Monitoring the Effects of Forage Kochia (*Bassia prostrata*) on Newly Established Wildfire Fuel Breaks and Adjoining Plant Communities

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

Forage kochia (*Bassia prostrata*) possess unique characteristics that make it an ideal species for greenstrip programs to break-up fuel continuity. Land management agencies are sometimes hesitant to use this species as part of a fire suppression and fuels reduction program because of its reported invasive potential and unknown interactions among the native plant communities. Greenstrip seeded areas, established by the Bureau of Land Management, were sampled to better understand forage kochia establishment, invasive potential, and interactions with other plant species. The study sites were located approximately 32 kilometers north of Minidoka, Idaho and adjacent to Craters of the Moon National Monument and Preserve. In 2012 soil attributes were analyzed, specifically soil electrical conductivity (EC) and soil sodium absorption ratio (SAR) , to determine the effect of saline and sodic soil conditions on forage kochia establishment. In 2012, 2013, and 2014 rooted frequency and percent cover was measured for all plant species present in both treated and untreated transects at each study site. There was a significant positive relationship between soil salinity (EC) and forage kochia frequency and percent cover. There was a significant positive relationship between forage kochia cover and SAR. With EC values ranging from 0.35-4.2, soil salinity had a significant positive relationship on perennial grasses and had a significant negative correlation with annual forbs. Sodium absorption ratio had a significant negative correlation on perennial forb cover. Forage kochia abundance increase significantly within the treated areas study wide for both cover and frequency sampling methods. Frequency and percent cover sampling methods did not detect forage kochia beyond the treated study area 4 and 5 years after planting. Over the three year sampling period there were no significant changes in cover for either the perennial or annual plant communities species. However, there was a significant increase in shrub cover, suggesting that the landscape is moving toward a more stable, shrub-dominated state. Over the three year sampling period, there was a significant negative correlation between bareground and forage kochia cover and a significant positive correlation between litter and kochia cover. Species richness was significantly higher for the treated transects compared to the untreated transects. However, there were no significant differences in the Shannon-Wiener Index for diversity between the treated and untreated transects. These findings suggest that forage kochia is tolerant of saline soils, has low invasive potential, contributes to landscape diversity, and that the presence of forage kochia does not alter the perennial and annual plant community.

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INTRODUCTION

For the past several decades, the western United States has been affected by large, intensive, reoccurring wildfires. Wildfires in sagebrush steppes are devastating to sagebrush obligate wildlife habitat, fire suppression and rehabilitation efforts are expensive, and valuable natural resources are lost. The increased fire frequency (Knick et al. 2005) has made it extremely challenging for land managers to restore these sites to their native plant community (Ellis 2011). These rehabilitation activities have been continuously set back by repeated wildfires that occur on a 5-10 year cycle. Native plant communities are being replaced with invasive annuals and weedy species. Cheatgrass (*Bromus tectorum*) is the dominate invasive species that contributes to the frequency of these destructive wildfires.

Craters of the Moon National Monument and Preserve contain one of the most critical areas for wildfire occurrences in south-central Idaho (Knick et al. 2005, Davies et al. 2011). Prior to the series of wildfires that initiated in 1972, the Craters of the Moon National Monument and Preserve was a mature sagebrush steppe that provided critical habitat for sage grouse (*Centrocercus urophasianus*), mule deer (*Odocoileus hemionus*), and other wildlife species (Fischer et al. 1996, Knick et al. 2005). The Bureau of Land Management (BLM) has an active fire suppression, hazardous fuels reduction, and emergency stabilization and restoration program. Yet, large fires continue despite these efforts (Ellis 2011). Without intervention to reduce the fuel continuity, these habitats will continue to burn at 5-10 year intervals (Knick et al. 2005). Sagebrush steppe vegetation cannot withstand the repeated wildfires and continue to maintain habitat for sagebrush obligate plant and animal species.

The greenstripping program was implemented by the Idaho BLM in 1985 to help reduce the impact of wildfires (Pellant 1992). Greenstripping is characterized by low flammability vegetation strips paralleling roadways in wildfire prone landscapes, and range from of 9 to 122 m in width. The concept of the greenstrip is that these strips of green, high moisture vegetation will reduce the speed and intensity of a wildfire, allowing firefighters better opportunity to suppress the wildfire. Monsen (1992) described the following species characteristics for a successful greenstripping program; easily adapt to semiarid environments, easily established, can compete with invasive annuals and weedy species, low flammability, open canopy and compact structure, and palatable.

Forage kochia (*Bassia prostrata*) is used for rangeland restoration, soil stabilization, greenstripping and firebreak projects, and for wildlife and livestock forage. McArthur et al. (1996) and Stevens et al. (1985) reported that land agencies have successfully used forage kochia to prevent soil erosion and suppress invasive annuals following a wildfire or other disturbance. Pellant (1989) stated that forage kochia performed well when seeded as part of a greenstrip seed mixture.

Forage kochia is tolerant of saline and sodic soils and productive under these soil conditions. Francois (1976) found that forage kochia is tolerant of soil salinity levels up to 17 mmhos/cm without plant injury. He also reported that forage kochia tolerated sodium chloride concentrations up to 50-85 meq/100grams without plant injury.

Forage kochia exhibits characteristics that make it an ideal component for a greenstrip. Forage kochia established well in environments that receive 15-40 cm of annual precipitation and on a wide range of soil textures (USDA, Plant Database). Forage kochia possess attributes of low flammability. Harrison et al. (2000) described the plant as having a green understory throughout the year. Forage kochia has a deep taproot (USDA, Plant Database) and exhibits C4 photosynthesis and the Kranz anatomy (Pyankov et al. 2001) enhancing its drought tolerance. Forage kochia competes well with invasive annual plant species. Monaco et al. (2003), Harrison et al. (2000), and McArthur et al. (1989) all reported a decrease in cheatgrass cover when forage kochia was interseeded into invasive annual landscapes. Because of the properties described above, forage kochia appears to be a viable greenstrip plant species, as it can provide land managers the opportunity to decrease the fire interval by reducing cheatgrass cover (Clements et al. 1997).

While forage kochia appears to be an optimal species to suppress invasive annuals and reduce wildfire frequency, some scientists and land managers are concerned by its non-native status, invasive potential, and interactions with the native perennial and annual plant community.

Objectives of this research are:

- To determine whether soil attributes have a significant effect on the establishment of forage kochia.
- Evaluate changes in treated sites' species composition over time.
- To determine whether treatment areas differ significantly from adjacent untreated plant communities with respect to species diversity

- Evaluate the invasiveness of forage kochia by determining if forage kochia spread to the untreated plant community.

