio (SAR) and pH of the 12 soil samples. Sample location within Antelope Pasture is shown in Figure 22. Soils with EC greater than 4 dS/m are considered saline, and soils with an SAR greater than 13 are considered sodic (Brady and Weil 2010). Soil horizons chosen for testing were subsurface horizons showing clay illuviation and/or high pH.

Sample #	Sample Depth (cm)	pH	EC (dS/m)	SAR	Soil Family
50	23-67	8.5	4.28	32.0	Fine-silty Sodic Xeric Haplocalcids
53	10-44	8.7	2.42	15.7	Fine-silty Sodic Xeric Haplocalcids
92	6-33	7.5	0.81	2.20	Fine-silty Xeric Natrargids
98	7-50	8.6	6.00	46.1	Fine-silty Xeric Natrargids
158	10-57	8.3	3.14	24.9	Fine-silty Sodic Xeric Haplocalcids
200	10-56	8.6	1.86	14.3	Fine-silty Sodic Xeric Haplocalcids
215	11-44	7.6	9.06	26.5	Fine-silty Xeric Natrargids
260	9-49	8.5	4.79	44.7	Fine-silty Sodic Xeric Haplocalcids
308	22-67	8.6	2.43	21.5	Fine-silty Sodic Xeric Haplocalcids
377	29-89	8.6	2.56	21.8	Fine-silty Sodic Xeric Haplocalcids
482	7-39	8.2	1.91	17.4	Fine-silty Xeric Natrargids
530	7-58	8.4	2.91	27.0	Fine-silty Xeric Natrargids

Table 4. Canonical correspondence analysis factor loading values soil/vegetation data analysis. Included are two native shrub species (ARTRI and SARVER), one introduced annual grass (BROTEC), two introduced annual forbs (DESSOP and LEPPER) and four soil variables. Explanatory soil variables are shown in blue, and plant response variables in red. For all, p-value <0.05. The accompanying CCA biplot is shown in Figure 32.

Code	Species Name	Factor Loading Values: CCA1	Factor Loading Values: CCA2	Factor Loading Values: CCA3
Response Variables				
ARTTRI	*Artemisia tridentata*	-0.060	**-0.818**	-0.182
BROTEC	*Bromus tectorum*	**-0.240**	0.060	0.013
DESSOP	*Descurainia sophia*	0.498	**-0.585**	0.517
LEPPER	*Lepidium perfoliatum*	**0.349**	**0.021**	-0.031
SARVER	*Sarcobatus vermiculatus*	**0.957**	0.361	-0.047
Explanatory Variables				
A.depth	Thickness of A horizon	-0.613	0.181	**0.766**
A.pH	A horizon pH	0.381	**0.662**	-0.064
Clay.30	% Clay at 30 cm from soil surface	**0.823**	-0.543	0.132
CaCO3.depth	Depth to calcium carbonate concentrations	**-0.677**	-0.519	-0.203

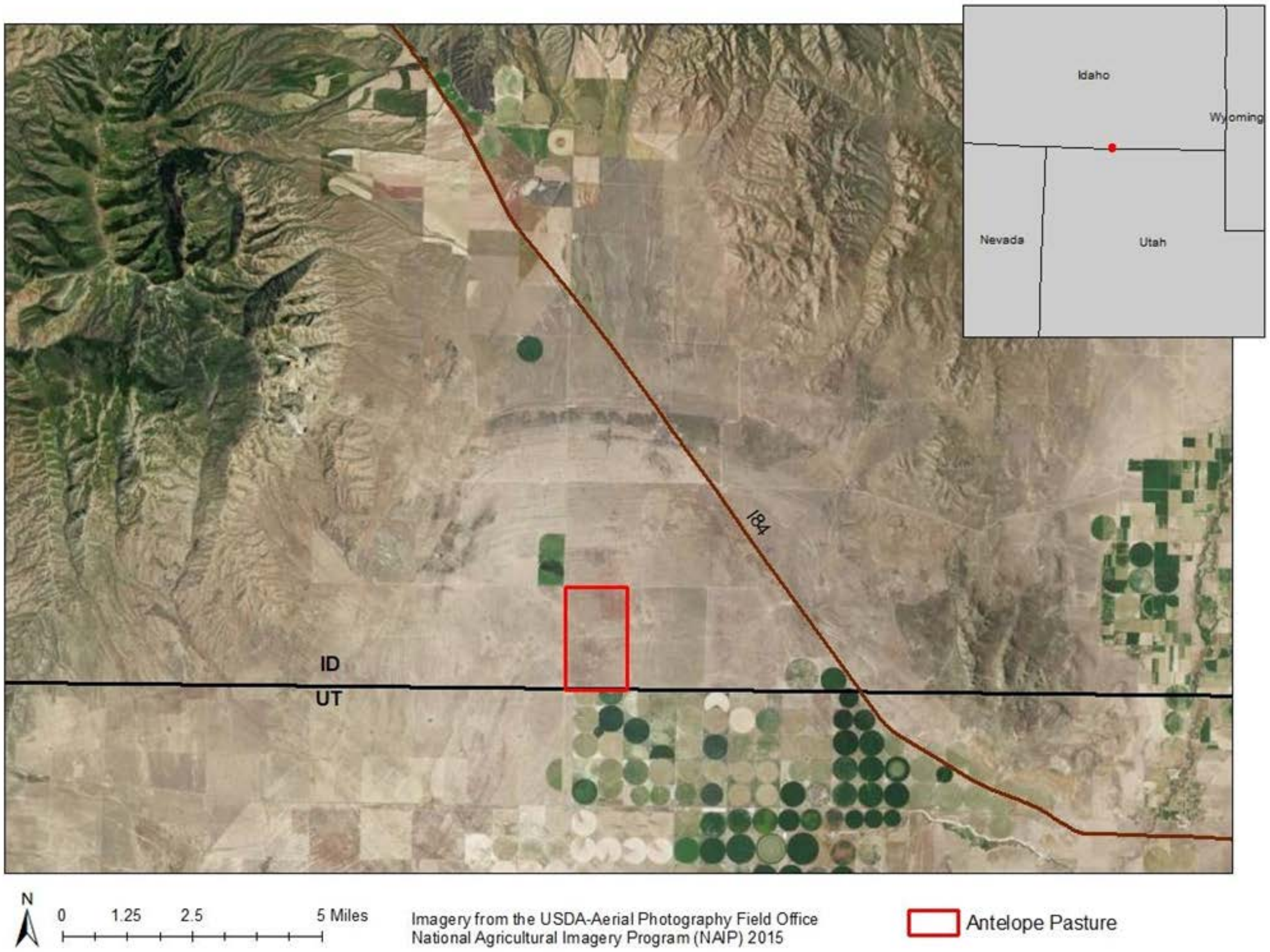
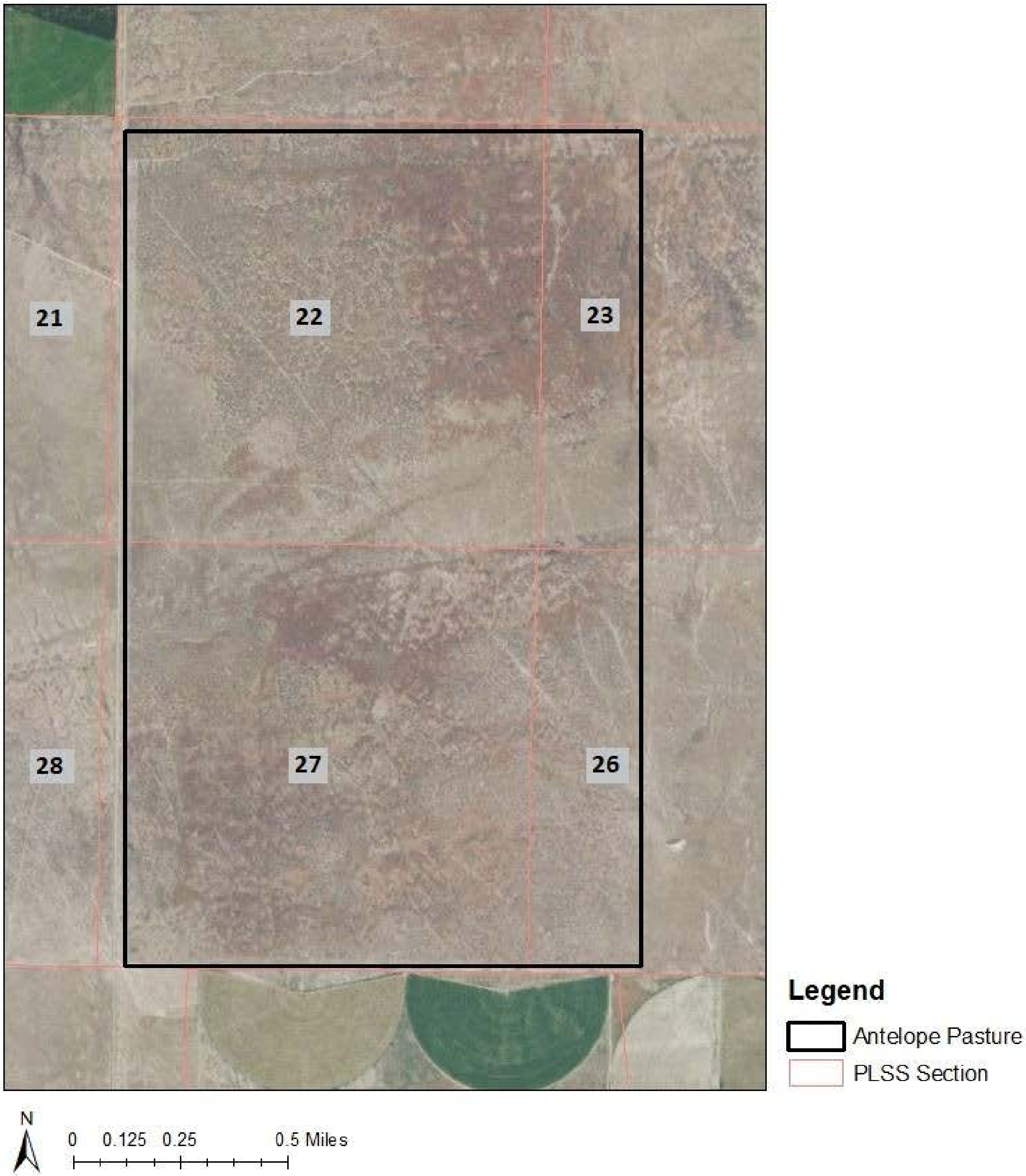


Figure 1. Location of Antelope Pasture in the Curlew Grazing Allotment.



Imagery from the USDA-Aerial Photography Field Office
National Agricultural Imagery Program (NAIP) 2015

Township sections from the
BLM Public Land Survey System (PLSS)

Figure 2. Township Sections of Antelope Pasture. Township and range coordinates are 16 S 30 E.

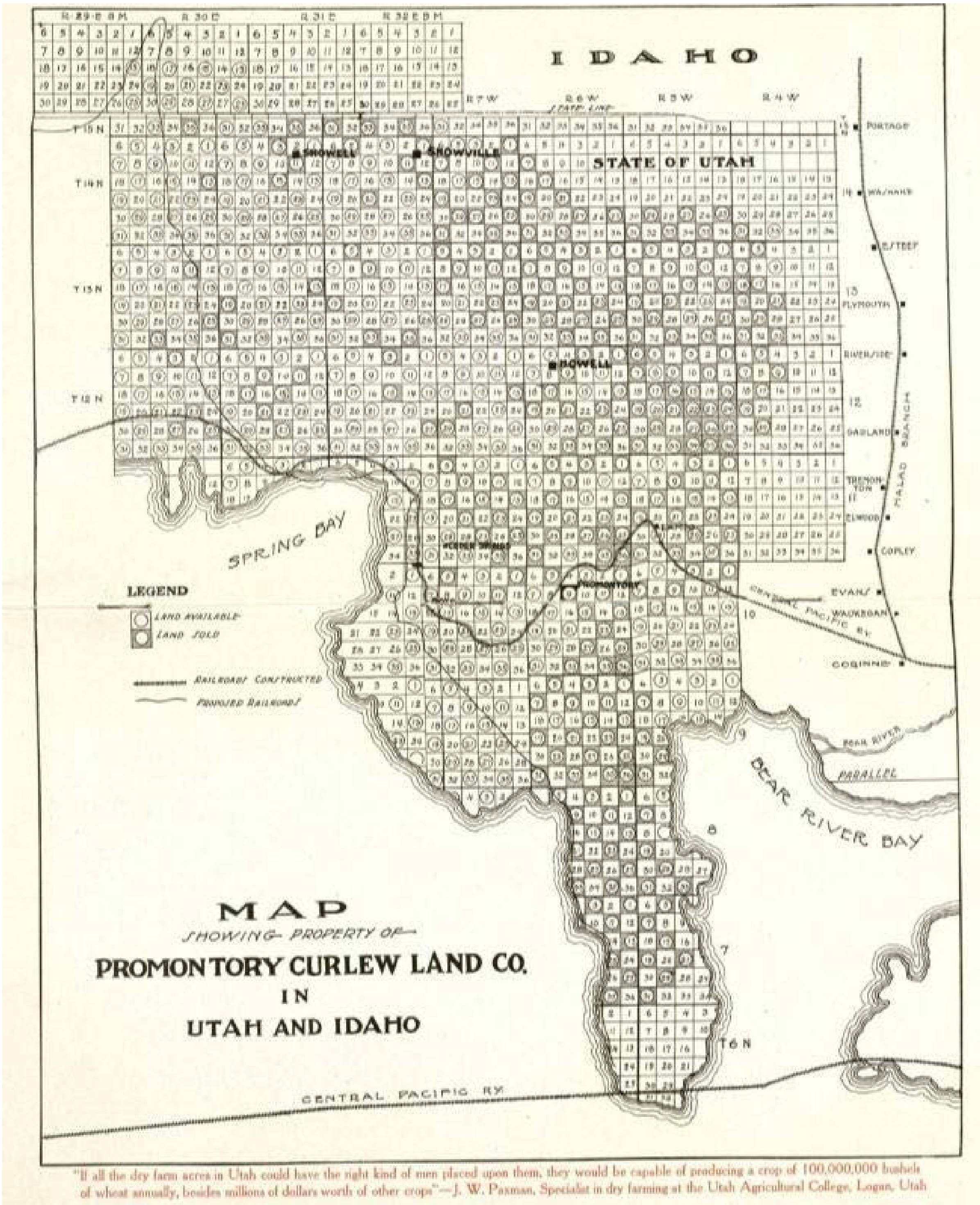


Figure 3. Promontory-Curlew Land Company holdings, taken from the company's 1917 advertisement, "A Winning Combination" (Bullen Jr. 1966b). Antelope Pasture is located at the north end, on the Utah/Idaho border.

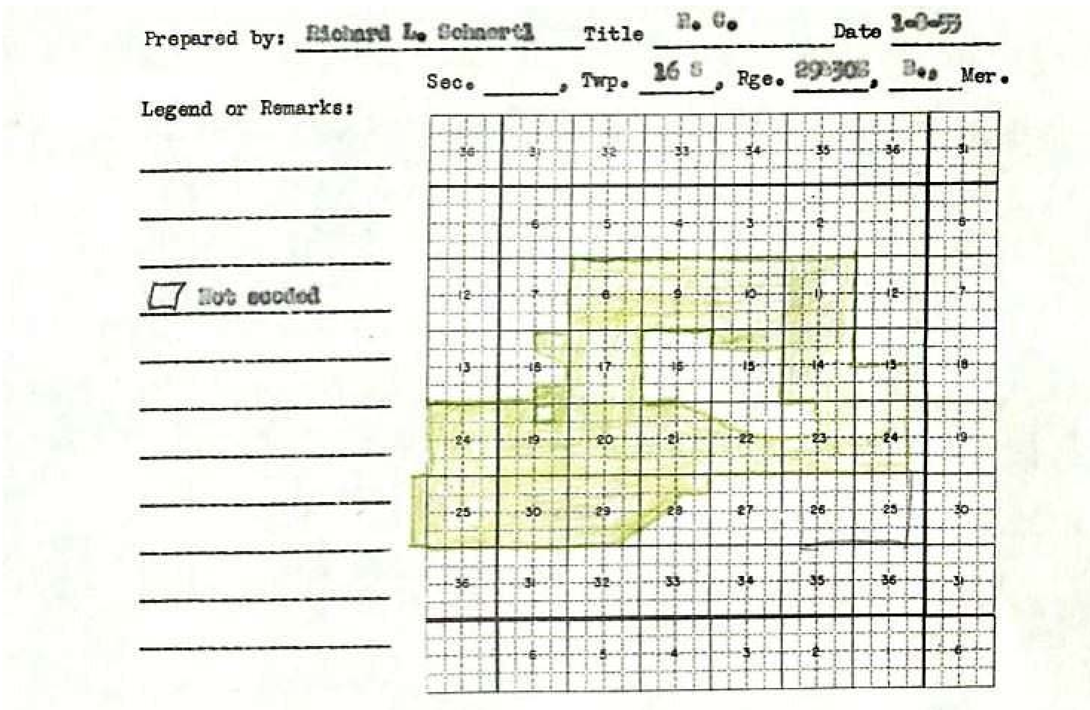


Figure 4. Township sections included in the 1952 BLM seeding of crested wheatgrass and yellow sweet clover. Within Antelope Pasture, sections 22 and 23 were partially seeded. Image taken from *Black Pine Reseeding #1; Project #12-0-372; Final Project Report*; BLM Form 4-120 (Department of Interior 1953).

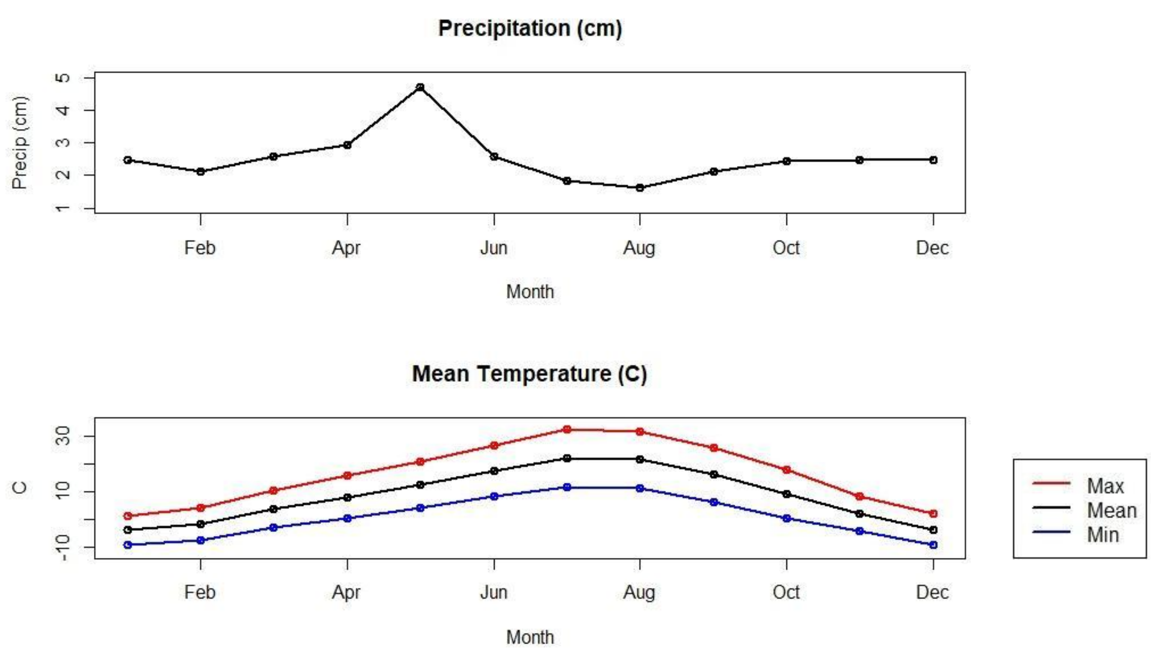


Figure 5. Mean monthly precipitation and temperature for Antelope Pasture. Data coordinates are 42°00'38.1600" N, -112°54'30.6000" W., elevation 1363 m. Data is monthly normals for the 30-year period of 1981-2010, sourced from the PRISM Climate Group, Oregon State University, downloaded April 2018.

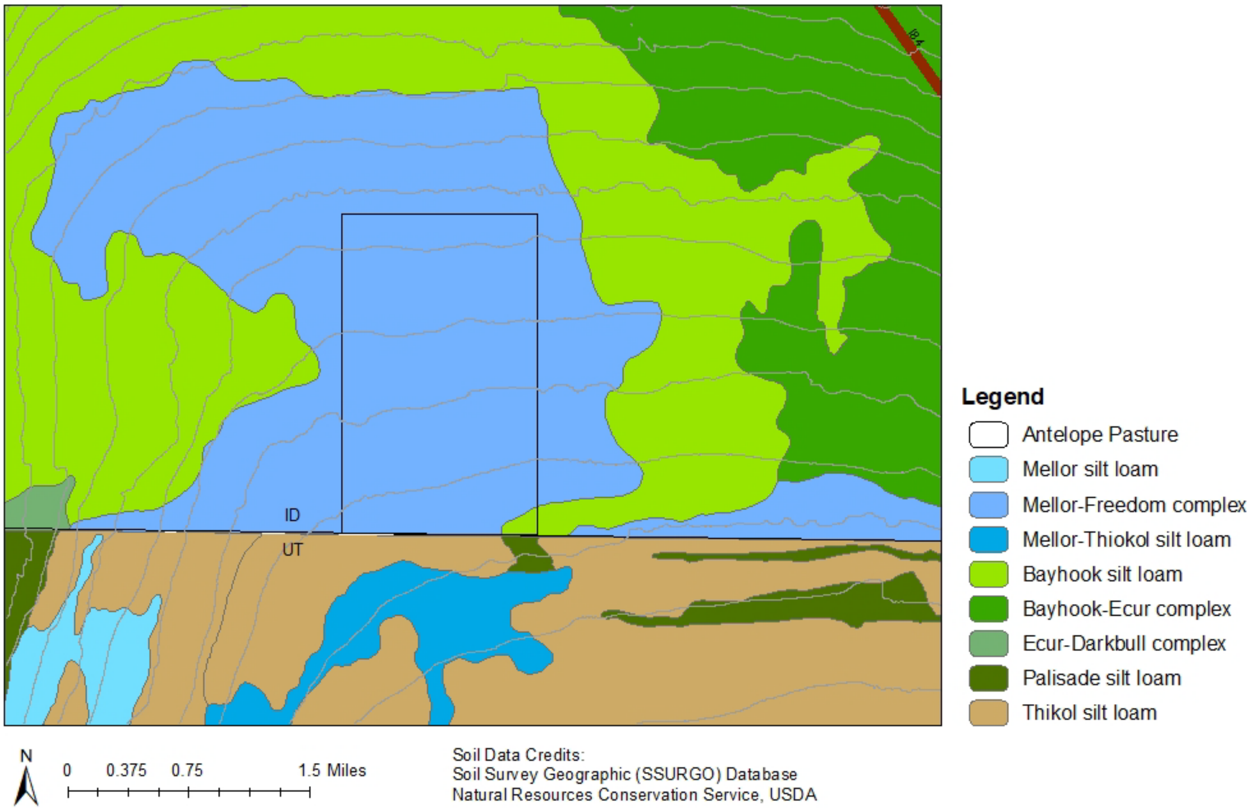


Figure 6. Natural Resources Conservation Service (NRCS) soil classification of Antelope Pasture (center rectangle) and surrounding soils. Contour lines were created using a 10-meter DEM sourced from The National Map, USGS. Sodic Xeric Haplocalcids are shown in green. Soils or soil complexes with natric horizons present are shown in blue. Soil series descriptions and mapping unit descriptions for soils within Antelope Pasture can be found in Appendix 2.

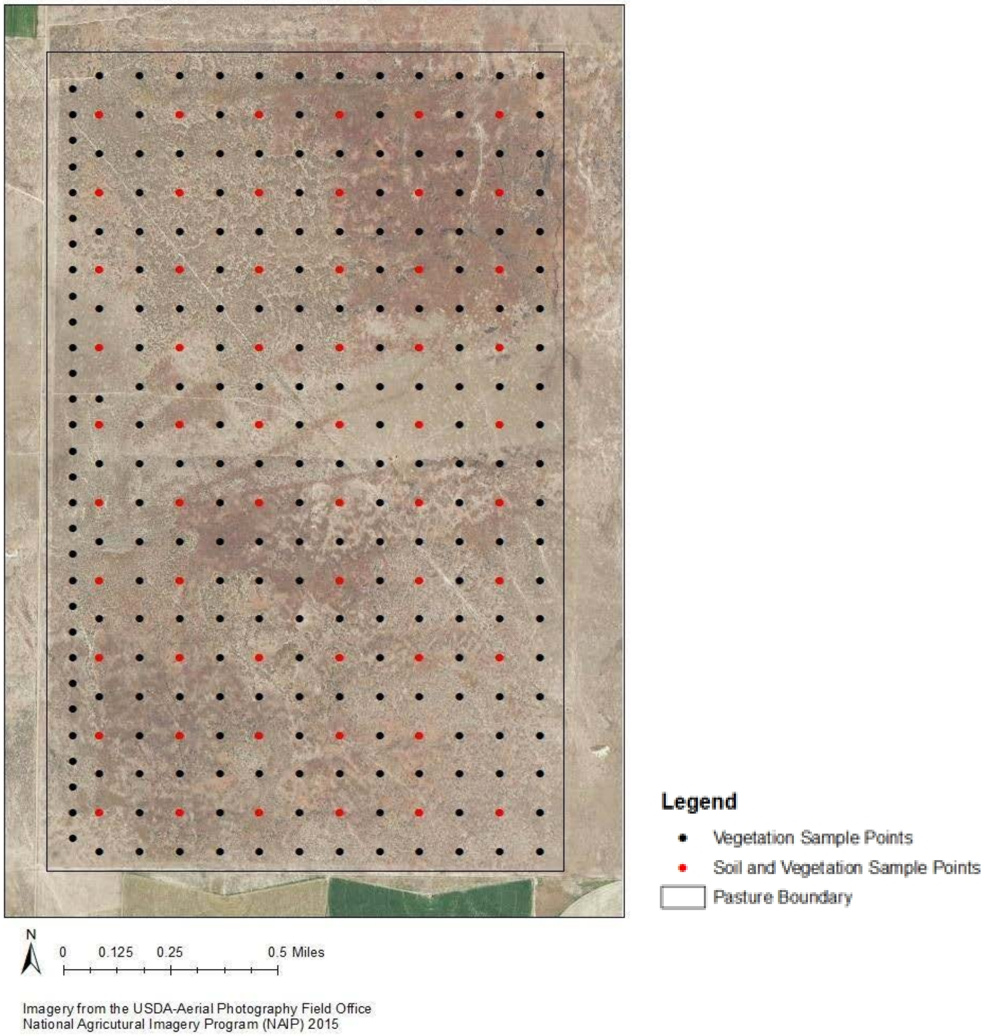


Figure 7. The sampling layout showing the 282 plots. Plots were 150m apart except for western column points, which are 100m apart. All plots were sampled for vegetation; out of those 58 (300m apart) were also sampled for soils.

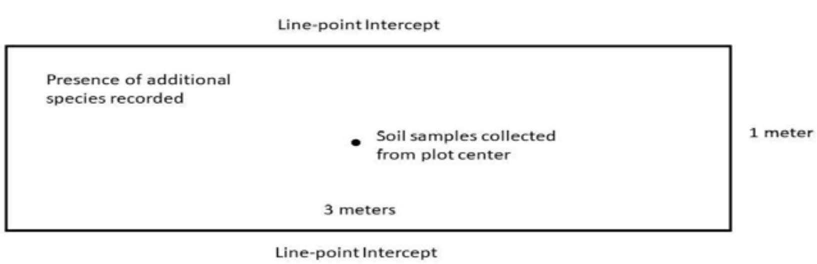


Figure 8. Diagram of a sampling plot. Line-point intercepts, collected every 30cm, were collected along both 3-meter sides, and the presence of additional species within the 1x3 m plot was recorded.

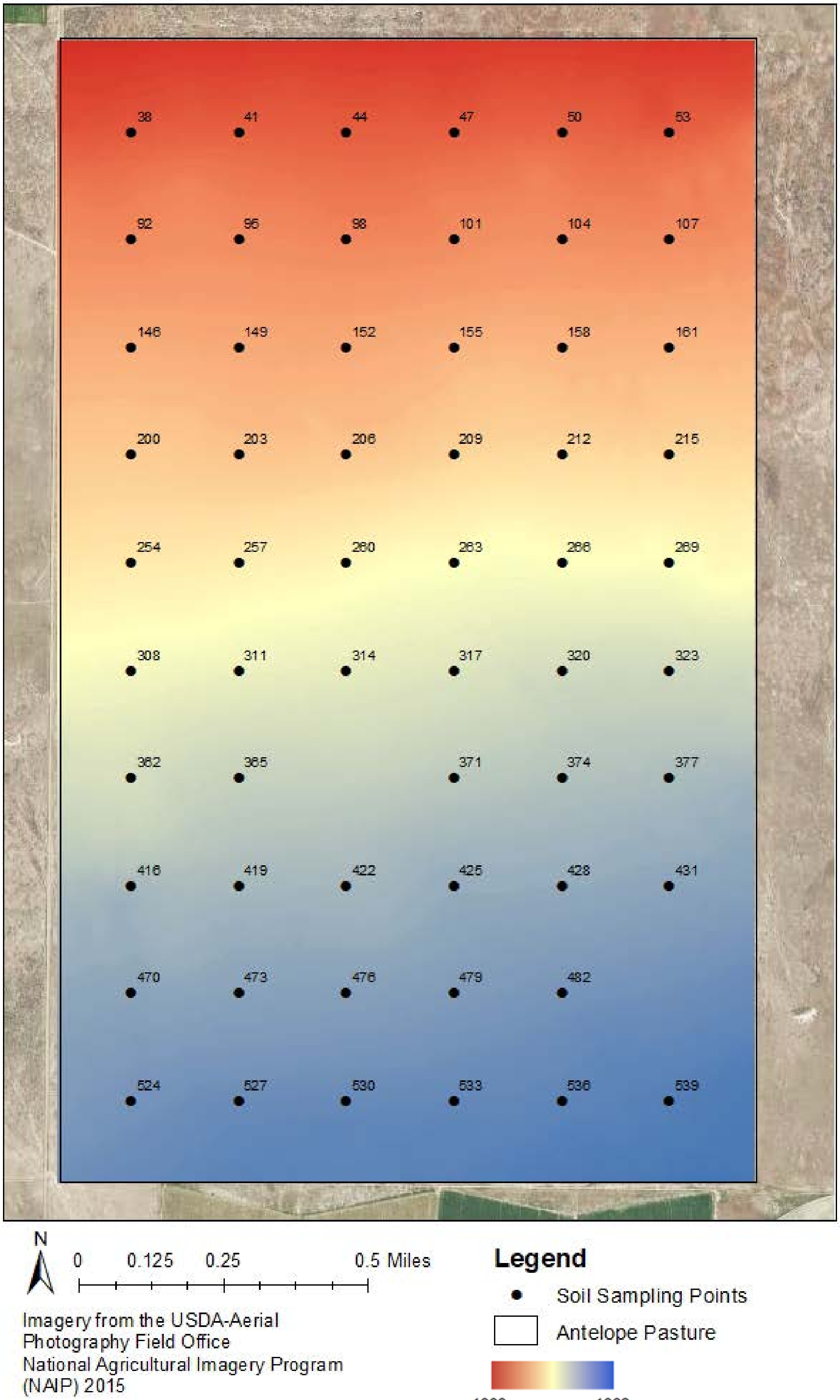


Figure 9. 10-m Digital Elevation Model of Antelope Pasture, sourced from The National Map, USGS.

Figure 10. Percent cover of introduced, annual grasses. Map symbology displays cover as dot density over a grid of 5.5-acre (300m x 300m) polygons. Dots are randomly distributed within each polygon, with their sum representing total cover for that polygon.

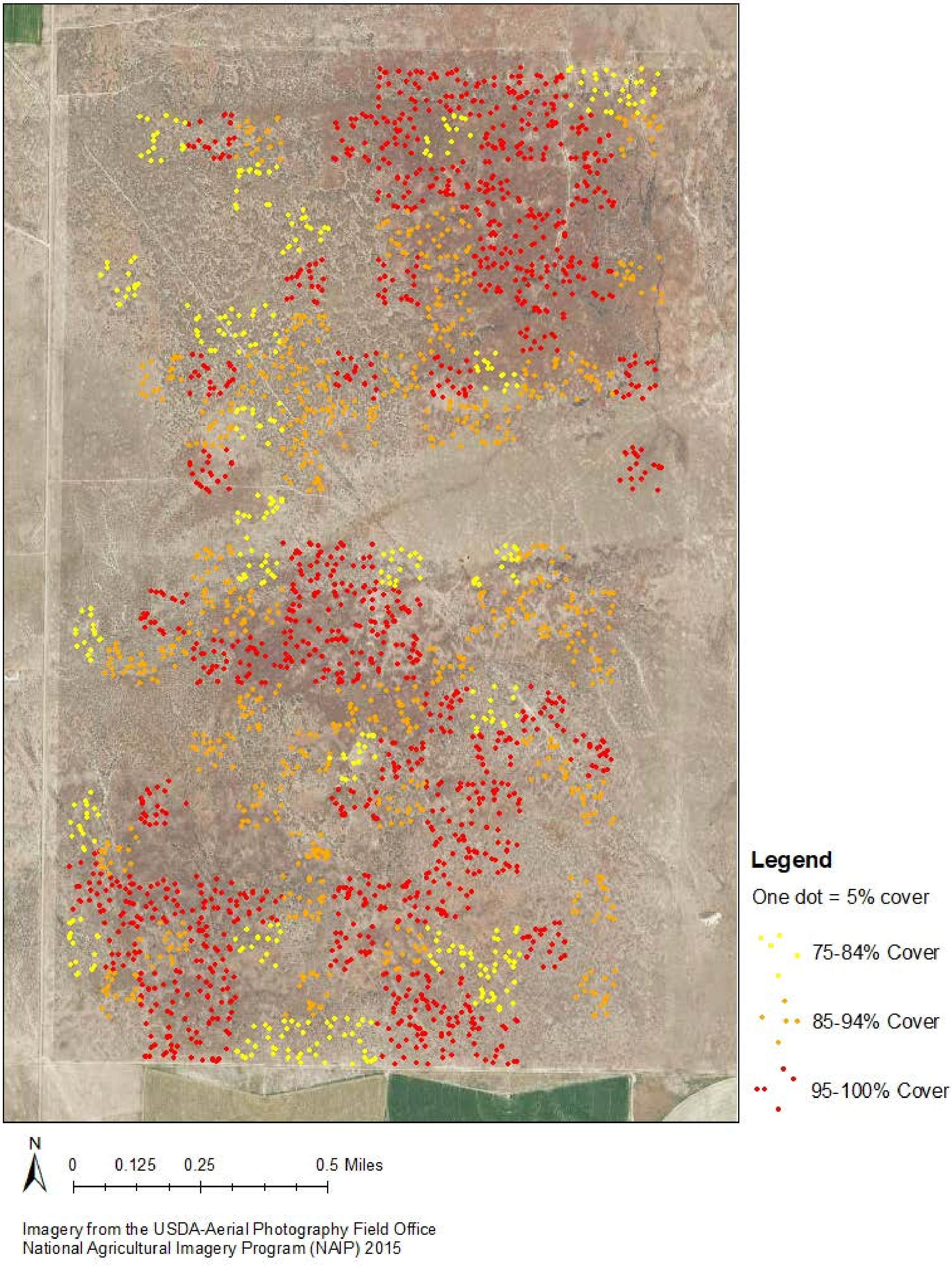


Figure 11. Areas with 75% cover or greater of *Bromus tectorum* (Cheatgrass). Map symbology displays cover as dot density over a grid of 5.5-acre (300m x 300m) polygons. Dots are randomly distributed within each polygon, with their sum representing total cover for that polygon. Cover has been stratified into cover classes.