LITERATURE REVIEW

Wildfire intensity and frequency has increased over the past 50 years. In 1965, there were 113,684 wildfire occurrences nationwide that totaled 1.1 million hectares. In 2015, there were 68,151 wildfires reported in the U.S. that destroyed 4.1 million hectares. In 2014, wildfire suppression cost taxpayers over $1.5 billion (National Interagency Fire Center 2015). This value does not include the habitat and economic losses or land rehabilitation costs. Historically, wildfires in sagebrush plant communities reoccurred at intervals of 30-100 years or greater (Wright et al. 1979, Miller and Tausch 2001, Knick et al. 2005). Today some areas of the western U.S. experience wildfire occurrence at 10-year intervals (Pellant 1989, Knick et al. 2005). The increase in wildfire frequency is heavily influenced by invasive annuals, primarily cheatgrass. Cheatgrass has an advantage over other plant species in that it can adapt to a wide range of environments, is capable of early germination in cooler temperature, takes advantage of early season moisture, and is a prolific seed producer (Young et al. 1987). Cheatgrass provides an abundance of fine textured litter that fuels rangeland wildfires that burn sagebrush steppe communities (Young et al. 1987). Cheatgrass competition of soil moisture limits the establishment of other plant species, including perennial grasses, forbs and shrubs (Young et al. 1987).

Forage kochia is a semi-evergreen, perennial shrub that belongs to the Chenopodiaceae (Goosefoot) family. Forage kochia is an introduced species from Eurasia, where it is utilized as rangeland forage for livestock and wildlife (Davis 1979). Shepherds from Uzbek refer to forage kochia as the “alfalfa of the desert” (Waldron et al. 2005). Forage kochia is a long lived plant, with plant heights that vary from 2.5-cm for seedlings to 1-m for mature plants.

Forage kochia is an abundant producer of seed (Stevens et al. 1985) and readily germinates from seed (USDA, NRCS). Forage kochia seed is naturally dispersed by the wind and can collect in low areas of the landscape. Forage kochia has a deep taproot and a vast fibrous root system that enhances its drought tolerance. This property along with C4 photosynthesis and the Kranz anatomy (Pyankov et al. 2001) allows the plant to remain in the vegetative stage longer into the growing season. Monsen and Turnipseed (1989) observed that forage kochia seedlings remained green and succulent throughout the entire growing season. Forage kochia is characterized by green to gray-green succulent leaves and stems (Stevens et al. 1985). Harrison et al. (2000) described the forage kochia plant as having green lower leaves throughout the year, while the seed stalk and upper stems turn reddish-brown in the fall. Forage kochia is oftentimes confused with the troublesome annual weed, kochia (*Bassia scoparia*) which is prominent in cultivated land.

A competitive advantage that forage kochia has over native and exotic plant species is the ability to adapt to a wide range of environmental conditions (Waldron et al. 2001, Monsen 1992, Harrison 2000). Forage kochia thrives in a variety of plant communities, including sagebrush steppe, shadescale, saltbrush, and pinyon juniper communities. Stevens et al. (1985) reported that forage kochia cultivar, ‘Immigrant’, has been successfully seeded into a number of vegetation types including Wyoming big sagebrush (*Artemisia tridentata* w*yomingensis*), basin big sagebrush (*Artemisia tridentata tridentata*) and black sagebrush (*Artemisia nova*) , as well as juniper (*Juniperus* spp.), pinyon/juniper (*Pinus* spp.), rubber rabbitbrush (*Ericameria nauseosa*), shadescale (*Atriplex confertifolia*), black greasewood (*Sarcobatus vermiculatus*), and fourwing saltbrush (*Artiplex canescens*) communities. Forage kochia is best suited for arid and semiarid environments that receive 15-40 cm of annual precipitation (USDA, NRCS). Forage kochia was found in greater abundance on sites characterized by lower precipitation compared to higher precipitation sites. (Waldron et al. 2001, Gray and Muir 2013). Forage kochia establishes well on a wide range of soil textures, but prefers a silt loam textured soil (USDA, NRCS). Waldron et al. (2001) reported that 'Immigrant' is widely adapted and has been successfully established on a range of soils including fine to course textured, shallow to deep, gravelly to stony, and saline to alkaline and in numerous plant communities.

Forage kochia thrives in a well drained soil. Balyan (1972) reported that forage kochia does not tolerate flooding or soil with a water table near the surface. Forage kochia grows well in basic soils but it is not well adapted to neutral and acidic soils (Stevens et al. 1985). Forage kochia is considered a halophyte species, tolerant of saline and sodic soils, and can be productive in these soil conditions. Research conducted by Francois (1976) found that forage kochia is tolerant of salinity levels up to 17 mmhos/cm without plant injury. Akhzari et al. (2012) reported a decrease in forage kochia productivity with EC values > 30 mmhos/cm. Research suggests that sodium plant uptake by forage kochia increases with increasing salinity levels (Francois 1976). Romo and Haferkamp (1987) stated that forage kochia appears moderately tolerant of sodium chloride and potassium chloride during germination and growth. Forage kochia tissue concentrations of sodium chloride may reach 50 to 85 meq/100 grams dry matter without plant injury (Francois 1976).

It has been well documented that forage kochia can spread into high saline sites that are often referred to as "slickspots" (Stevens et al. 1985, Harrison et al. 2000, Gray and Muir 2013, Waldron et al. 2001). There is concern that because of the invasive potential of forage kochia, native vegetation would be suppressed by forage kochia, with forage kochia eventually dominating the landscape. This is an especially sensitive issue for plant species like slickspot peppergrass (*Lepidium papilliferum*) which is classified as proposed endangered by the U. S. Fish and Wildlife Services (United States Fish and Wildlife Services).

Forage kochia, like most plants, has been reported to spread naturally in the right environmental conditions and lack of competition from other plant species (Harrison et al. 2000). Some research suggests that forage kochia is not an aggressive spreader. For example, in forage kochia seeding areas ranging from 10-30 years old, Harrison et al. (2000) found the mean distance of a single plant from its original seeding was 28 m and maximum distance of a single plant from the original seed boundary was 386 m. McArthur (1989) found forage kochia plants established 100 m from the original seeding in 12-15 year old plantings. Clements et al. (1997) found forage kochia to not be invasive in the Great Basin. Other researchers claim that forage kochia is mildly invasive. In forage kochia seedings that ranged from 3-24 years old, Gray and Muir (2013) found a mean distance of 208 m to an individual forage kochia plant and a maximum distance of 710 m from the original seed boundary. Gray and Muir (2013) also found large, isolated forage kochia patches outside of the seed boundary and these patches had their own satellite patches of kochia, therefore increasing the potential for forage kochia to dominate a landscape.

Encroachment of forage kochia into the native landscape is influenced by several environmental factors including elevation, soil moisture, soil disturbance, soil salinity and sodicity levels, and competition from other vegetation (Harrison et al. 2000, McArthur 1989, Waldron et al. 2001, Gray and Muir 2013). Harrison et al. (2000) reported that forage kochia recruits in droughty soils with high saline and sodic concentrations, including slickspots. They also reported that forage kochia was more likely to invade landscapes with low annual precipitation compared to landscapes with high annual precipitation and observed encroachment on sites that receive >46 cm of annual precipitation. Gray and Muir (2013) found the greatest abundance of forage kochia on sites characterized by low elevation and silty soils texture. Waldron et al. (2001) reported that forage kochia will spread naturally in disturbed areas and areas lacking vegetation, especially perennial vegetation and the amount and distance of the spread is dependent on the severity of the disturbance and the plant competition from both annual and perennial species. Forage kochia cover increased significantly without competition compared to those plants with competition from other vegetation (Van Epps and McKell 1983). However, Gray and Muir (2013) reported that plant community composition was not related to the spread of forage kochia, and that forage kochia encroached on established perennial communities as well as annual plant communities.

Some research suggests that seeding age is a contributing factor to the spread of forage kochia. Not all scientists are in agreement on the theory that the rate and distance of spread increases with time. Harrison et al. (2000) reported that the age of the plantings was not significantly correlated to the distance of a plant from the original seeding. Ten years after planting into a cheatgrass dominated community, forage kochia did not spread beyond the boundary of the seeded area (Monaco et al. 2003). Gray and Muir (2013) found that forage kochia spread was linear with time at an estimated mean spread rate of 25 m per year. In a study conducted by McArthur et al. (1989) an 18-year old seeding of forage kochia had spread beyond its seed boundary into an abandoned farm land that was infested with cheatgrass and competitively co-existed with the plant community.

Forage kochia possess the characteristics that make it a favorable species for greenstripping and rangeland reclamation such as: 1) can adapt and persist in disturbed environments, 2) competitive against annuals, 3) valuable forage for wildlife and livestock, 4) drought tolerant, 5) salt tolerant, and 6) low flammability (Waldron et al 2001, Stevens et al. 1985 and Monsen 1992). McArthur et al. (1996). Stevens et al. (1985) reported that land management agencies have successfully used forage kochia to prevent soil erosion and suppress invasive annuals following a wildfire or other disturbance. Pellant (1989) reported that forage kochia performs well where it was seeded as a greenstrip component and that it exhibits all five desirable characteristics of a favorable greenstrip species. Important factors that land managers must consider prior to planting forage kochia are seed viability, seeding rate, timing of planting, seedbed preparation, and seeding method. Sullivan et al. (2013) found that out of four pre-plant disturbance techniques, soil disturbance significantly increased forage kochia emergence, establishment, and density. Stevens and McArthur (1989) reported that forage kochia had the best seeding results when seeded into disturbed soil. Six years after planting there was significantly more kochia in the disturbed plots compared to the undisturbed plots. Monsen and Turnipseed (1989) reported that forage kochia plants established amid dense stands of annual weeds, such as cheatgrass, and that the presence of associated vegetation did not appear to depress the growth of the surviving seedlings. Although, they recommend a higher seeding rate when interseeding in an annual dominated plant community.

It is well documented that forage kochia is an excellent competitor against exotic annuals (Monsen and Turnipseed 1989, Monaco et al. 2003, Stevens and McArthur 1989, and Waldron et al. 2001). Sullivan et al. (2013) reported an increase in forage kochia density when seeded in an annual plant community and a decrease in density when seeded in a perennial and shrub community. Stevens and McArthur (1989) stated that when forage kochia was interseeded into an established halogeton (*Halogeton glomeratus*) stand; halogeton density and cover was reduced in the treated plots compared to the untreated plots seven years following planting. Monsen and Turnipseed (1989) found that after emergence forage kochia was tolerant of competition from other plant species, and reported that there was no significant relationship between the density of the forage kochia seedlings and percent ground cover for any annual or perennial species. Stevens et al. (1985) also reports that once established, forage kochia competes well with annual species including cheatgrass and halogeton. Dense surface and standing litter, often associated with annual dominated sites, did not appear to be detrimental to seedling establishment (Monsen and Turnipseed 1989). Although, Gray and Muir (2013) found there to be a negative relationship between forage kochia abundance and plant litter. Monsen and Turnipseed (1989) demonstrated that out of all plant species groups, summer annuals posed the largest threat to the survival of forage kochia seedlings.

Forage kochia has been demonstrated to be competitive among invasive annuals, including cheatgrass and halogeton. However, there is limited scientific research regarding the interactions between forage kochia and established native perennial plant communities. Monaco et al. (2003) reported that little is known about forage kochia's compatibility with desirable native species. Harrison et al. (2000) found Sandberg bluegrass (*Poa secunda*) thriving as an understory to forage kochia, Harrison et al. (2000) also observed forage kochia co-existing with crested wheatgrass (*Agropyron cristatum*), Wyoming big sagebrush, and winter fat (*Krascheninnikovia lanata*). Two years following planting, forage kochia appeared to be more capable of withstanding competition from other vegetation compared to the other species in the trial; Russian wildrye (*Psathyrostachys juncea*), winterfat, and fourwing saltbrush (Van Epps and McKell 1983). Waldron et al. (2001) observed forage kochia in its native range in Eurasia growing in association with grasses and *Artemisia* species communities and contributing to the biodiversity of the landscape. However, Waldron et al. (2001) reported that in the United States forage kochia does not compete well in established perennial plant communities. Gray and Muir (2013) found that forage kochia abundance was negatively associated with both native and exotic perennial grasses and shrubs and exotic annuals including cheatgrass. Sullivan et al. (2013) reported that competition with perennial plants reduces forage kochia growth and survival.

METHODS

Study Site

This was a cooperative research project between the University of Idaho and the Twin Falls District Bureau of Land Management, Burley Field Office. The study site is located approximately 32 kilometers north of Minidoka, Idaho, and both within and adjacent to the Craters of the Moon National Monument (Figure 1). The study was implemented in the fall of 2009, 2010, and 2011. Bureau of Land Management established 30.5 m fuel breaks parallel to and on either side of the roadway. Seedbeds were prepared by either harrowing or blading to remove existing vegetation. Seeding methods included broadcasting seed onto dry soil and cultipacking or broadcasting seed onto dry soil without cultipacking (Table 1). Forage kochia 'Immigrant' Lot # KOPR40640, was seeded at 3.5 kg/ha and forage kochia, 'Immigrant' Lot # 07113 was seeded at 1.75 kg/ha on the fuel break. Sites were randomly selected based on adequate seedling establishment to meet project objectives. Locations were recorded using GPS technology and permanent markers were installed.

The United States Department of Agriculture, Natural Resources Conservation Service, Web Soil Survey (websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey. Accessed January 2016) was used to determine soil characteristics for the study sites (Table 2). The study site receives 29 cm of annual precipitation, mean maximum air temperature is 23˚ C and mean minimum air temperature is -7˚ C (www.raws.dri.edu Accessed January 2016). Elevation ranges from 975-1430 m (websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey. Accessed January 2016).