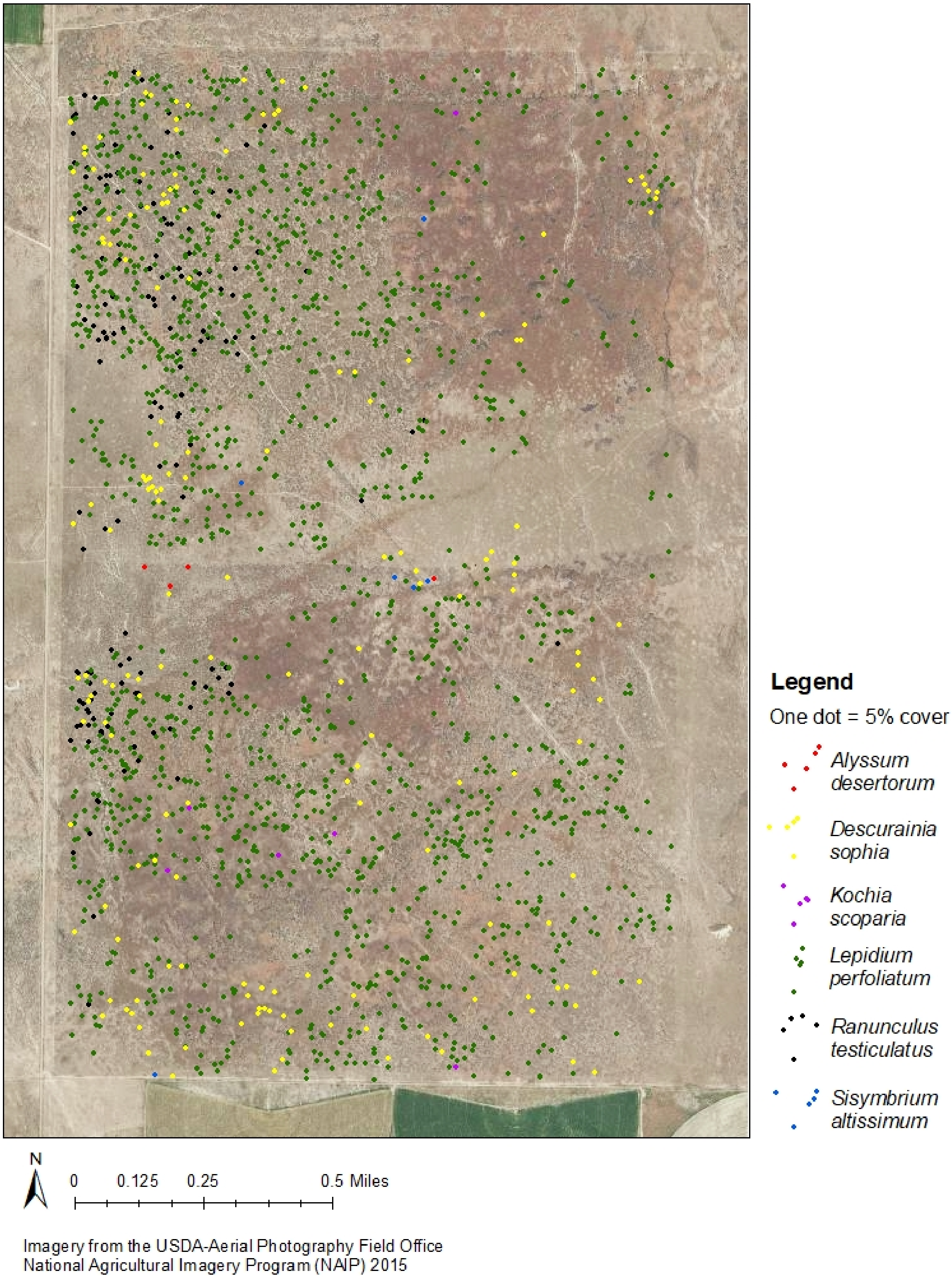


Figure 12. Percent cover of introduced, annual forbs. Map symbology displays cover as dot density over a grid of 5.5-acre (300m x 300m) polygons. Dots are randomly distributed within each polygon, with their sum representing total cover for that polygon.

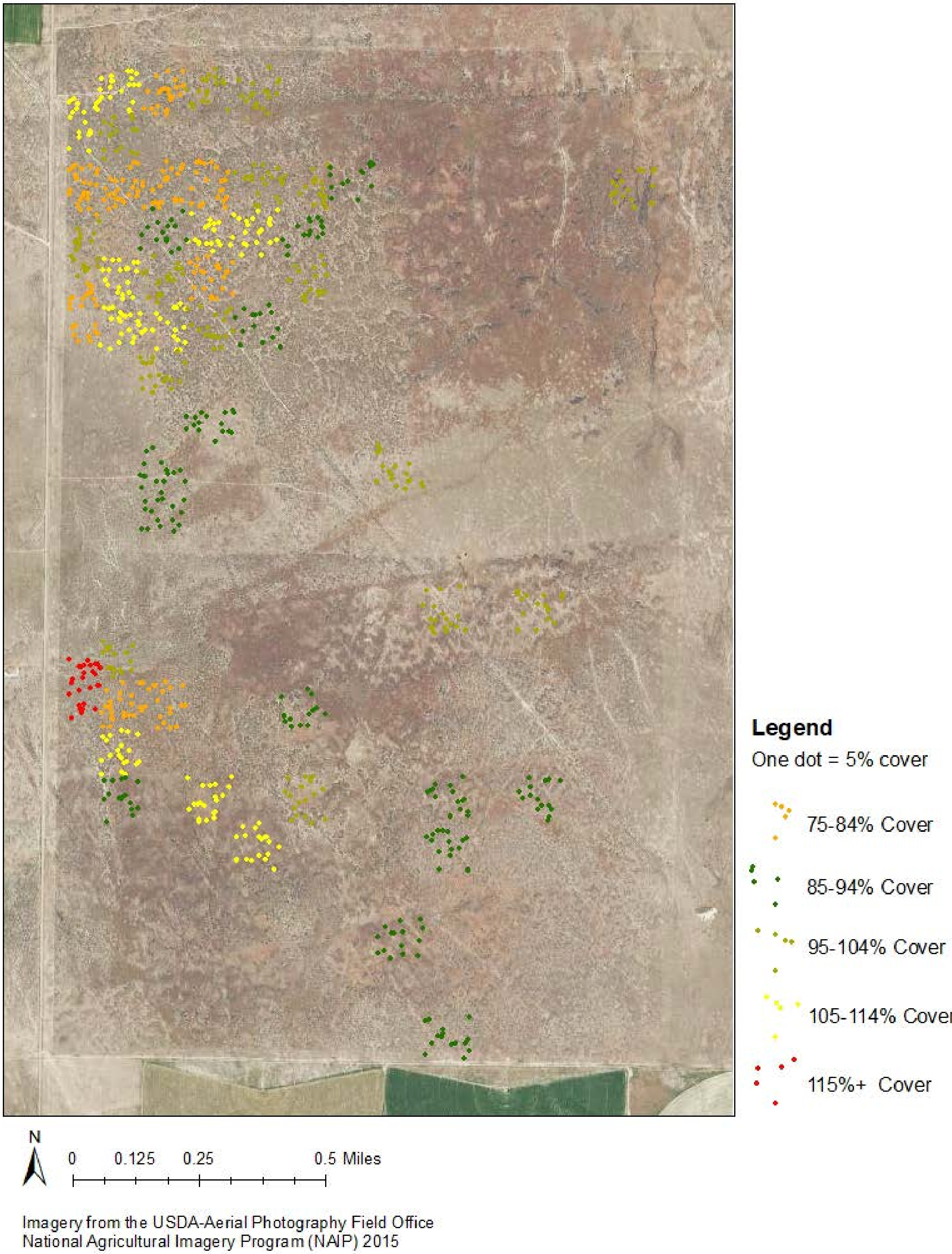


Figure 13. Areas with 75% combined cover or greater of introduced, annual forbs. Map symbology displays cover as dot density over a grid of 5.5-acre (300m x 300m) polygons. Dots are randomly distributed within each polygon, with their sum representing total cover for that polygon. Cover has been stratified into groups and coded by color.

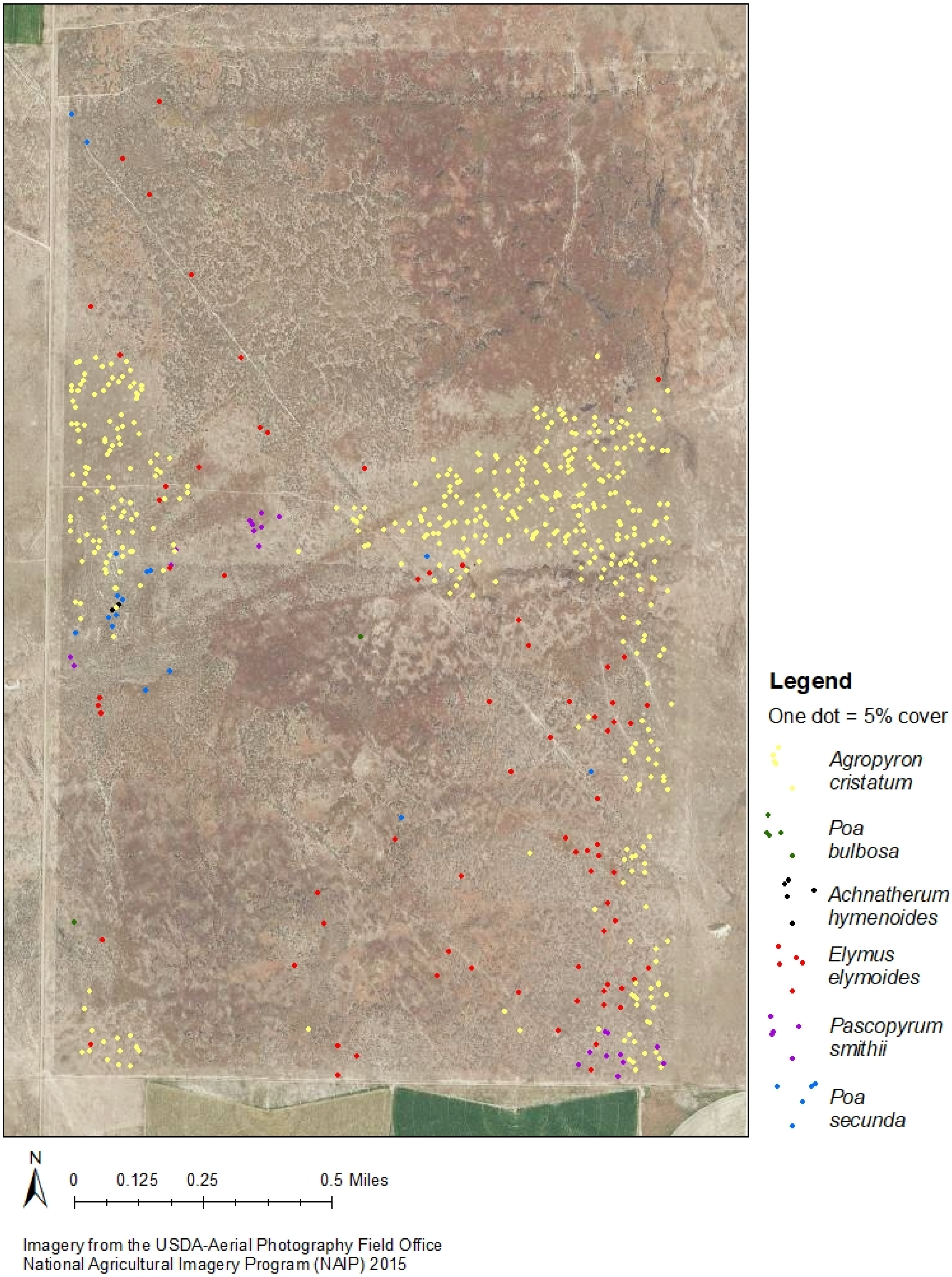


Figure 14. Percent cover of perennial grasses. Map symbology displays cover as dot density over a grid of 5.5-acre (300m x 300m) polygons. Dots are randomly distributed within each polygon, with their sum representing total cover for that polygon.

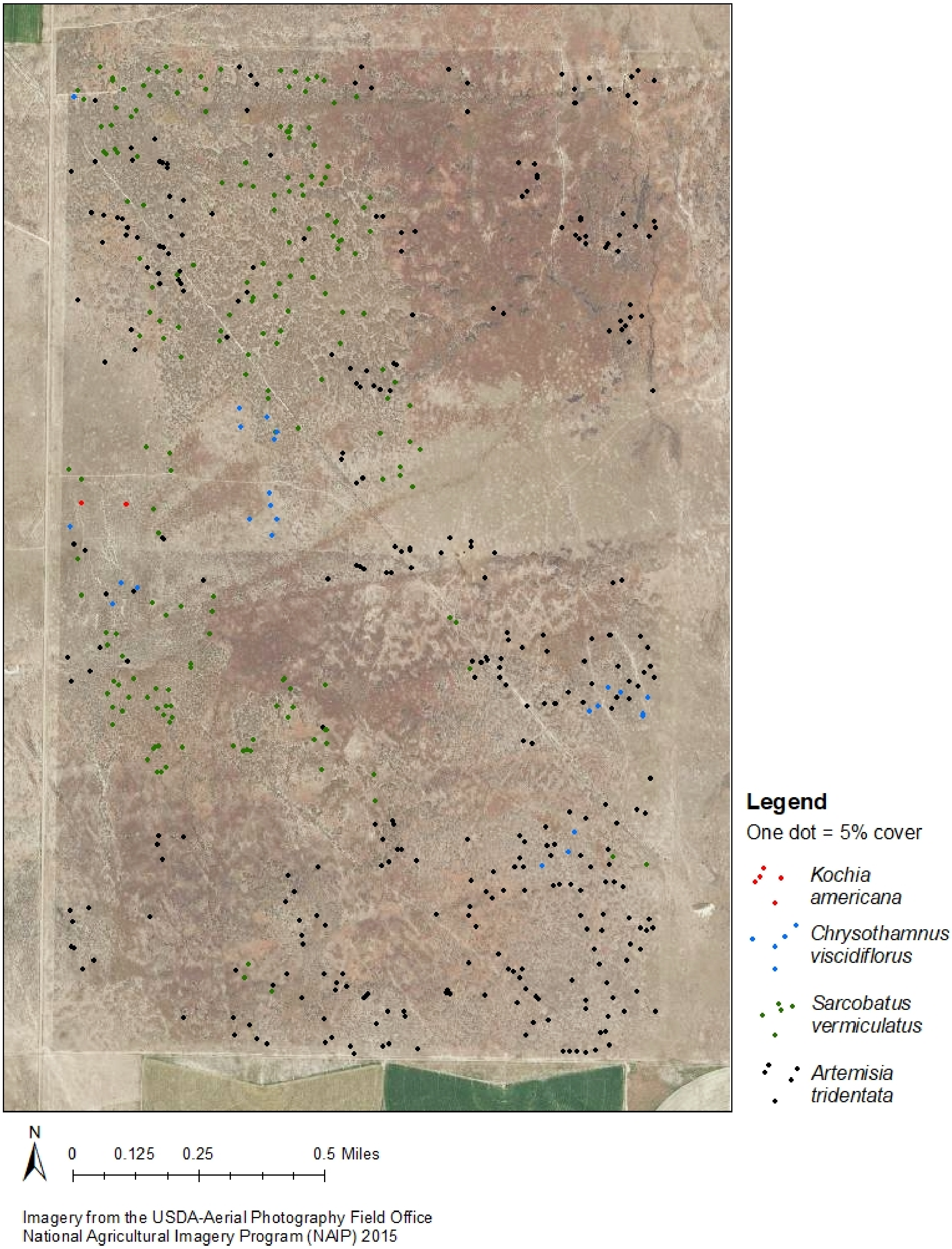


Figure 15. Percent cover of shrubs. Map symbology displays cover as dot density over a grid of 5.5-acre (300m x 300m) polygons. Dots are randomly distributed within each polygon, with their sum representing total cover for that polygon.