Prior to the series of wildfires that initiated in 1972, Craters of the Moon National Monument and Preserve was a mature sagebrush steppe that provided critical habitat for sage grouse, mule deer, and many other species. Over the past 30 years, 116 separate wildfires have burned within the 132,000 ha project site (Smith, D. USDI Bureau of Land management. 2011. Personal communication). The Bureau of Land Management has been committed to emergency stabilization and land rehabilitation activities after wildfire to the project area. Over 4 million dollars have been spent on wildfire rehabilitation activities in the project area (Smith, D. USDI Bureau of Land management. 2011. Personal communication). These rehabilitation activities have been continuously set back by repeated wildfires that occur on a 5-10 year cycle (Smith, D. USDI Bureau of Land Management. 2011. Personal communication). For the majority of the project area, success has been achieved in establishing perennial grasses. However, the efforts to establish sagebrush have been consistently set back by the trend of large stand replacing wildfires. These reoccurring wildfires have also increased the incidence of invasive annuals.

Vegetation Sampling

August 1 to August 15, 2012, eight sampling sites were randomly selected with visually significant stands of forage kochia to accomplish project objectives. Four 25-m transects were established within the treatment area and perpendicular to the planting direction at each site. One 25-m transect was established 5 m outside of the treatment area parallel to the treatment and perpendicular to the other four transects to monitor the potential encroachment of forage kochia at each sampling site. Vegetation sampling occurred in 2012, 2013, and 2014 during the time period of July 14 to July 22. Line point cover for bareground, litter, and all vegetative species was measured at 0.5-m intervals, as described by Goodall (1952). The point end of a field flag was used to mark the vertical projection, perpendicular to the ground, that passes through the vegetation at every 0.5 m along a 25-m transect. Total number of observations per species was recorded as a percentage of the total number sampling points. Twenty-five nested frequency quadrats were sampled by rooted species at 1-m intervals along the 25-m transect, as described by Smith et al. (1986). The nested frequency quadrat consisted of three sizes nested within a 50x50 cm quadrat including 5x5, 25x25, and 25x50 cm. Herbaceous species canopy cover was visually estimated to the nearest percent of the total area measured, using a 50x50 cm frame. Canopy cover percent was estimated by the area influenced by the plants outermost perimeter.

Soil Analyses

In 2012, ten soil subsamples were taken from the treated area of each study site from the surface to a depth of 30 cm using a pro-series mud auger, 5.175 cm in diameter. The ten subsamples were composited into a single sample for each study site. The soil samples were naturally air dried at the time of sampling, and were therefore stored in plastic, zip top bags at room temperature until analysis, without the need of an additional drying step. Soil samples were analyzed for soil texture, soil pH, electrical conductivity (EC) and sodium absorption ratio (SAR), as described below.

Soil texture was determined using soil particle size analysis with the hydrometer method using an ASTM 152H-Type hydrometer (Gavlak et al. 2005). Soil pH was determined following the 1:2 soil:water extract ratio method (Gavlak et al. 2005). Soil pH was measured using an Oakton pH/mV/°C Meter, pH 11 Series.

Soil EC and soluble K, Ca, Mg, and Na were determined using the saturated paste extract method described in Gavlak et al. (2005). Soil pastes were placed in Buchner funnels and extracted for soil water using an applied vacuum pressure of 80 kPa and Whatman No. 42 filter paper. Electrical conductivity of the extracts was determined using the Thermo Scientific Orion 3 Star Conductivity Benchtop meter, following methods described in Gavlak et al. (2005). Extracts were refrigerated and later analyzed for soluble K, Ca, Mg, and Na. Water soluble K, Ca, Mg, and Na concentrations were determined using a Perkin-Elmer Optima 3200 inductively coupled plasma atomic emission spectroscopy. Sodium Absorption Ratio (SAR) was calculated using the established equation for $SAR = \frac{[Na^{+}]}{\sqrt{0.5[Ca^{2+}] + 0.5[Mg^{2+}]}}$ and the K, Ca, Mg, and Na concentration values (Brady and Weil 2002).

Statistical analyses

Principle Components Analysis was performed in JMP (SAS Institute Inc. 2007) to determine the differences in soil attributes between study sites.

For ease of interpretation of forage kochia and vegetation life form, cover distribution by soil salinity (EC) and soil sodium absorption ratio (SAR); EC was categorized by (L) <1.0 dS/m and (H) 3.9-4.2 dS/m and SAR was categorized by (L) 1.0-3.99, (M) 4.0-7.99 and (H) 8.0-13.0. Boxplots were created in SAS 9.3 (SAS Institute Inc. 2011) using PROC Boxplot procedure, to illustrate the vegetation life form cover distribution by the variability in soil EC and SAR.

Data were analyzed using SAS 9.3 (SAS Institute Inc. 2011). A linear regression analysis was conducted using the PROC REG procedure to determine the relationship between forage kochia frequency and cover and soil salinity (EC) and soil sodium absorption ratio (SAR), to determine how these soil attributes influenced the establishment and survival of forage kochia. A linear regression analysis was also used to determine the relationship between forage kochia, and litter and bareground. Significance was tested at α=0.05 level. The samples were collected from an arid environment with low annual precipitation and no irrigation. The assumption was made that the soil attributes did not change significantly over the three year period of the study, therefore, soil samples were only collected and analyzed for 2012 and used as a factor in plant measurements among all sample years.

It was determined that the 25x25 cm quadrat size was the appropriate size to estimate forage kochia frequency as described by Smith et al. (1986). A Chi-squared test in SAS 9.3 (SAS Institute Inc. 2011) was conducted using the PROC FREQ procedure to determine significant changes in forage kochia frequency. Significance was tested at α=0.05 level.

For ease of interpretation, the cover data were categorized by life form groups: perennial grasses, annual grasses, perennial forbs, annual forbs, and shrubs. Forage kochia cover was analyzed independent of these groups. An analysis of variance in SAS 9.3 (SAS Institute Inc. 2011) was performed using the PROC GLM procedure to determine significant changes in forage kochia cover and perennial and annual grass cover, perennial and annual forb cover and shrub cover.

Diversity was determined by measuring species richness and calculating the Shannon-Wiener Index, as described by Magurran (2013). Species richness is expressed as the number species present on a site. The Shannon-Wiener Index is a combination of species richness and abundance and was calculated using an established equation for SWI, $H' = -\sum\left[\left(\frac{ni}{\mathcal{N}}\right) x \ln\left(\frac{ni}{\mathcal{N}}\right)\right]$.Where n_i = the abundance of the i^{th} species, and N = the sum of all species abundances.