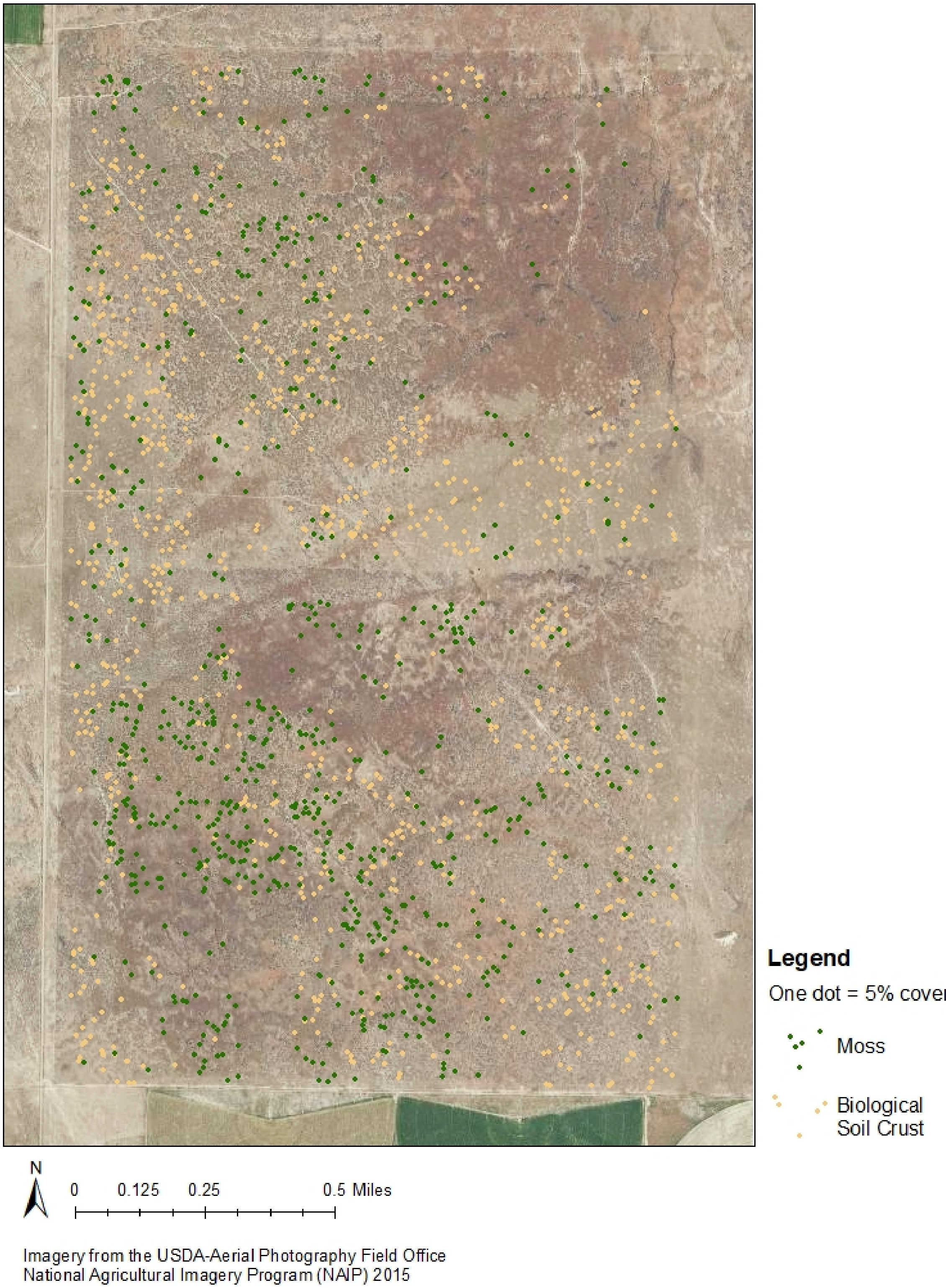


Figure 16. Percent cover of moss and biological soil crust. Map symbology displays cover as dot density over a grid of 5.5-acre (300m x 300m) polygons. Dots are randomly distributed within each polygon, with their sum representing total cover for that polygon.

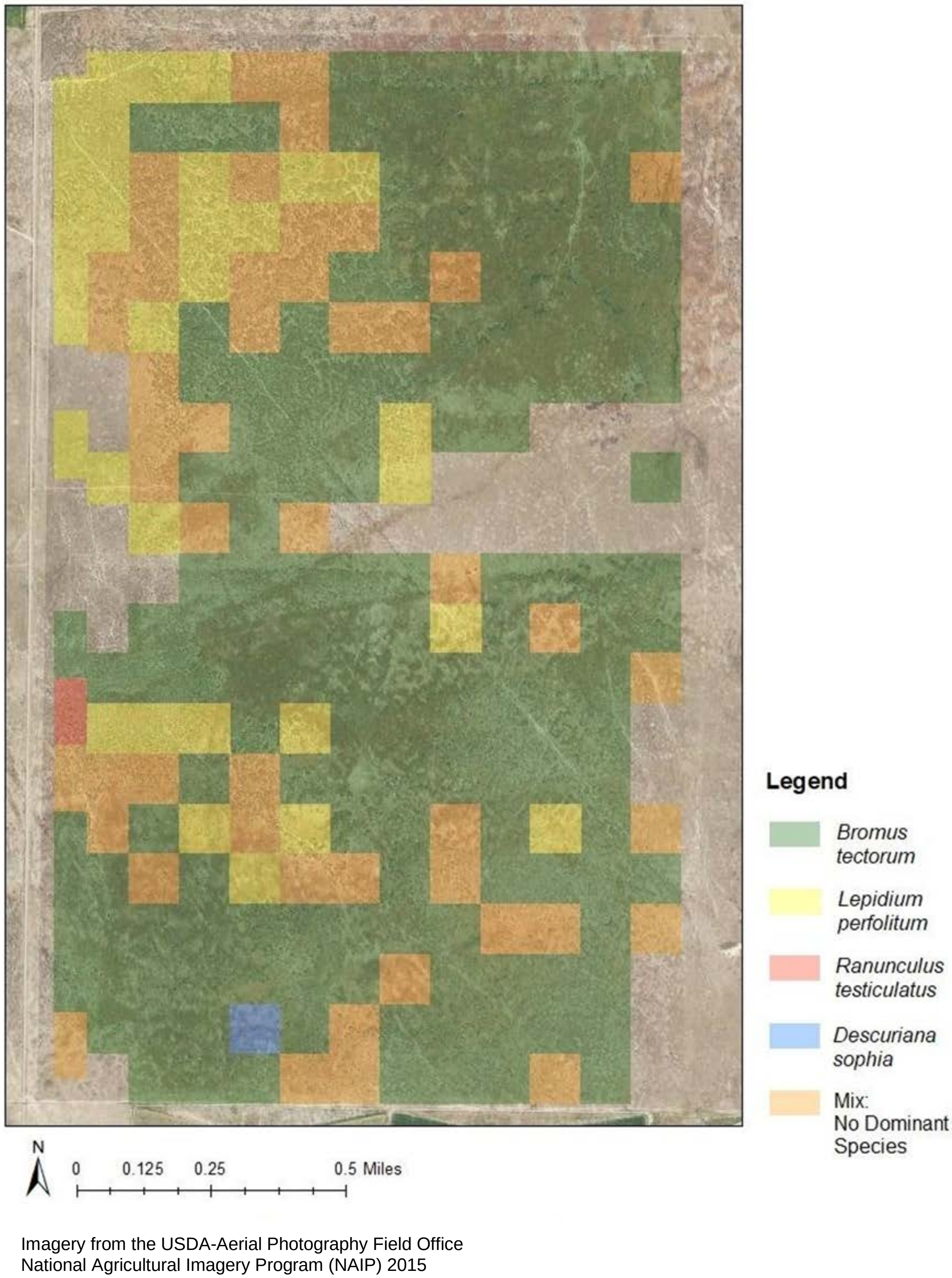


Figure 17. Dominant introduced annuals. Map symbology displays dominant species over a 5.5-acre grid of polygons. Species were considered dominant if percent cover was at least 25% greater than any other introduced, annual species within each grid polygon. Polygons with less than 25% combined cover of introduced annuals were not assigned a dominant species.

Figure 18. Percent cover of *Bromus tectorum* (cheatgrass) shown over shrub functional group and *Agropyron cristatum* (crested wheatgrass) presence. Map symbology displays cover as dot density over a grid of 5.5-acre (300m x 300m) polygons. Dots are randomly distributed within each polygon, with their sum representing total cover for that polygon. Polygons were shaded based on presence/absence data.

Figure 19. Combined percent cover of introduced, annual forbs shown over shrub functional group and *Agropyron cristatum* (crested wheatgrass) presence. Map symbology displays cover as dot density over a grid of 5.5-acre (300m x 300m) polygons. Dots are randomly distributed within each polygon, with their sum representing total cover for that polygon. Polygons were shaded based on presence/absence data.

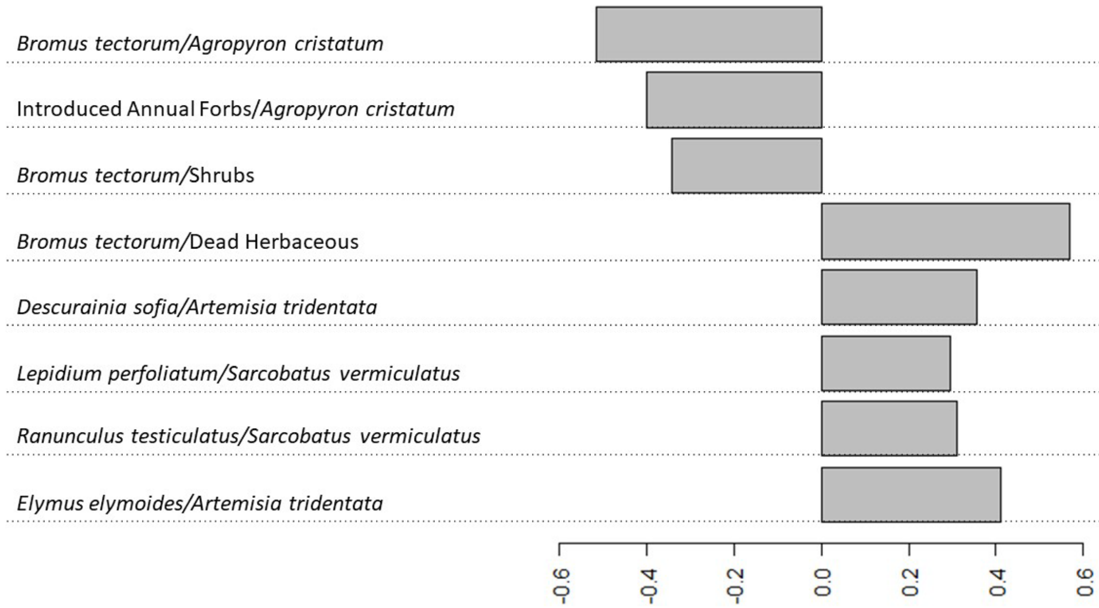


Figure 20. Significant correlations between plant species of Antelope Pasture. Spearman rank correlations with r > |0.2| and p-value <0.001 are shown above. Introduced annual forb species and shrubs were lumped into functional groups when individual correlations were in the same direction.

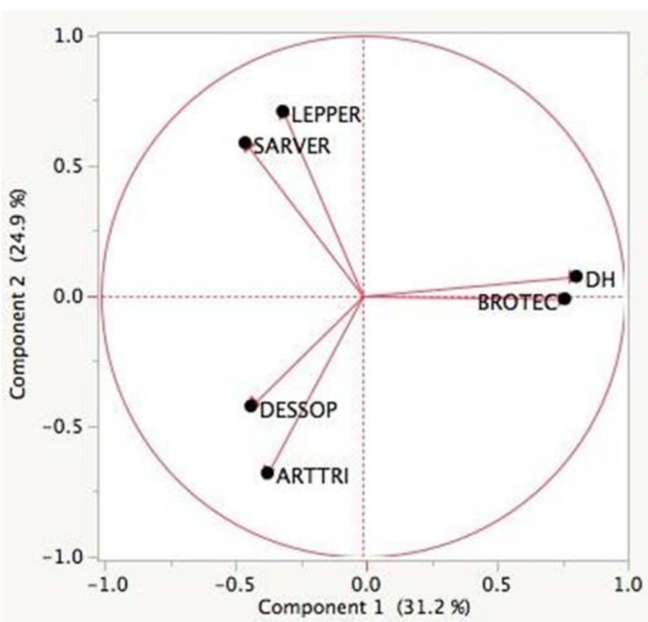


Figure 21. Principal components analysis biplot. Axes are labeled by component and amount of variation explained. Plant species are labeled using 6-letter codes. Included are two native shrub species (ARTTRI/*Artemisia tridentata* and SARVER/*Sarcobatus vermiculatus*), one introduced annual grass (BROTEC/*Bromus tectorum*), two introduced annual forbs (DESSOP/*Descurainia sophia* and LEPPER/*Lepidium perfoliatum*) and standing dead herbaceous (DH). See Table 1 for loading values.

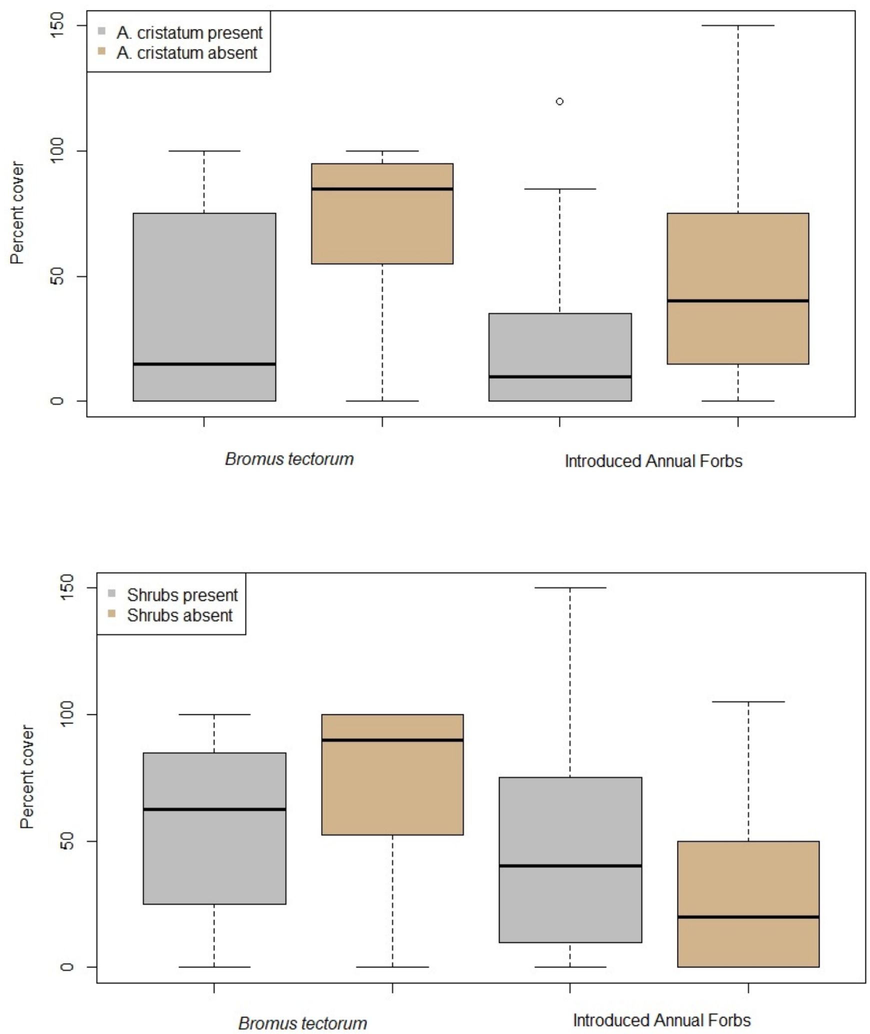


Figure 22. Effect of *Agropyron cristatum* (crested wheatgrass) presence and shrub functional group presence on the percent cover of introduced annual species at Antelope Pasture. We subset cheatgrass and introduced annual forbs into populations with and without the presence of crested wheatgrass, and with and without the presence of shrubs. Cover for functional groups may exceed 100% due to overlapping species. Box-and-whisker plots display the median, interquartile range, maximum and minimum values.

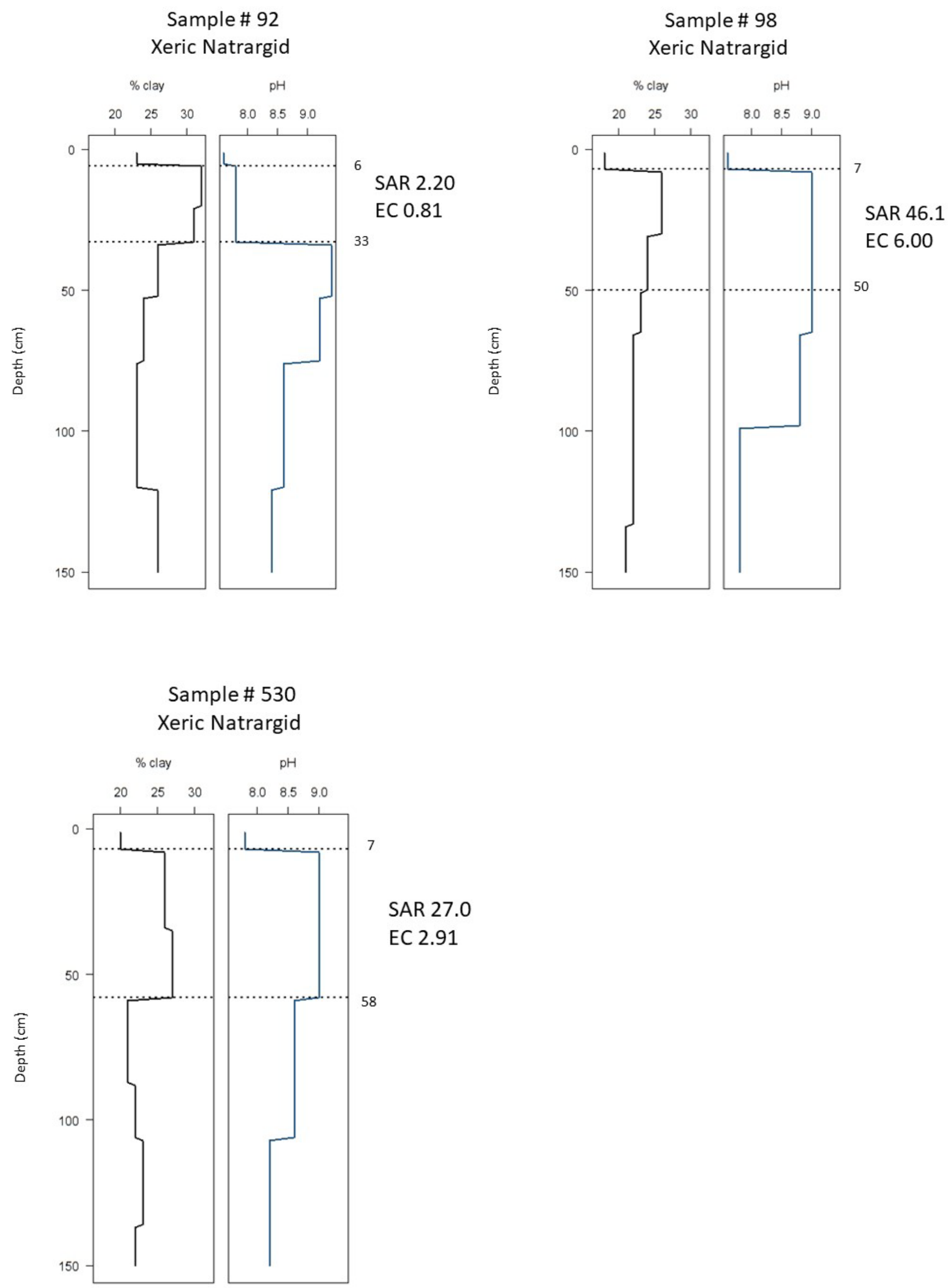


Figure 23. Soil pH and percent clay for three representative Xeric Natrargids: soil pedons 92, 98 and 530. These soils demonstrated the minimum clay increase and high pH (indicating SAR>13) required for the natric horion.