SOILS

Results

Analyses of the soil samples indicated that there were only minor differences in the measured characteristics among sites (Table 3). The most noticeable difference was at Wapi Park 1, largely due to the variation in soil pH, EC, Mg, Na, and SAR (Figure 2). Wapi Park 1 was characterized by an EC value that was threefold of the mean EC value of the seven other sites. Wapi Park 1 SAR was also nearly threefold of the mean SAR value of the seven other study locations. Generally, the values found were within the expected ranges reported for these soils (USDA NRCS Web Soil Survey). For this study soil EC was categorized as, low <1.0 dS/m, and high 3.9-4.2 dS/m, and SAR was categorized as low 1.0-3.99, medium 4.0-7.99, and high 8.0-13.0.

Forage kochia and soil interaction

There was a significant (P=0 0.0374) positive relationship between forage kochia rooted frequency and EC across all three years of the study. EC was positively correlated with rooted frequency of forage kochia (y=5.896x + 39.652, R^2=.1852). There was a significant (P=0.0191) relationship between forage kochia canopy cover and EC across all three years of the study. EC was positively correlated with the canopy cover of forage kochia, though the amount of variability explained is low (y=0.9286x + 8.0244, R^2=0.0570) (Figure 3).

There was no significant relationship (P=0.5906) between forage kochia rooted frequency and SAR over the three year study period. There was a significant relationship (P=0.0332) between forage kochia canopy cover and SAR. SAR was positively correlated with canopy cover of forage kochia however, the amount of variability explained is low (y=0.3237x + 7.7277, R^2=0.0473) (Figure 3).

Other vegetation and soil interactions

There was a significant relationship (P=<0.0001) between perennial grasses canopy cover and soil EC over the three year study period. There was a positive correlation between perennial grass and EC (y=0.3116x + 9.2768, R^2= 0.1649) (Figure 4). However, there was no significant relationship (P=0.5107) between perennial grass cover and SAR (Figure 5).

EC and SAR did not have an influence on annual grass canopy cover over the three year study period. There was no significant relationship between annual grass canopy cover and EC or SAR, P=0.1602 and P=0.1152, respectively (Figures 4 and 5).

There was no significant relationship between shrub canopy cover and EC or SAR, P=0.1927 and P=0.3302, respectively (Figures 4 and 5).

There was no significant relationship (P=.0820) between perennial forb canopy cover and EC (Figure 4). Interestingly, there was a significant relationship (P= <0.0001) between perennial forb canopy cover and SAR. There was a negative correlation between SAR and perennial forb cover (y=-0.2496x + 2.8735, R^2=0.2722) (Figure 5).

There was a significant relationship (P=0.0145) between annual forb canopy cover and EC over the three year study. There was a slight negative correlation between EC and annual forb canopy cover, though the amount of variability explained was low (y= -0.2727x + 1.2432, R^2=0.0619) (Figure 4). There was no significant relationship (P=0.110) between annual forb canopy cover and SAR (Figure 5).

Discussion

All sampling sites were characterized by silt loam soil texture, with the exception of Bear Trap that was characterized by a sandy loam. These soil textures are in line with those as described by the USDA plant database as the preferred soil texture for forage kochia (USDA, NRCS Plant database). They also had similar pH ranges at or near basic, with the exception of Bear Trap which was characterized as slightly acidic. Wapi Park 1 was characterized by EC and SAR values that were a three fold increase of the mean EC and SAR values of the seven other study sites. It is interesting to note, that Wapi Park 2 is located in a similar geographic area as Wapi Park 1 and was also characterized by an EC value that was threefold greater than the mean, but exhibited an SAR value threefold less than the mean SAR.

There were two distinct levels of soil salinity for this study, the low level of, <1.0 dS/m, and a high level of, 3.9-4.2 dS/m (Table 3). Our findings were consistent with the USDA, NRCS Web Soil Survey classification of the project area as nonsaline to moderate saline (0.0 to 8.0 dS/m). The soils from the project sites were all formed in loess, colluvium, residuum and alluvium over basalt plains, outcropping, benches and ridges (USDA NRCS Web Soil Survey). Since these soils were all formed from the same parent material, it was unexpected to have such great differences in soil salinity between sites. Salt affected soils occur in arid and semiarid environments where soil is enriched with salts faster than they are leached (Buol et al. 2011) These environments are characterized by minimal precipitation to flush the salts through the soil profile. Salt accumulation occurs at or near the soil surface as water evaporates (Buol et al. 2011); the areas of high soil salinity may have been depressions in the landscape with low permeability, therefore salts accumulated. The areas of high soil salinity are also shallow depth to duripan (USDA, NRCS Web Soil Survey), therefore restricting the leaching of the accumulated salts through the soil profile. Another possible theory that explains the range of soil salinity is eolian (wind) deposits of salt from nearby playas to uplands that is reported as a common process in arid environments (Reid et al.1993, reported in Buol et al. 2011)

There were three distinct levels of sodium absorption ratio; low 1.0-3.99, medium 4.0-7.99 and 8.0-13.0 for this study (Table 3). The same principles that apply to soil salinity also apply to SAR; occur in areas of low precipitation, in low areas of the landscape where water pools and in shallow soils. Research conducted by Francois (1976) indicates that sodium uptake increased with increasing salinity levels.

While the range in soil salinity in this study is not extreme (0.35 to 4.2 dS/m), this research suggests that there is a positive correlation between soil salinity and forage kochia canopy cover and rooted frequency. Across all three years there was a significant relationship between forage kochia canopy cover and rooted frequency and soil salinity. It must be noted that even though the p-values are significant, the R^2 values are low and careful consideration of these results is advised. Our study supports other documentation that forage kochia establishes well and survives in soils of high salinity. In a greenhouse study Francois (1976) discovered that forage kochia was tolerant of soil salinity levels up to 17 mmhos/cm without injury to the plant. It has been well documented that forage kochia can spread into high saline sites called “slickspots” (Stevens et al. 1985, Harrison et al. 2000).

Romo and Haferkamp (1987) reported that forage kochia appears moderately tolerant of sodium chloride and potassium chloride during germination and growth. Our research indicates there was no significant relationship between sodium absorption ratio, and forage kochia rooted frequency, but there was a significant positive relationship between SAR and canopy cover of forage kochia. Again, it is important to note that while the p-values are significant, the R^2 values are low. As SAR increased forage kochia canopy cover increased. Wapi Park 1 and Wapi Park 2 both had high EC values of 3.9 and 4.2, respectively, but Wapi Park 1 had nearly twofold the amount of forage kochia cover as Wapi Park 2. These results possibly suggest that although SAR does not affect the frequency of occurrence of forage kochia it does affect the size of the plant. Ungar (1978) reports that of all the ions common in saline soils, sodium is the least toxic to the germination of halophytes (Ungar 1978 reported in Romo and Haferkamp 1987).

There was a significant positive correlation between perennial grass cover and soil salinity, indicating that perennial grasses in this study were tolerant of saline soil conditions with EC values up to 4.2 dS/m. Crested wheatgrass, was one of the most common perennial grasses present on the sites, is classified as being moderately tolerant of saline soils with a zero percent yield reduction at EC value of 3.5 dS/m and a 10% yield reduction at 6.0 dS/m (Cardon et al. 2014). However, there was no significant relationship between SAR and perennial grass canopy cover, indicating that in this study perennial grass cover is not influenced by SAR.

Over the three year study period, with the reported range of EC and SAR values, a significant relationship was not detected between those values and annual grass cover or shrub cover.

There was no significant relationship between perennial forb canopy cover and soil EC. There was a significant negative correlation between annual forb canopy cover and EC, though the amount of variability explained was low. Perennial forbs are established plants with extensive root systems that are able to penetrate deeper into the soil profile for water and nutrients avoiding the salt accumulation zone, whereas annual forbs are shallow rooted absorbing water and nutrients from near the soil surface where salts have accumulated. Sodium absorption ratio appears to be detrimental for perennial forb cover; there was significant negative correlation between SAR and perennial forb canopy cover. As the SAR of the soil increased perennial forb cover decreased, suggesting possible plant growth stunting with increased levels of SAR.

VEGETATION

Results

Kochia cover and frequency

As discussed in the methods and materials section, three sampling methods were used to evaluate the establishment and recruitment of forage kochia: quadrat canopy cover as a percent, linepoint canopy cover, and frequency. Both canopy cover sampling methods were also used to evaluate the general plant community.

There was a significant (P=0.0002, P=0.0240) increase in forage kochia cover across all sites, over the three year study period, for both canopy cover and linepoint cover sampling methods, respectively. Three of the eight sampling sites had a significant increase in forage kochia canopy cover over the three year study; Wapi Park 1, (P=0.0043), Wapi Park 2, (P=0.0096), and Southwest 2 (P=<0.0001) (Table 4). Bear Trap, Whiskey Butte South, Whiskey Butte, and Wapi Park all had significant differences in linepoint cover for the three sampling years (P=0.0045, P=0.0140, P=0.0033, and P=0.0145) (Table 5).

It was determined that the 25 x 25 cm quadrat was the appropriate size to detect changes in forage kochia, as described by Smith et al. (1986). Forage kochia rooted frequency also increased significantly (P=<0.0001) across all sites, during the course of the study. Five of the eight sampling sites had a significant increase in forage kochia over the three year study: Whiskey Butte S (P= <0.0001), Whiskey Butte N (P=0.0079), Whiskey Butte (P=<0.0001), Southwest (P=0.0128), and Southwest 2 (P=<0.0001) (Table 6).

Line point cover was used to evaluate the amount of bareground and litter present on the study sites. A regression analysis used to determine how bareground and litter affect forage kochia cover. There was a significant correlation between forage kochia and bareground over the three year study period (P= 0.0189). Bareground was negatively correlated with forage kochia cover (y=16.599x + -0.13811, R^2=0.0573). There was a significant relationship between forage kochia and litter over the three-year study period (P=0.0161). Litter was positively correlated with forage kochia cover, though the amount of variability explained was low (y=3.75x+0.12865, R^2=0.0161).

For this particular study, forage kochia did not spread outside of the treatment area. There were no observations of forage kochia plants in the untreated transect with any of the sampling methods used. Frequency and percent cover sampling methods did not detect forage kochia beyond the treated study area 4 and 5 years after planting

Other Vegetation-Percent Cover

Throughout the study, trend changes varied depending on whether one was focusing on results across the study as a whole or on an individual site basis.

Over the three year study, there were no significant differences in perennial grass cover across all sites with either the canopy cover or linepoint sampling method (P=0.3059, P=0.0866, respectively). However, at the site level Whiskey Butte-South, Whiskey Butte, and Southwest 2 all had significant (P= 0.0154, P= 0.0079, and P<0.0001, respectively), differences in perennial grass canopy cover during the three year study period. The above mentioned sites had an increase in perennial grass cover from 2012-2013, but cover decreased from 2013-2014 (Table 4). Over the course of the study perennial grass canopy cover at Whiskey Butte-North decreased significantly (P=0.0024) (Table 4). Whereas, Wapi Park 1 had a significant

(P=0.0002) increase in perennial grass canopy cover over the three years (Table 4). Wapi Park 2 had a significant (P=0.0540) increase in perennial grass linepoint cover (Table 5).

Annual grass canopy cover did not change significantly (P=0.4093, P= 0.1440) across all sites during the three year study period regardless of sampling method. However, at the site level there were differences between years. Both Whiskey Butte North and Whiskey Butte South had a significant, P=<0.0001 and 0.0024, respectively, increase in annual grass canopy cover during the study period. There was a significant decrease in annual grass canopy cover for Bear Trap (P=0.0002) and Wapi Park 1 (P=0.0046) (Table 4). Over the three year study period there was a significant (P= 0.0002) difference in annual grass canopy cover at Southwest 1, annual grass cover increased from 2012-2013 and decreased from 2013-2014 (Table 4). Whiskey Butte South, Whiskey Butte North, and Whiskey Butte all had significant (P=0.0346, P=0.0002, and P=0.0026, respectively) decreases in annual grass cover using the linepoint sampling method (Table 5).

Shrub canopy cover increased significantly (P=0.0221) among all sites over the three year study period. Although, at the individual site level only Southwest 1 had a significant (P=0.00134) increase in shrub canopy cover over the three years (Table 4). Linepoint sampling did not detect any significant (P= 0.0955) differences in shrub cover over the three year sampling period. However, at that site level Wapi Park 1 had a significant (P=0.0154) decrease in shrub cover using the linepoint method (Table 5).

Perennial forb canopy cover did not change significantly (P=0.6791, P=0.0813) across all study sites over the three year period, regardless of sampling method used. At the site level, Whiskey Butte had a significant (P=0.0029) decrease in perennial forb canopy cover and

Wapi Park 1 had a significant (P=<0.0001) increase in perennial forb cover (Table 4). Wapi Park 2 had a significant (P=0.0029) difference in perennial canopy cover over the course of the study, perennial forbs decreased from 2012 to 2013, increased from 2013 to 2014 (Table 4). Linepoint cover detected a significant (P=0.0520) increase in perennial forbs at Southwest 1 (Table 5).

Annual forb canopy cover also did not change significantly (P=0.1004, 0.3766) across all sites over the three year study, regardless of sampling method. Whiskey Butte South and Whiskey Butte both had a significant (P= 0.0096 and P=0.0447, respectively) increase in annual forb canopy cover (Table 4). Interestingly, linepoint sampling detected a significant (P=0.0192) decrease in annual forb cover at Whiskey Butte South (Table 5).

Along with vegetation, linepoint cover was used to estimate percent bareground and litter present at each of the sampling sites.