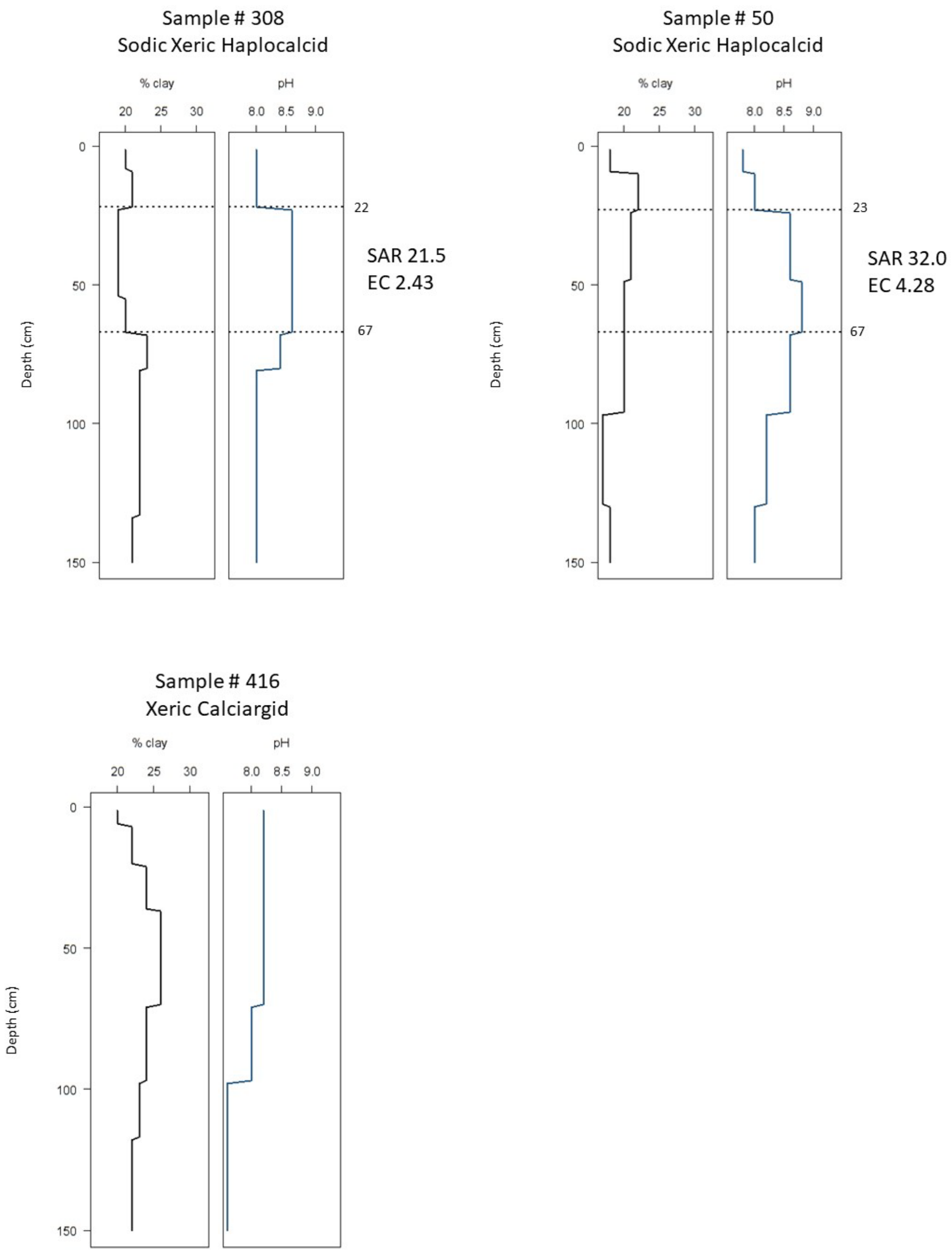


Figure 24. Soil pH and percent clay for two representative Sodic Xeric Haplocalcids and one representative Xeric Calciargid: soil pedons 308, 50 and 416. These soils lacked the minimum clay increase coupled with high pH required for a natric horizon.

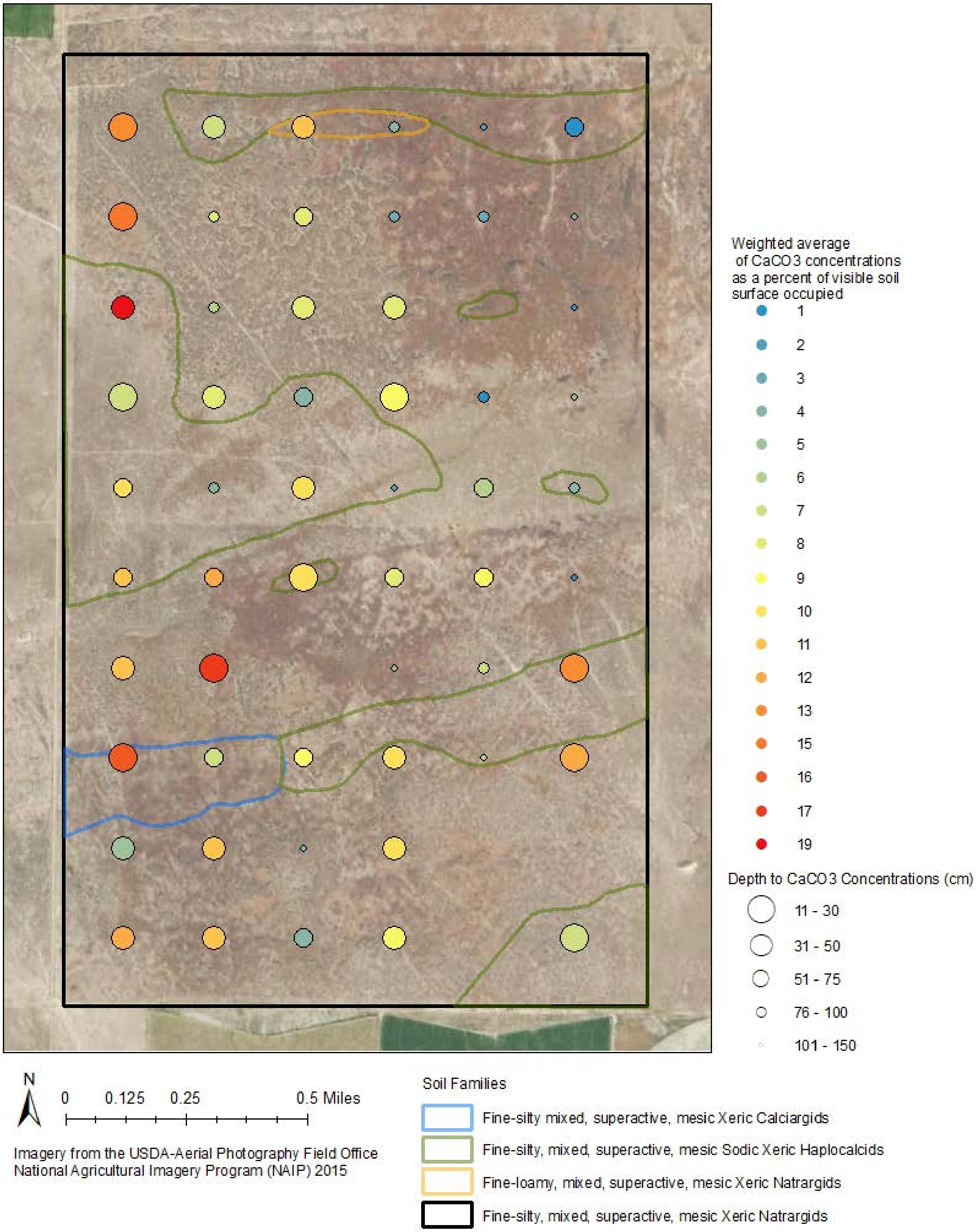


Figure 25. Distribution, depth and amount of calcium carbonate concentrations. Map symbology uses size to depict depth (cm) to concentrations and color to depict weighted average (as a percent of visible soil surface occupied). Soil pedons without calcium carbonate concentrations are not shown. Final soil family characterizations (Figure 30), which were derived in part from these data, are shown for reference.

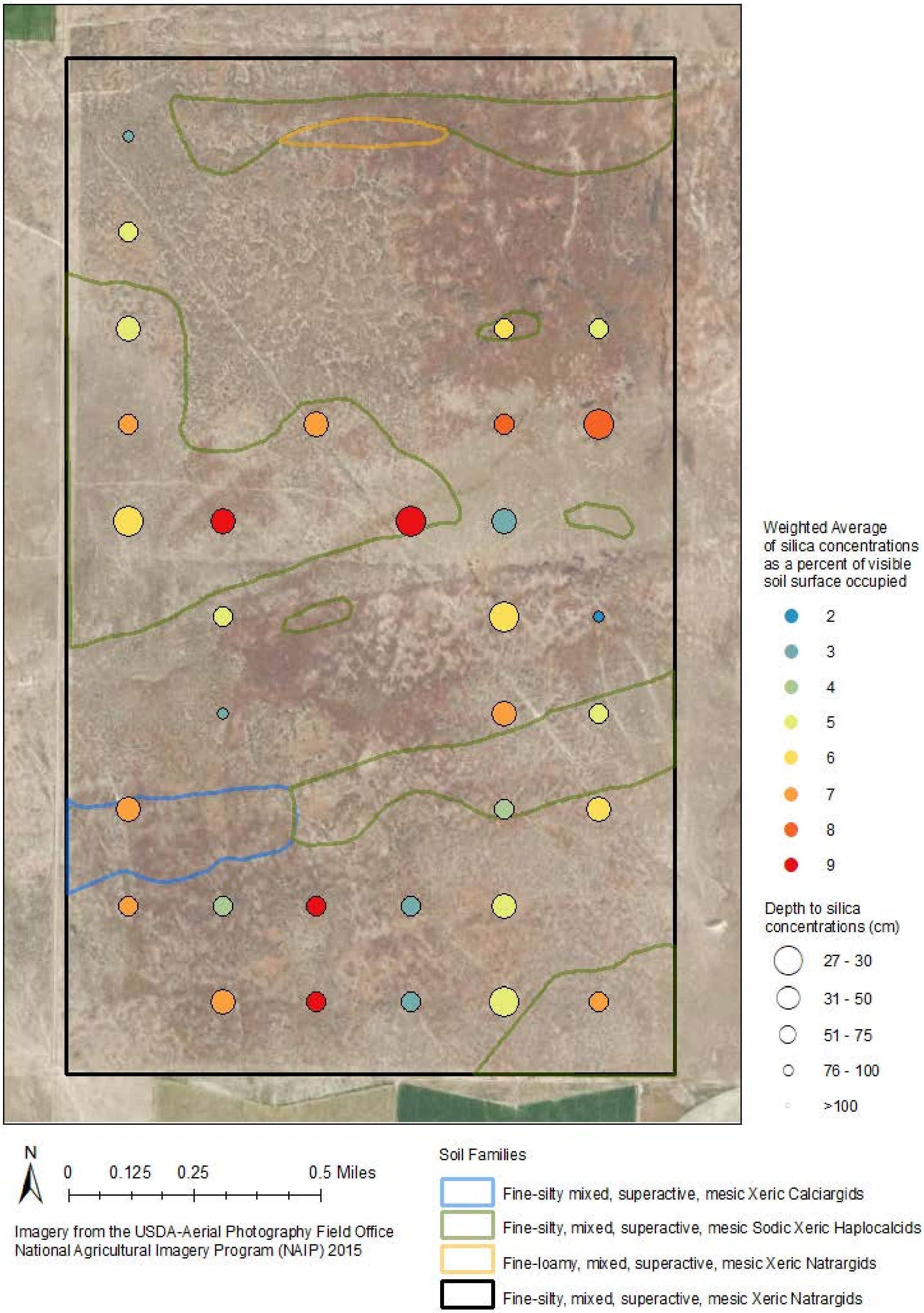


Figure 26. Distribution, depth and amount of silica concentrations. Map symbology uses size to depict depth depth (cm) to concentrations and color to depict weighted average (as a percent of visible soil surface occupied). Soil pedons without silica concentrations are not shown. Final soil family characterizations (Figure 30), are shown for reference.

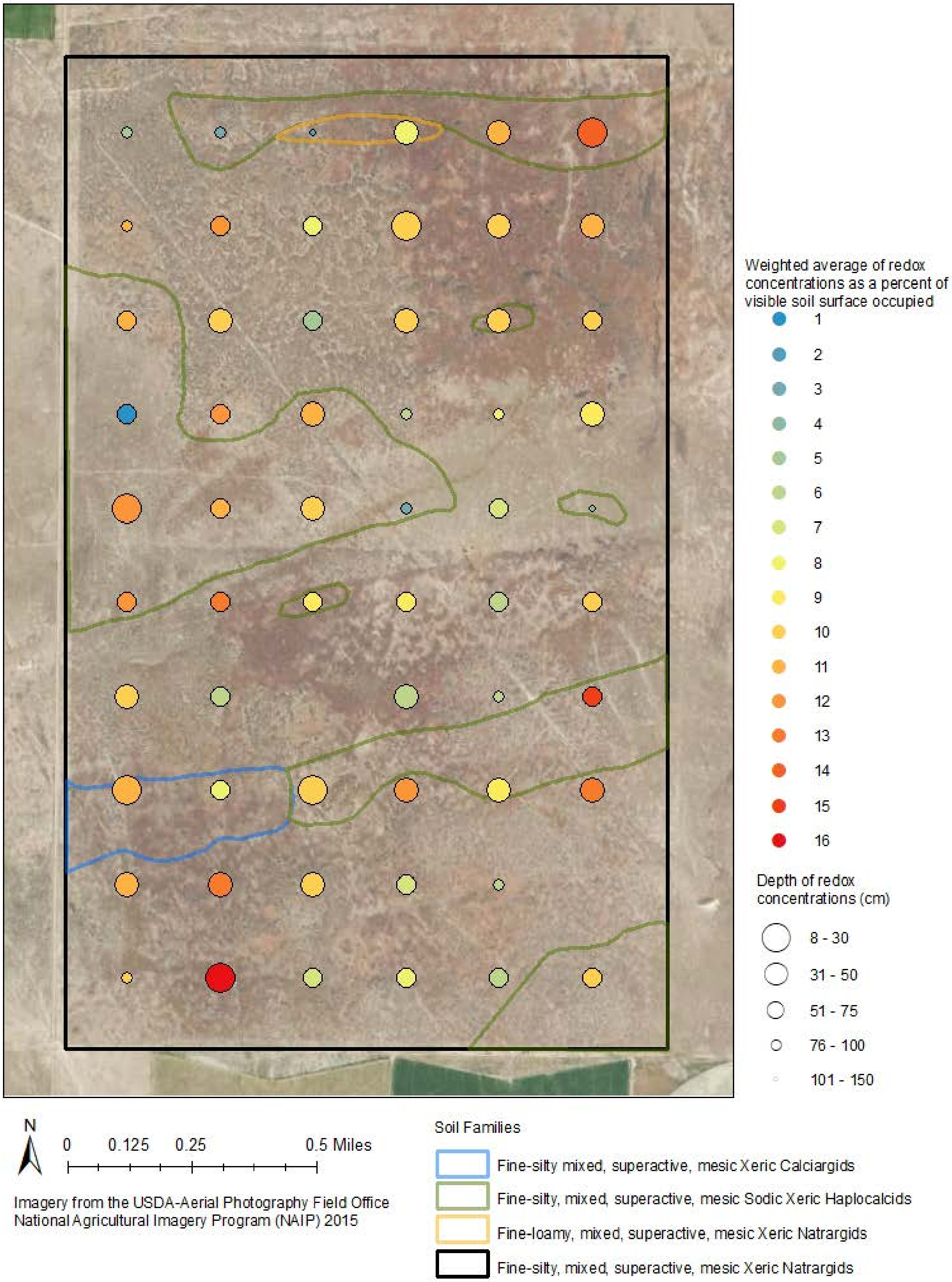


Figure 27. Distribution, depth and amount of redoximorphic concentrations. Map symbology uses size to depict depth (cm) to concentrations and color to depict weighted average (as a percent of visible soil surface occupied). Soil pedons without redoximorphic concentrations are not shown. Final soil family characterizations (Figure 30), are shown for reference.