Study wide there were no significant differences in bareground and litter, (P=0.2499 and P=0.3889, respectively) over the three-year study period. However, at the site level there were differences between years. Whiskey Butte had significant differences in both bareground (P= 0.0169) and litter (P= 0.0449) over the course of the study (Table 5). Bareground decreased from 2012-2013 and increased from 2013-2014 and litter increased from 2012-2013 and decreased from 2013-2014. (Table 5). Whiskey Butte South had a significant (0.0169) difference in litter, litter increased 2012-2013 and decreased from 2013-2014 (Table 5).

Diversity

There were no significant (P=0.0921) differences in species richness between the eight sampling sites during the three year study period in the treated transects (1-4). There was however, significant (P=<0.0001) differences in species richness in the untreated transect (5) between the eight sampling sites (Table 7). Southwest 1 and Southwest 2 had mean species richness values of <50% of the other sample sites (Table 7). Shannon-Wiener Index (SWI) for diversity in the treated and the untreated transects was significantly (P=0.0016, P=0.0088, respectively) different between the eight sampling sites over the three year study (Table 7). Time was not a significant factor for species richness and Shannon-Wiener Index for diversity in either the treated or untreated transects.

Study wide species richness was significantly (P=0.0001) different between the treated and the untreated transects. Species richness increased in the treated transects compared to the untreated transect in seven of the eight study sites. Wapi Park 2 had no significant (P=1.000) changes in species richness between the treated and untreated transects. Study wide SWI was not significantly (P=0.0583) different between the treated and the untreated transects. On an individual site bases SWI increased significantly on the treated transects compared to the untreated transects at Whiskey Butte North (P=0.0113) and Southwest 1 (P=0.0163) (Table 7). Interestingly, Wapi Park 2 had a significant (P=0.0082) decrease on the treated transect compared to the untreated transect (Table 7).

Discussion

Kochia

Forage kochia rooted frequency increased significantly study wide. New plants are establishing over time and distributing across the treatment area. Forage kochia cover also increased significantly over the three year study period, regardless of sampling method used. The kochia plants are becoming firmly established and competing well with the rest of the plant community. With the increase in frequency along with well established, mature kochia plants, it is evident that forage kochia is becoming a part of the plant community.

It is interesting to note, that on an individual site basis, two of the eight sites had a significant increase in forage kochia cover and four of the eight sites had a significant increase in frequency. Whiskey Butte South, Whiskey Butte North, Whiskey Butte, and Southwest 1 all had a significant increase in rooted frequency and did not have a significant increase in cover, suggesting that although plants were present, they were small, not well established, and perhaps competing with other vegetation for water and nutrients. Wapi Park 1 and Wapi Park 2 had a significant increase in cover, but did not have a significant increase in forage kochia rooted frequency, indicating that although there were fewer plants present, they were well established, mature plants, thriving within the plant community. Research also suggests that frequency is more sensitive than cover to changes in the plant community over time. This is in agreement with Smith et al. (1986) who found frequency sensitive to vegetation trends.

Line point canopy cover was used to evaluate the amount of bareground and litter present at each site. Line point canopy cover detected a negative correlation between bareground and forage kochia cover. These findings are not in agreement with other research. Gray and Muir

(2013) observed that the soil cover was positively correlated to the invasive potential of forage kochia, as bareground increased forage kochia increased. Waldron et al. (2001) reported that forage kochia invades bareground and disturbed sites where there was a lack of vegetation. Stevens et al. (1985) observed forage kochia filling in the interspaces between established perennial plants. McArthur et al. (1989) stated that forage kochia was not selective and equally invaded established native plant communities, invasive plant communities, as well as highly disturbed landscapes. Stevens and McArthur (1989) reported that forage kochia establishes best on disturbed soils, clean of other vegetation.

Although, these results are not in agreement with other research, they do coincide with our findings in that forage kochia abundance is increasing where it was planted. The plants are becoming well established, they are larger, more mature and occupy greater areas of the landscape, therefore reducing bareground. This research also indicates that forage kochia has a low invasive potential.

This research found a positive correlation between forage kochia cover and litter; forage kochia cover increased as litter increases. Again, these observations are not in agreement with other research. Gray and Muir (2013) found forage kochia abundance negatively correlated with litter.

Sampling was conducted in July when most of the annual vegetation has completed its lifecycle and therefore during the maximum litter period. It is well documented that forage kochia competes with annual grass plant communities such as cheatgrass dominated landscapes (McArthur et al. 1989, Monsen and Turnipseed 1989, Harrison et al. 2000) and cheatgrass contributes large amounts of fine litter to the landscape. Litter reduces evaporation of water from the soil surface, helping to conserve soil moisture. Litter also serves as an insulator to protect against soil temperature fluctuations (Hatfield and Sauer 2011). This increase in litter, coupled with strong stands of forage kochia help explain the positive association between forage kochia and plant litter.

Frequency and cover sampling methods did not detect forage kochia outside of the treatment boundary four to five years after planting. These observations are in agreement with Monaco et al. (2003) findings that forage kochia seeded into cheatgrass, did not spread beyond its planted boundary within the first 10 years. Waldron et al. (2001) reported that forage kochia is not an aggressive spreader and will not encroach into established perennial plant communities. However, these findings are contrary to what other researchers have found. In seedings that ranged from 3-24 year old in southern Idaho, Gray and Muir (2013) found forage kochia plants at a mean distance of 208 m and a maximum distance of 710 m from the original seed boundary. Harrison et al. (2000) observed forage kochia a mean distance of 28 m and max distance of 386 m from the original seed boundary in 10-30 year old seedings planted in the Great Basin region. McArthur et al. (1989) reported that forage kochia plants encroached 100 m beyond its planted boundary in both native and invasive plant communities.

Gray and Muir (2013) found that forage kochia spread was linear with time at an estimated mean spread rate of 25 m per year. For this particular research and this age of seeding forage kochia does not appear to be a threatening invasive plant and spreading beyond its seeded boundary. Although, further sampling at later dates are needed to validate if age of seeding influenced rate of spread.

Other Vegetation

The increase in frequency and cover of forage kochia did not appear to alter the plant community as a whole. There were no significant changes in either the perennial or annual plant communities. Harrison et al. (2000) observed forage kochia thriving among perennials species such as Sandberg bluegrass and crested wheatgrass, as well as Wyoming big sagebrush. Harrison et al. (2000) also observed that forage kochia competes well with annuals primarily: cheatgrass, halogeton, medusahead rye, and tumble mustard (*Sisymbrium altissimum*). Stevens et al. (1985) reported that forage kochia competes well with annuals and fills in the interspaces between perennial without over taking them. Results from McArthur et al. (1989) indicated that forage kochia will associate with a variety of native and introduced species, both annual and perennial.

There was a significant increase in shrub canopy cover over the three year study period. Like the forage kochia plants, shrubs are becoming well established and are competitive among the rest of the plant community. Precipitation and environmental conditions were likely favorable for shrub establishment and growth. The increase in shrub cover suggests the landscape is moving toward a more stable plant community. Research conducted by Niering and Goodwin (1974) reported in Anderson and Holte (1981) validate that shrub cover is an indication of stability in a plant community and its resistance to invasion by other species. There is a positive correlation between cover and species richness (Anderson and Inouye 2001) and species richness is positively correlated to productivity (Anderson and Inouye 2001). They concluded that landscapes with a greater cover, accompanied by greater species richness, result in greater productivity, therefore increasing stability and increasing resistance to invasion.