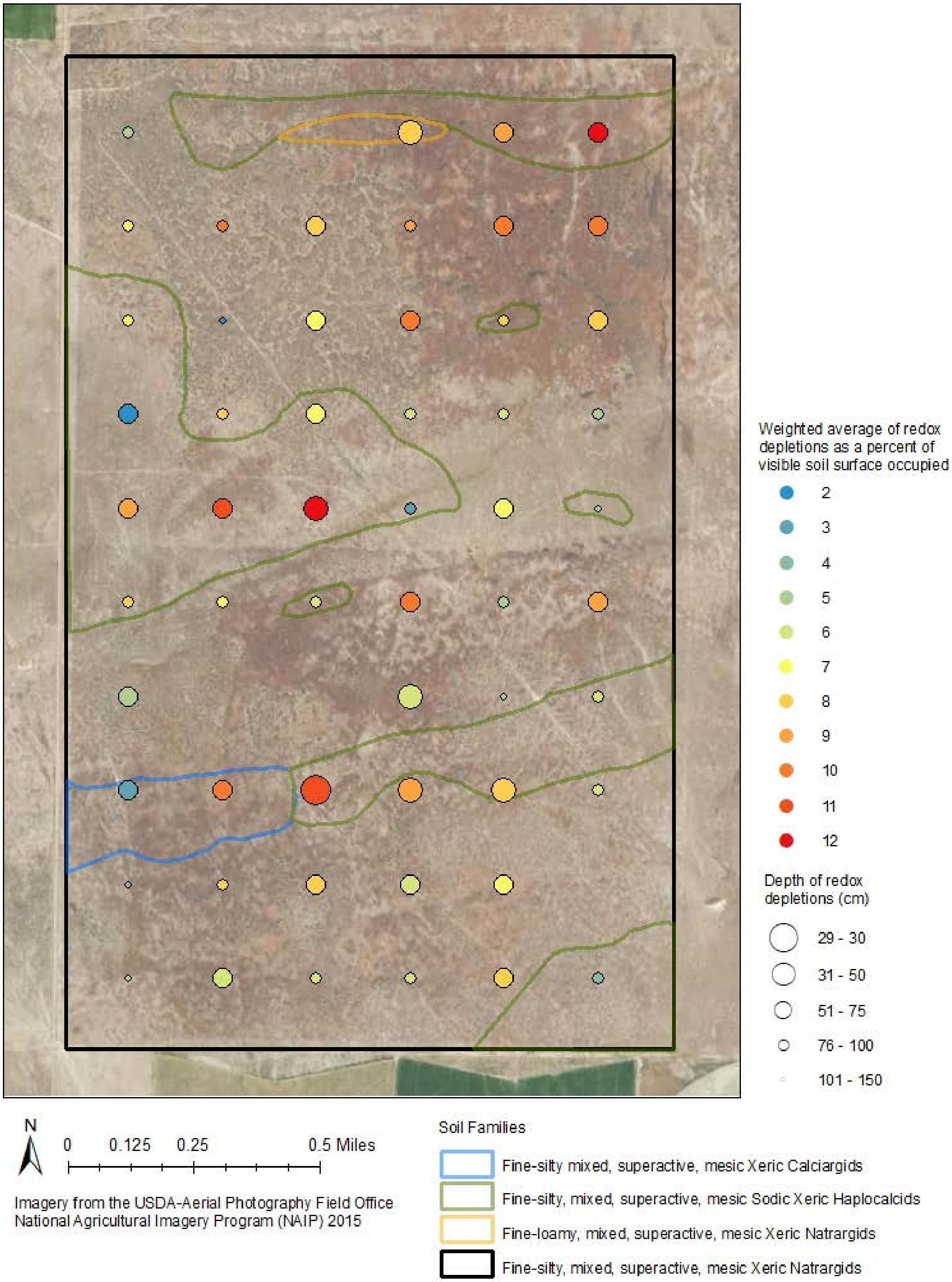


Figure 28. Distribution, depth and amount of redoximorphic depletions. Map symbology uses size to depict depth (cm) to depletions and color to depict weighted average (as a percent of visible soil surface occupied). Soil pedons without redoximorphic depletions are not shown. Final soil family characterizations (Figure 30), are shown for reference.

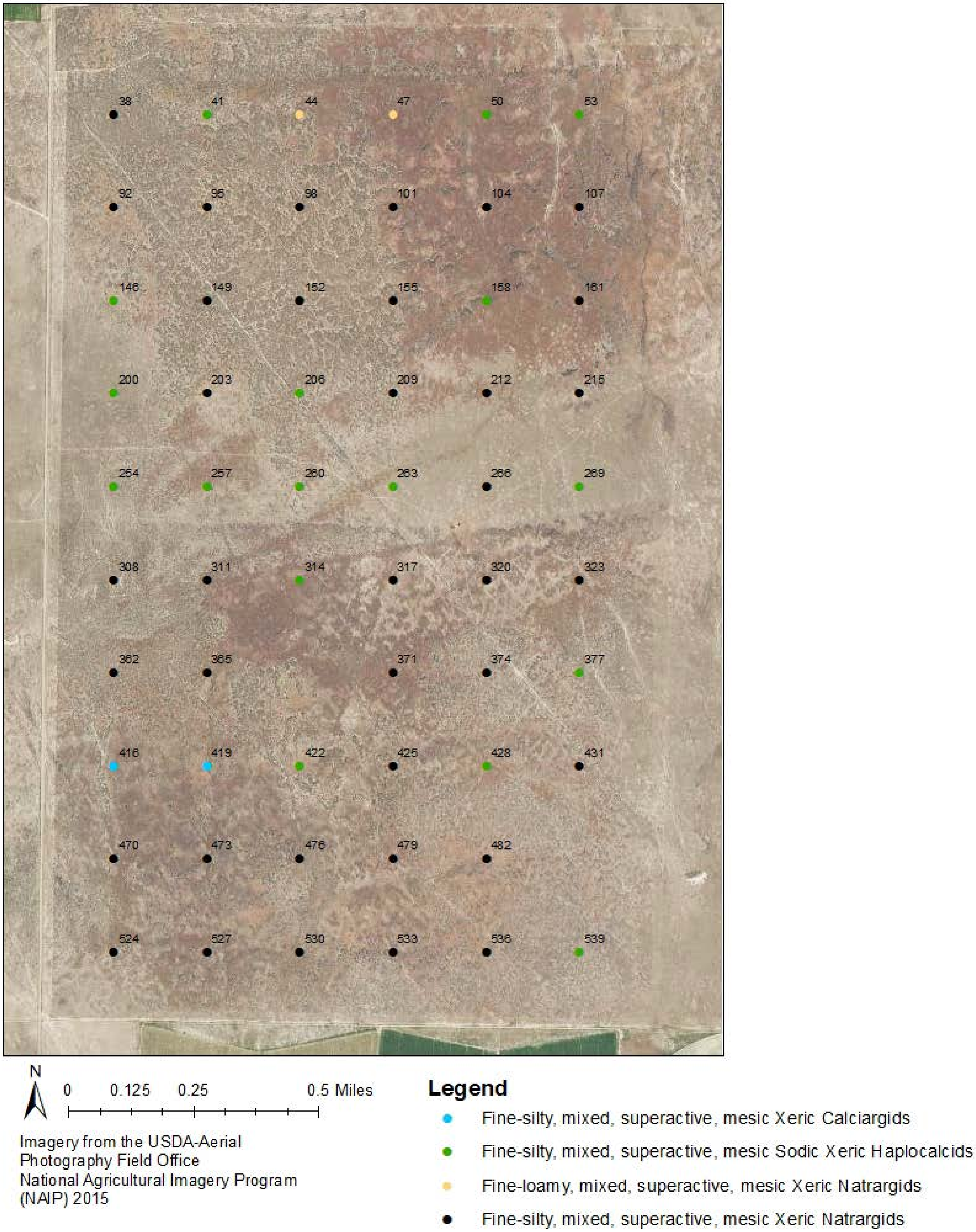


Figure 29. Family classification of soil samples, 2017 survey. Written soil descriptions for pedons 47, 92, 101, 260, 308, 377 and 416 are in Appendix 2. SAR and EC results for pedons 50, 53, 92, 98, 158, 200, 215, 260, 308, 377, 482 and 530 are in Table 3.

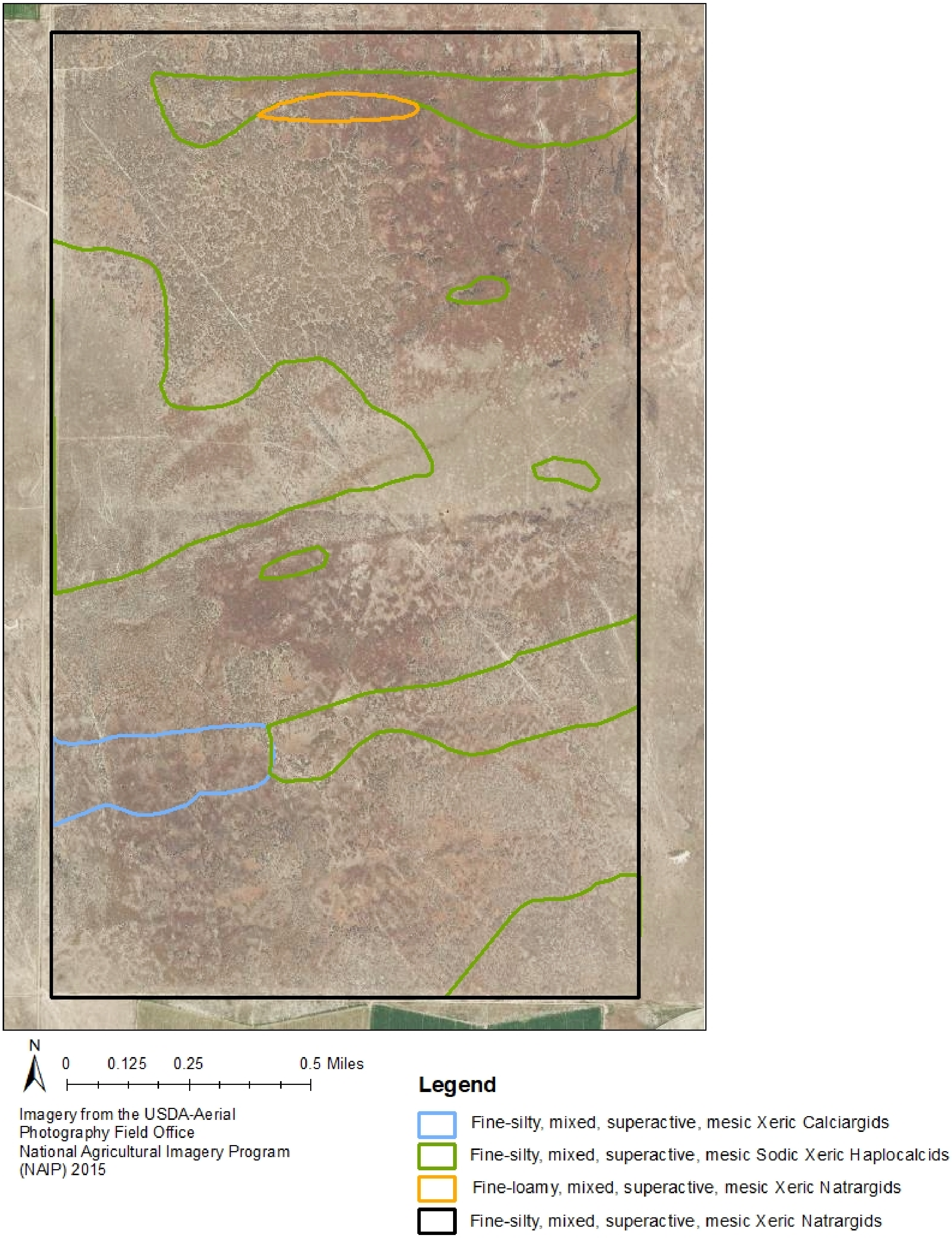


Figure 30. Soil map of Antelope Pasture, 2017 survey. Soils are classified to family.

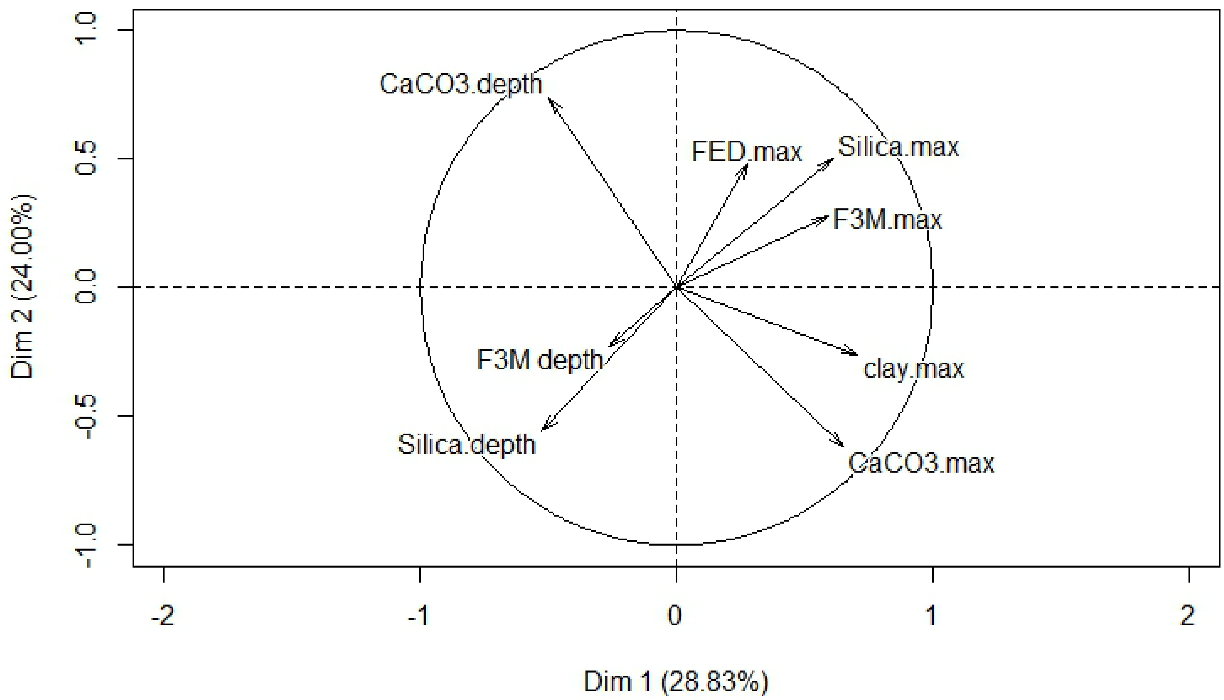


Figure 31. Principal components analysis biplot for soil variables. Axes are labeled by component and amount of variation explained. Variables included are: CaCO3 depth (depth to calcium carbonate concentrations), FED.max (maximum value for redoximorphic depletions), Silica.max (maximum value for silica concentrations), F3M.max (maximum value for redoximorphic concentrations), clay.max (maximum value for percent clay within a horizon), CaCO3.max (maximum value for calcium carbonate concentrations), Silica.depth (depth to silica concentrations) and F3M.depth (depth to redoximorphic concentrations). Values for concentrations and depletions were calculated as a percent of the visible soil surface area occupied in a horizon. Loading values are given in Table 2.

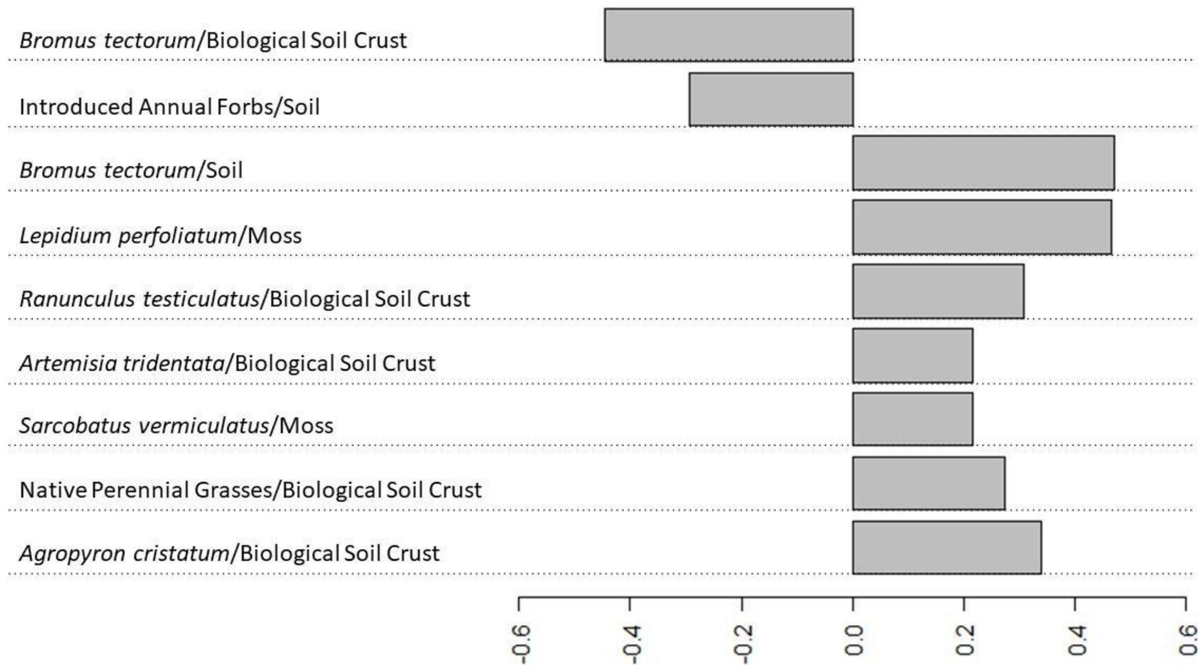


Figure 32. Significant correlations between plant species and soil surface categories of Antelope Pasture. For all, p-value <0.001. Spearman rank correlations with r > |0.2| and p-value <0.001 are shown above. Introduced annual forb species and shrubs were lumped into functional groups when individual correlations were in the same direction.

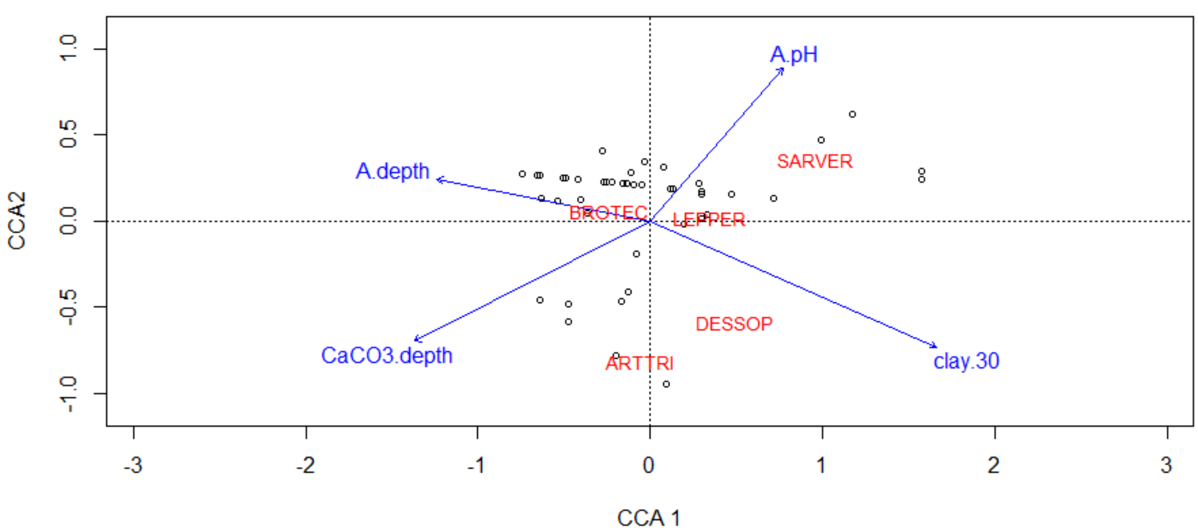


Figure 33. Canonical correspondence analysis biplot. Graph displays data matrix and eigenvectors. Axes are labeled by component. Included are two native shrub species (*Artemisia tridentata* and *Sarcobatus vermiculatus*), one introduced annual grass (*Bromus tectorum*), two introduced annual forbs (*Descurainia sophia* and *Lepidium perfoliatum*). Soil variables include A. depth (thickness of A horizon), A.pH (pH of surface horizon), CaCO3.depth (depth to calcium carbonate concentrations), and clay.30 (percent clay at a depth of 30cm). See Table 4 for loading values. Explanatory soil variables are shown in blue, and plant response variables in red. For all, p-value <0.05.

Appendix 1.
Antelope Pasture Species List and Vegetation Maps

Table 1-1. Plant species identified at Antelope Pasture in 2017. Taxonomy and nativity follow the Integrated Taxonomic Information System (ITIS). Functional groups follow the Natural Resources Conservation Service (USDA) Plant Database.

Family	Species Code	Scientific Name	Common Name	Functional Group	Introduced
Apiaceae	CYMPUR	*Cymopterus purpurascens*	Widewing Spring Parsley	Perennial Forb	
Amaranthaceae	ATRCAN	*Atriplex canescens*	Fourwing Saltbush	Shrub	
	ATRCON	*Atriplex confertifolia*	Shadscale	Shrub	
	ATRROS	*Atriplex rosea*	Tumbling Saltbush	Annual Forb	X
	HALGLO	*Halogeton glomeratus*	Halogeton	Annual Forb	X
	KOCAME	*Kochia americana*	Greenmolly	Subshrub	
	KOCSCO	*Kochia scoparia*	Kochia	Annual Forb	X
	SALTRA	*Salsola tragus*	Russian Thistle	Annual Forb	X
Amaryllidaceae	ALLNEV	*Allium nevadense*	Nevada Onion	Perennial Forb	
Asteraceae	ARTTRI	*Artemisia tridentata* ssp. *wyomingensis*	Wyoming Big Sagebrush	Shrub	
	CHRVIS	*Chrysothamnus viscidiflorus*	Yellow Rabbitbrush	Shrub	
	ERINAU	*Ericameria nauseosa*	Rubber Rabbitbrush	Shrub	
	LACSER	*Lactuca serriola*	Prickly Lettuce	Annual/Biennial Forb	X
	TRADUB	*Tragopogon dubius*	Yellow Salsify	Annual/Biennial Forb	X
Boraginaceae	CRYsp	*Cryptantha* spp.	Catseye	Annual Forb	
	LAPOCC	*Lappula occidentalis*	Stickseed	Annual/Biennial Forb	
Brassicaceae	ALYDES	*Alyssum desertorum*	Desert Alyssum	Annual Forb	X
	CHOTEN	*Chorispora tenella*	Purple Mustard	Annual Forb	X
	DESPIN	*Descurainia pinnata*	Tansymustard	Annual/Biennial/Perennial Forb	
	DESSOP	*Descurainia sophia*	Flixweed	Annual/Biennial Forb	X
	LEPPER	*Lepidium perfoliatum*	Clasping Pepperweed	Annual Forb	X

Table 1-1 Continued. Plant species identified at Antelope Pasture in 2017. Taxonomy and nativity follow the Integrated Taxonomic Information System (ITIS). Functional groups follow the Natural Resources Conservation Service (USDA) Plant Database.

Family	Species Code	Scientific Name	Common Name	Functional Group	Introduced
Brassicaceae	SISALT	*Sisymbrium altissimum*	Tumble Mustard	Annual/Biennial Forb	X
	SISLIN	*Sisymbrium linifolium*	Flaxleaf Plainsmustard	Perennial Forb	
Cactaceae	OPUPOL	*Opuntia polyacantha*	Plains Pricklypear	Shrub	
Fabaceae	ASTLEN	*Astragalus lentiginosus*	Freckled Milkvetch	Perennial Forb	
	ASTPUR	*Astragalus purshii*	Woollypod Milkvetch	Perennial Forb	
Poaceae	ACHHYM	*Achnatherum hymenoides*	Indian Rice Grass	Perennial Grass	
	AGRCRI	*Agropyron cristatum*	Crested Wheatgrass	Perennial Grass	X
	ARIPUR	*Aristida purpurea*	Purple Threeawn	Perennial Grass	
	BROTEC	*Bromus tectorum*	Cheatgrass	Annual Grass	X
	ELYELY	*Elymus elymoides*	Bottlebrush Squirreltail	Perennial Grass	
	ERETRI	*Eremopyrum triticeum*	Annual Wheatgrass	Annual Grass	X
	LEYCIN	*Leymus cinereus*	Basin Wildrye	Perennial Grass	
	PASSMI	*Pascopyrum smithii*	Western Wheatgrass	Perennial Grass	
	POABUL	*Poa bulbosa*	Bulbous Bluegrass	Perennial Grass	X
	POASEC	*Poa secunda*	Sandberg Bluegrass	Perennial Grass	
	VULOCT	*Vulpia octoflora*	Sixweeks Fescue	Annual Grass	
Polemoniaceae	LINPUN	*Linanthus pungens*	Prickly Phlox	Perennial Forb	
	PHLHOO	*Phlox hoodii*	Hood's Phlox	Perennial Forb	
	PHLLON	*Phlox longifolia*	Longleaf Phlox	Perennial Forb	
Ranunculaceae	RANTES	*Ranunculus testiculatus*	Burr Buttercup	Annual Forb	X
Sarcobataceae	SARVER	*Sarcobatus vermiculatus*	Greasewood	Shrub	

Table 1-2. Annual/biennial species cover and frequency (calculated as the percentage of plots with species present) by nativity. Species with no recorded cover were not intercepted along any transect line. Species with no recorded frequency were found incidentally, outside of sample plots. Group cover may exceed 100%, due to overlapping plant canopies.

Annual/Biennial Forbs, Native					
Species Code	**Species Name**	**Common Name**	**Mean Cover**	**SE**	**Frequency**
CRYsp	*Cryptantha* species	Catseye	N/A	N/A	N/A
DESPIN	*Descurainia pinnata*	Tansymustard	0.57%	0.21%	6.74%
LAPOCC	*Lappula occidentalis*	Stickseed	0.07%	0.04%	3.19%
Group Total			0.64%	0.21%	9.57%

Annual/Biennial Forbs, Introduced					
Species Code	**Species Name**	**Common Name**	**Mean Cover**	**SE**	**Frequency**
ALYDES	*Alyssum desertorum*	Desert Alyssum	0.07%	0.06%	1.06%
ATRROS	*Atriplex rosea*	Tumbling Saltbush	N/A	N/A	N/A
CHOTEN	*Chorispora tenella*	Purple Mustard	N/A	N/A	0.35%
DESSOP	*Descurainia sophia*	Flixweed	3.28%	0.49%	40.43%
HALGLO	*Halogeton glomeratus*	Halogeton	N/A	N/A	N/A
KOCSCO	*Kochia scoparia*	Kochia	0.11%	0.04%	4.26%
LACSER	*Lactuca serriola*	Prickly Lettuce	N/A	N/A	8.87%
LEPPER	*Lepidium perfoliatum*	Clasping Pepperweed	32.22%	1.83%	85.82%
RANTES	*Ranunculus testiculatus*	Burr Buttercup	3.39%	0.63%	27.66%
SALTRA	*Salsola tragus*	Russian Thistle	N/A	N/A	N/A
SISALT	*Sisymbrium altissimum*	Tumble Mustard	0.11%	0.06%	4.61%
TRADUB	*Tragopogon dubius*	Yellow Salsify	N/A	N/A	1.42%
Group Total			39.17%	2.12%	94.33%

Annual Grass, Native					
Species Code	**Species Name**	**Common Name**	**Mean Cover**	**SE**	**Frequency**
VULOCT	*Vulpia octoflora*	Sixweeks Fescue	0.05%	0.05%	0.35%
Group Total			0.05%	0.05%	0.35%

Annual Grass, Introduced					
Species Code	**Species Name**	**Common Name**	**Mean Cover**	**SE**	**Frequency**
BROTEC	*Bromus tectorum*	Cheatgrass	62.54%	2.15%	94.68%
ERETRI	*Eremopyrum triticeum*	Annual Wheatgrass	0.07%	0.07%	1.42%
Group Total			62.61%	2.15%	94.68%

Table 1-3. Perennial species cover and frequency (calculated as the percentage of plots with species present) by nativity. No introduced, perennial forbs were found in the 2017 survey. Species with no recorded cover were not intercepted along any transect line. Species with no recorded frequency were found incidentally, outside of sample plots. Group cover may exceed 100%, due to overlapping canopies.

Perennial Forbs, Native					
Species Code	**Species Name**	**Common Name**	**Mean Cover**	**SE**	**Frequency**
ALLNEV	*Allium nevadense*	Nevada Onion	N/A	N/A	0.35%
ASTLEN	*Astragalus lentiginosus*	Freckled Milkvetch	N/A	N/A	N/A
ASTPUR	*Astragalus purshii*	Woollypod Milkvetch	N/A	N/A	N/A
CYMPUR	*Cymopterus purpurascens*	Widewing Spring Parsley	N/A	N/A	N/A
LINPUN	*Linanthus pungens*	Prickly Phlox	N/A	N/A	N/A
PHLHOO	*Phlox hoodii*	Hood's Phlox	N/A	N/A	0.35%
PHLLON	*Phlox longifolia*	Longleaf Phlox	N/A	N/A	2.13%
SISLIN	*Sisymbrium linifolium*	Flaxleaf Plainsmustard	0.02%	0.02%	0.35%
Group Total			0.02%	0.02%	3.19%

Perennial Grasses, Native					
Species Code	**Species Name**	**Common Name**	**Mean Cover**	**SE**	**Frequency**
ACHHYM	*Achnatherum hymenoides*	Indian Rice Grass	0.04%	0.04%	0.35%
ARIPUR	*Aristida purpurea*	Purple Threeawn	N/A	N/A	1.06%
ELYELY	*Elymus elymoides*	Bottlebrush Squirreltail	1.37%	0.24%	28.37%
LEYCIN	*Leymus cinereus*	Basin Wildrye	N/A	N/A	0.35%
PASSMI	*Pascopyrum smithii*	Western Wheatgrass	0.39%	0.20%	2.84%
POASEC	*Poa secunda*	Sandberg Bluegrass	0.33%	0.12%	6.38%
Group Total			2.11%	0.36%	35.11%

Perennial Grasses, Introduced					
Species Code	**Species Name**	**Common Name**	**Mean Cover**	**SE**	**Frequency**
AGRCRI	*Agropyron cristatum*	Crested Wheatgrass	8.48%	1.24%	26.95%
POABUL	*Poa bulbosa*	Bulbous Bluegrass	0.05%	0.04%	3.19%
Group Total			8.53%	1.24%	28.72%

Table 1-4. Shrub cover and frequency (calculated as the percentage of plots with species present) by nativity. No introduced shrubs were found in the 2017 survey. Species with no recorded cover were not intercepted along any transect line. Species with no recorded frequency were found incidentally, outside of sample plots. Group cover may exceed 100%, due to overlapping plant canopies.

Shrubs, Native					
Species Code	**Species Name**	**Common Name**	**Mean Cover**	**SE**	**Frequency**
ARTTRI	*Artemisia tridentata* ssp. *wyomingensis*	Wyoming Big Sagebrush	6.13%	0.66%	40.78%
ATRCAN	*Atriplex canescens*	Fourwing Saltbush	N/A	N/A	N/A
ATRCON	*Atriplex confertifolia*	Shadscale	N/A	N/A	0.35%
CHRVIS	*Chrysothamnus viscidiflorus*	Yellow Rabbitbrush	0.46%	0.17%	7.80%
ERINAU	*Ericameria nauseosa*	Rubber Rabbitbrush	N/A	N/A	N/A
KOCAME	*Kochia americana*	Greenmolly	0.04%	0.03%	2.84%
OPUPOL	*Opuntia polyacantha*	Plains Pricklypear	N/A	N/A	0.71%
SARVER	*Sarcobatus vermiculatus*	Greasewood	3.51%	0.52%	21.63%
Group Total			10.14%	0.81%	57.45%

Table 1-5. Cover of non-living plant matter.

Additional Intercepts				
Species Code	**Species Name**	**Definition**	**Mean Cover**	**SE**
DH	Dead Herbaceous	Standing dead herbaceous from previous growth years	33.07%	1.64%
DS	Dead Shrub	Standing dead shrub	1.72%	0.27%
LITT	Litter	Detached plant matter	42.91%	1.36%
WD	Woody Debris	Detached, woody plant matter sized greater than 5 mm	2.22%	0.26%

Table 1-6. Cover of soil surface categories.

Soil Surface				
Species Code	**Species Name**	**Definition**	**Mean Cover**	**SE**
BSC	Biological Soil Crust	Living soil crust	19.57%	1.43%
DUFF	Duff	Decomposed litter	2.25%	0.36%
GRAV	Gravel	Rocky material sized 0.2 cm-7.6 cm	0.18%	0.06%
LICH	Lichen	Lichen	0.39%	0.08%
MOSS	Moss	Moss	14.36%	1.24%
PB	Plant Base	Base of live plant	1.83%	0.28%
ROCK	Rock	Rocky material sized greater than 7.6 cm	0.05%	0.03%
SOIL	Soil	Bare soil	61.33%	1.93%

Appendix 2.

Descriptions of Representative Pedons

The following seven pedon descriptions were prepared by Merran Owen and are based on data collected during our summer 2017 soil survey. These pedons were determined to best represent the four soil families that occur within Antelope pasture in 2017 (Figure 22).

Master horizons are designated by upper case letters and are defined as follows: A horizons form at the soil surface and consist of mineral soil mixed with accumulations of organic matter. They may have properties resulting from cultivation or pasturing. B horizons are subsurface, mineral horizons that show evidence of pedogensis such as the accumulation of silicate clay, iron, carbonates, sesquioxides, etc. C horizons are mineral soil or soft bedrock that have been little affected by pedogensis. A designation such as AB or BC indicates a horizon with characteristics of both master horizons but dominated by that which is listed first. Horizon suffixes are lowercase letters that indicate specific characteristics: “t” indicates an accumulation of silicate clay; “k” an accumulation of secondary carbonates; “n” an accumulation of exchangeable sodium and “q” indicates the accumulation of secondary silica (Schoeneberger et al. 2012).

Pedon #47

This pedon is a very deep, well drained soil formed in fine grained lacustrine sediments derived from sedimentary rocks. The pedon is on a nearly level surface at an elevation of 1378 m. Slopes are 0 to 1 percent. Mean annual precipitation is 203 to 254 mm and mean annual air temperature is 8.3° C. Current vegetation is *Artemisia tridentata* ssp. *wyomingensis* (sagebrush) and *Bromus tectorum* (cheatgrass). Native vegetation is presumed to be sagebrush, perennial grasses and forbs.

TAXONOMIC CLASS: Fine-loamy, mixed, superactive, mesic Xeric Natrargids

TYPICAL PEDON: This pedon is in Antelope Pasture, Curlew Grazing Allotment, Oneida County, ID. Exact coordinates are 42◦1’30.7” N, 112◦55’54.4” W. (Colors are for dry soil unless otherwise noted. When described on July 12, 2017, soil was dry to slightly moist.)

A1--0 to 9 cm; light gray (10YR 7/2) loam, brown (10YR 4/3) moist; moderate medium granular structure; soft, very friable, slightly sticky and slightly plastic; many very fine and common fine roots; slightly effervescent, slightly alkaline (pH 7.8); clear smooth boundary.

A2--9 to 25 cm; light gray (10YR 7/2) silt loam, brown (10YR 5/3) moist; moderate fine subangular blocky structure; soft, very friable, moderately sticky and moderately plastic; many very fine roots; 3% fine gravel; slightly effervescent, strongly alkaline (pH 8.8); clear smooth boundary.

Btn--25 to 42 cm; light gray (2.5Y 7/2) silt loam, grayish brown (2.5Y 5/2) moist; moderately sticky and moderately plastic; 1% gravel; violently effervescent, strongly alkaline (pH 9.0).

Bn--42 to 75 cm; pale brown (2.5Y 8/2) loam, pale brown (2.5Y 7/3) moist; slightly sticky and slightly plastic; few medium prominent iron masses; few medium prominent iron depletions; 1% gravel; violently effervescent, strongly alkaline (pH 9.0).

Bk--75 to 114 cm; light gray (2.5Y 7/2) loam, light yellowish brown (2.5Y 6/3) moist; slightly sticky and slightly plastic; few coarse carbonate masses; few medium prominent iron masses; few medium prominent iron depletions; 5% gravel; violently effervescent, strongly alkaline (pH 8.6).

C--114 to 121 cm; light gray (2.5Y 7/2) loam, light yellowish brown (2.5Y 6/3) moist; slightly sticky and slightly plastic; few coarse carbonate masses; few medium prominent iron masses; 35% coarse gravel; violently effervescent, moderately alkaline (pH 8.2).

Excavation of this pedon was limited by gravelat 121 cm.

Pedon #92

This pedon is a very deep, well drained soil formed in fine grained lacustrine sediments derived from sedimentary rocks. The pedon is on a nearly level surface at an elevation of 1381 m. Slopes are 0 to 1 percent. Mean annual precipitation is 203 to 254 mm and mean annual air temperature is 8.3° C. Current vegetation is *Artemisia tridentata* ssp. *wyomingensis* (sagebrush) and *Bromus tectorum* (cheatgrass). Native vegetation is presumed to be sagebrush, perennial grasses and forbs.

TAXONOMIC CLASS: Fine-silty, mixed, superactive, mesic Xeric Natrargids

TYPICAL PEDON: This pedon is in Antelope Pasture, Curlew Grazing Allotment, Oneida County, ID. Exact coordinates are 42°1’20.5” N, 112°56’20.18” W. (Colors are for dry soil unless otherwise noted. When described on June 20, 2017, soil was dry to slightly moist.)

A--0 to 5 cm; light gray (2.5Y 7/2) silt loam, grayish brown (2.5Y 5/2) moist; moderate medium platy structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine and many fine roots; noneffervescent, slightly alkaline (pH 7.6); clear smooth boundary.

Bt--5 to 20 cm; light gray (2.5Y 7/2) silty clay loam, grayish brown (2.5Y 5/2) moist; moderate very fine granular structure; slightly hard, friable, moderately sticky and moderately plastic; many very fine and many fine and few coarse roots; slightly effervescent, slightly alkaline (pH 7.8); clear smooth boundary.

Btk--20 to 33 cm; light gray (2.5Y 7/2) silty clay loam, light brownish gray (2.5Y 6/2) moist; moderately sticky and moderately plastic; common medium carbonate masses; strongly effervescent, slightly alkaline (pH 7.8).

Bkn1--33 to 52 cm; white (2.5Y 8/1) silt loam, light brownish gray (2.5Y 6/2) moist; moderately sticky and moderately plastic; common medium carbonate masses; violently effervescent, very strongly alkaline (pH 9.4).

Bkqn--52 to 75 cm; white (2.5Y 8/1) silt loam, light gray (2.5Y 7/2) moist; slightly sticky and slightly plastic; common coarse silica masses; few medium carbonate masses; violently effervescent, strongly alkaline (pH 9.2).

BC--75 to 120 cm; light gray (2.5Y 7/2) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few medium carbonate masses; few medium prominent iron masses; few medium prominent iron depletions; violently effervescent, strongly alkaline (pH 8.6).

C--120 to 153 cm; light gray (2.5Y 7/2) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few coarse carbonate masses; common medium prominent iron masses; few medium prominent iron depletions; violently effervescent, moderately alkaline (pH 8.4).

Pedon # 101

This pedon is a very deep, well drained soil formed in fine grained lacustrine sediments derived from sedimentary rocks. The pedon is on a nearly level surface at an elevation of 1383 m. Slopes are 0 to 1 percent. Mean annual precipitation is 203 to 254 mm and mean annual air temperature is 8.3° C. Current vegetation is *Artemisia tridentata* ssp. *wyomingensis* (sagebrush) and *Bromus tectorum* (cheatgrass). Native vegetation is presumed to be sagebrush, perennial grasses and forbs.

TAXONOMIC CLASS: Coarse-silty, mixed, superactive, mesic Xeric Natrargids

TYPICAL PEDON: This pedon is in Antelope Pasture, Curlew Grazing Allotment, Oneida County, ID. Exact coordinates are 42◦1’20.96” N, 112◦55’54.08” W. (Colors are for dry soil unless otherwise noted. When described on July 12, 2017, soil was dry to slightly moist.)

A--0 to 7 cm; light gray (10YR 7/2) silt loam, dark grayish brown (10YR 4/2) moist; moderate medium platy structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots and few fine roots; very slight effervescent, slightly alkaline (pH 7.6); clear smooth boundary.

Btn—7 to 28 cm; light gray (10YR 7/2) silt loam, brown (10YR 5/3) moist; moderate fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common very fine and few coarse roots; strongly effervescent, strongly alkaline (pH 9.0); clear smooth boundary.

Bt1--28 to 58 cm; light gray (2.5Y 7/2) silt loam, light yellowish brown (2.5Y 6/3) moist; slightly sticky and slightly plastic; few fine roots; few medium prominent iron masses; violently effervescent, strongly alkaline (pH 8.8).

Bt2--58 to 78 cm; light gray (2.5Y 7/2) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few medium prominent iron masses; violently effervescent, strongly alkaline (pH 8.6).

B1--78 to 99 cm; light gray (2.5Y 7/2) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few medium prominent iron masses; few medium prominent iron depletions; violently effervescent, moderately alkaline (pH 8.2).

BCk--99 to 136 cm; white (2.5Y 8/1) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few medium carbonate masses; few medium prominent iron masses; few medium prominent iron depletions; violently effervescent, moderately alkaline (pH 8.0).

C—136 to 157 cm; white (2.5Y 8/1) silt loam, light brownish gray (2.5Y 6/2) moist slightly sticky and slightly plastic; few coarse carbonate masses; few medium prominent iron masses; few medium prominent iron depletions; violently effervescent, moderately alkaline (pH 8.0).

Pedon #260

This pedon is a very deep, well drained soil formed in fine grained lacustrine sediments derived from sedimentary rocks. The pedon is on a flat surface at an elevation of 1370 m. Slopes are 0-1 percent. Mean annual precipitation is 203-254 mm and mean annual air temperature is 8.3° C. Current vegetation is *Sarcobatus vermiculatus* (greasewood) and *Bromus tectorum* (cheatgrass). Native vegetation is presumed to be greasewood, perennial grasses and forbs.

TAXONOMIC CLASS: Fine-silty, mixed, superactive, mesic Sodic Xeric Haplocalcids

TYPICAL PEDON: This pedon is in Antelope Pasture, Curlew Grazing Allotment, Oneida County, ID. Exact coordinates are 42°0’51.55” N, 112°56’6.25” W. (Colors are for dry soil unless otherwise noted. When described on July 17, 2017, soil was dry to slightly moist.)

A--0 to 8 cm; light gray (10YR 7/2) loam, grayish brown (10YR 5/2) moist; strong medium platy structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; slightly effervescent, strongly alkaline (pH 8.6); clear smooth boundary.

Btn1—8 to 22 cm; white (2.5Y 8/1) silty clay loam, light brownish gray (2.5Y 6/2) moist; moderate medium subangular blocky structure; slightly hard, friable, moderately sticky and moderately plastic; common very fine and few fine and coarse roots; violently effervescent, strongly alkaline (pH 9.0); clear smooth boundary.

Btn2--22 to 49 cm; white (2.5Y 8/1) silt loam, light yellowish brown (2.5Y 6/3) moist; moderately sticky and moderately plastic; few fine and coarse and very coarse roots; violently effervescent, strongly alkaline (pH 9.0).

Bk--49 to 80 cm; white (2.5Y 8/1) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few medium carbonate masses; violently effervescent, strongly alkaline (pH 8.4).

Btk1--80 to 112 cm; light gray (2.5Y 7/2) silt loam, light brownish gray (2.5Y 6/2) moist; moderately sticky and moderately plastic; few coarse carbonate masses; violently effervescent, moderately alkaline (pH 8.0).

Btk2--112 to 150 cm; light gray (2.5Y 7/2) silt loam, light brownish gray (2.5Y 6/2) moist; moderately sticky and moderately plastic; few coarse carbonate masses; violently effervescent, moderately alkaline (pH 8.0).

Pedon #308

This pedon is a very deep, well drained soil formed in fine grained lacustrine sediments derived from sedimentary rocks. The pedon is on a nearly level surface at an elevation of 1370 m. Slopes are 0 to 1 percent. Mean annual precipitation is 203 to 254 mm and mean annual air temperature is 8.3° C. Current vegetation is *Artemisia tridentata* ssp. *wyomingensis* (sagebrush), *Sarcobatus vermiculatus* (greasewood), and *Bromus tectorum* (cheatgrass). Native vegetation is presumed to be sagebrush, greasewood, perennial grasses and forbs.

TAXONOMIC CLASS: Fine-silty, mixed, superactive, mesic Sodic Xeric Haplocalcids

TYPICAL PEDON: This pedon is in Antelope Pasture, Curlew Grazing Allotment, Oneida County, ID. Exact coordinates are 42°0’41.4” N, 112°56’32.03” W. (Colors are for dry soil unless otherwise noted. When described on June 30, 2017, soil was dry to slightly moist.)

A1--0 to 8 cm; light brownish gray (2.5Y 6/2) loam, dark grayish brown (2.5Y 4/2) moist; moderate fine granular structure; soft, friable, slightly sticky and slightly plastic; many very fine and common fine roots; violently effervescent, moderately alkaline (pH 8.0); clear smooth boundary.

A2--8 to 22 cm; light gray (2.5Y 7/2) silt loam, grayish brown (2.5Y 5/2) moist; moderate fine granular structure; soft, friable, slightly sticky and slightly plastic; common very fine and few fine roots; violently effervescent, moderately alkaline (pH 8.0); clear smooth boundary.

AB--22 to 54 cm; white (2.5Y 8/1) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few fine and coarse and very coarse roots; finely disseminated carbonates; violently effervescent, strongly alkaline (pH 8.6).

Bk1--54 to 67 cm; white (2.5Y 8/1) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; finely disseminated carbonates; few medium prominent iron masses; violently effervescent, strongly alkaline (pH 8.6).

Bk2--67 to 80 cm; white (2.5Y 8/1) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few medium carbonate masses; few medium prominent iron masses; violently effervescent, moderately alkaline (pH 8.4).

Bk3--81 to 96 cm; light gray (2.5Y 7/2) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few medium carbonate masses; few medium prominent iron masses; few medium prominent iron depletions; violently effervescent, moderately alkaline (pH 8.0).

BCk--96 to 133 cm; light gray (2.5Y 7/2) silt loam, grayish brown (2.5Y 5/2) moist; slightly sticky and slightly plastic; few medium carbonate masses; few medium prominent iron masses; few medium prominent iron depletions; violently effervescent, moderately alkaline (pH 8.0).

C--133 to 158 cm; light gray (2.5Y 7/2) silt loam, grayish brown (2.5Y 5/2) moist; slightly sticky and slightly plastic; common medium carbonate masses; few medium prominent iron masses; few medium prominent iron depletions; violently effervescent, moderately alkaline (pH 8.0).

Pedon # 377

This pedon is a very deep, well drained soil formed in fine grained lacustrine sediments derived from sedimentary rocks. The pedon is on a nearly level surface at an elevation of 1367 m. Slopes are 0 to 1 percent. Mean annual precipitation is 203 to 254 mm and mean annual air temperature is 8.3° C. Current vegetation is *Artemisia tridentata* ssp. *wyomingensis* (sagebrush) and *Bromus tectorum* (cheatgrass). Native vegetation is presumed to be sagebrush, perennial grasses and forbs.

TAXONOMIC CLASS: Coarse-silty, mixed, superactive, mesic Sodic Xeric Haplocalcids

TYPICAL PEDON: This pedon is in Antelope Pasture, Curlew Grazing Allotment, Oneida County, ID. Exact coordinates are 42°0'32.8" N, 112°55'26.54" W. (Colors are for dry soil unless otherwise noted. When described on July 4, 2017, soil was dry to slightly moist.)

A--0 to 8 cm; light brownish gray (10YR 6/2) loam, dark grayish brown (10YR 4/2) moist; moderate medium platy structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots and few coarse roots; slightly effervescent, slightly alkaline (pH 7.8); clear smooth boundary.

AB—8 to 28 cm; light brownish gray (10YR 6/2) loam, dark grayish brown (10YR 4/2) moist; moderate fine subangular blocky structure; slightly hard, friable, moderately sticky and moderately plastic; common very fine and few fine and coarse roots; strongly effervescent, moderately alkaline (pH 8.2); clear smooth boundary.

Bn--28 to 55 cm; light gray (2.5Y 7/2) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few medium carbonate masses; violently effervescent, very strongly alkaline (pH 9.2).

Bkqn--55 to 89 cm; white (2.5Y 8/1) silt loam, light brownish gray (2.5Y 6/2) moist; slightly sticky and slightly plastic; few coarse silica masses; few medium carbonate masses; common medium prominent iron masses; violently effervescent, very strongly alkaline (pH 9.2).

Bk1--89 to 111 cm; light gray (2.5Y 7/2) silt loam, grayish brown (2.5Y 5/2) moist; slightly sticky and slightly plastic; few coarse carbonate masses; common medium prominent iron masses; common medium prominent iron depletions; violently effervescent, strongly alkaline (pH 8.8).

Bk2--111 to 150 cm; light gray (2.5Y 7/2) silt loam, grayish brown (2.5Y 5/2) moist; moderately sticky and moderately plastic; few coarse carbonate masses; few medium prominent iron masses; few medium prominent iron depletions; violently effervescent, moderately alkaline (pH 8.2).

Pedon #416

This pedon is a very deep, well drained soil formed in fine grained lacustrine sediments derived from sedimentary rocks. The pedon is on a flat surface at an elevation of 1365 m. Slopes are 0-1 percent. Mean annual precipitation is 203-254 mm and mean annual air temperature is 8.3° C. Current vegetation is *Sarcobatus vermiculatus* (greasewood), *Bromus tectorum* (cheatgrass) and *Lepidium perfoliatum* (clasping pepperweed). Native vegetation is presumed to be sagebrush, greasewood, perennial grasses and forbs.

TAXONOMIC CLASS: Fine-silty, mixed, superactive, mesic Xeric Calciargids

TYPICAL PEDON: This pedon is in Antelope Pasture, Curlew Grazing Allotment, Oneida County, ID. Exact coordinates are 42°0’21.96” N, 112°56’31.42” W. (Colors are for dry soil unless otherwise noted. When described on June 30, 2017, soil was dry to slightly moist.)

A1--0 to 6 cm; white (2.5Y 8/1) loam, grayish brown (2.5Y 5/2) moist; weak medium platy structure; soft, very friable, slightly sticky and slightly plastic; common very fine roots; very slight effervescence, moderately alkaline (pH 8.2); clear smooth boundary.

A2--6 to 20 cm; white (2.5Y 8/1) loam, grayish brown (2.5Y 5/2) moist; moderate fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; slightly effervescent, moderately alkaline (pH 8.2); clear smooth boundary.

Bk1--20 to 36 cm; white (2.5Y 8/1) silt loam, light yellowish brown (2.5Y 6/3) moist; slightly sticky and slightly plastic; few medium carbonate masses; few medium prominent iron masses; strongly effervescent, moderately alkaline (pH 8.2).

Bkq--36 to 70 cm; white (2.5Y 8/1) silt loam, light yellowish brown (2.5Y 6/3) moist; moderately sticky and moderately plastic; common coarse silica masses; few medium carbonate masses; few medium prominent iron masses; violently effervescent, moderately alkaline (pH 8.2).

Bk2’--70 to 97 cm; light gray (2.5Y 7/1) silt loam, light brownish gray (2.5Y 6/2) moist; moderately sticky and moderately plastic; few medium carbonate masses; few medium prominent iron masses; few medium prominent iron depletions; violently effervescent, moderately alkaline (pH 8.0).

Bk3’--97 to 117 cm; light gray (2.5Y 7/2) silt loam, light brownish gray (2.5Y 6/2) moist; moderately sticky and moderately plastic; few medium carbonate masses; few medium prominent iron masses; few medium prominent iron depletions; violently effervescent, slightly alkaline (pH 7.6).

Bk4’--117 to 155 cm; light gray (2.5Y 7/2) silt loam, light brownish gray (2.5Y 6/2) moist; moderately sticky and moderately plastic; common medium carbonate masses; few medium prominent iron masses; violently effervescent, slightly alkaline (pH 7.6).