This research found there to be a more diverse plant community in the treated (seeded) transects in comparison to the untreated transects. Species richness was significantly higher on the treated verses the untreated transects in seven of eight sampling sites. This difference in species richness is most likely due to the disturbance by seedbed preparation and planting in the treated transects. Species richness and Shannon-Wiener Index for diversity did not change significantly over time, suggesting that the number of species present that occupied these sites remained relatively constant and stable throughout the three year study. Although, not statistically validated, annual grass and perennial and annual forbs had greater abundance in the treated transects compared to the untreated transects, whereas the untreated transect had greater abundance in perennial grasses. These findings are not in agreement with other research. Gray and Muir (2013) found that Shannon-Wiener Index for diversity, species richness, and cover to be higher in the unseeded areas compared to the seeded areas and that seeding does not necessarily increase diversity of a landscape. Anderson and Inouye (2001) reported that landscapes with higher species richness tend to have more stable cover. They also found that exotic species richness was positively correlated with native species richness and that sites with greater perennial cover had greater resistance to invasion. This theory that plant communities with greater perennial cover combined with higher species richness are more resistant to invasion, possibly explains that forage kochia was not detected outside of the treatment area.

Regardless of forage kochia's reputation of a highly invasive species and the fact that little is known regarding its interaction with other species, forage kochia appears to contribute to the diversity of the landscape in this particular study. One possible theory as to why the plant community has remained relatively stable, even though forage kochia frequency and cover has increased, is the "sampling effect" and the "complementary effect". Various research projects conducted throughout North America and Europe demonstrate that ecosystem function such as, nutrient cycling, soil stability, and resistance to weed invasion, increase with diversity (Naeem et al. 1999). The "sampling effect" is the theory that the greater the number of species present, each with varying measures of production and contributions to the landscape, the greater the ability of those species to take advantage of certain environmental conditions and therefore increasing productivity of the landscape (Naeem et al. 1999). The "complementary effect" is the idea that the greater the number of species that complement one another rather than compete with one another for resources, increasing resource efficiency and productivity of the landscape (Naeem et al. 1999). An example of the "complementary effect" would be hydraulic lift of soil moisture by deep rooted species such as Wyoming big sagebrush and forage kochia that could potentially benefit neighboring species (Caldwell and Richards 1989). For this particular research it appears that forage kochia can coexist with and perhaps benefit the plant community without dominating the landscape.

CONCLUSIONS

Forage kochia possess desirable characteristics that make it an ideal candidate species for rangeland rehabilitation and greenstripping. However, land management agencies are cautious about seeding a non-native species, with high invasive potential, and probable competitive interactions with the native plant community.

Forage kochia is tolerant of soil EC values 0.35-4.2 dS/m. This research suggests that there is a positive correlation between soil EC and forage kochia canopy cover and rooted frequency. There was no significant correlation between SAR and forage kochia rooted frequency. However, there was a significant positive correlation between SAR and forage kochia canopy cover. There was nearly a twofold increase, compared to the mean, in forage kochia cover on the site characterized by SAR > 13.These results suggest that SAR does not affect forage kochia's frequency of occurrence, but that it does influence plant size.

There was a significant positive correlation between perennial grass cover and soil salinity, indicating that perennial grasses in this study were tolerant of soil EC values up to 4.2 dS/m.

Study wide forage kochia increased significantly where it was planted regardless of sampling method used to assess abundance. It is evident that forage kochia is becoming a well established, fundamental part of the plant community. The increase in forage kochia cover and frequency did not appear to have a detrimental effect on the native plant community.

This research indicated that forage kochia is a non-invasive. Forage kochia was not detected outside of the treatment boundary four to five years after planting with either the frequency or cover sampling methods.

Throughout the study, cover sampling methods did not detect significant changes in the perennial or annual plant communities. Shrub canopy cover increased significantly study wide, indicating that the plant community was moving to a more stable state. The native plant community remained relatively stable despite the fact that forage kochia stands are developing. The study sites supported a variety of perennial and annual grasses and forbs, as well as shrubs. We found an increase in species richness in the treated transects where forage kochia was planted. This is likely due to the planting disturbance itself and an increase in early seral annual species. Our research indicates that the plant community is relatively stable and forage kochia contributes to the diversity of the landscape. Site stability may help explain why we did not observe forage kochia outside of the treatment boundary.

There was a negative correlation between bareground and forage kochia cover. Our results indicated that forage kochia plants are becoming well established and abundance is increasing where it was planted and not recruiting to nearby disturbed landscapes characterized by bareground. Forage kochia cover increased with increased litter cover, suggesting that it can compete with invasive annuals.

Results indicate that forage kochia is tolerant of salt affected soils, did not encroach onto disturbed sites characterized by bareground, was capable of survival in dense stands of plant litter, had low invasive potential, competed well with both perennial and annual plant communities, and contributed to landscape diversity.

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Table 1. Forage Kochia planting dates and treatments applied on the eight Minidoka fuelbreak sites sampled.

Site	Planting Date	Seedbed Prep	Seeding Method
Bear Trap	Fall 2009	Bulldozer blade	No cultipacking
Whiskey Butte-South	Fall 2010	Dixie harrow	Cultipacking
Whiskey Butte-North	Fall 2010	Bulldozer blade	Cultipacking
Whiskey Butte	Fall 2010	Bulldozer blade	Cultipacking
Wapi Park 1	Fall 2009	Bulldozer blade	No cultipacking
Wapi Park 2	Fall 2009	Bulldozer blade	No cultipacking
Southwest 1	Fall 2010	Bulldozer blade	Cultipacking before & after
Southwest 2	Fall 2010	Bulldozer blade	Cultipacking before & after

Table 2. Soil characteristics for the Minidoka fuelbreak study sites as classified by the USDA, NRCS, Web Soil Survey.

Site	**Soil Complex**	**Texture**	**Percent Slope**	**Depth**	**Drainage Class**	**Ecological Site**
Bear Trap	McCarey-Beartrap	Sandy Loam	1-6	Moderately Deep	Well drained	Loamy 12-16 ARTW8/PSSPS Loamy Bottom 8-14 ARTRT/LECI4
Whiskey Butte-South	McPan-Chijer	Silt Loam	1-6	Shallow	Well drained	Loamy 8-12 Provisional
Whiskey Butte-North	McPan-Chijer	Silt Loam	1-6	Shallow	Well drained	Loamy 8-12 Provisional
Whiskey Butte	McPan-Chijer	Silt Loam	1-6	Shallow	Well drained	Loamy 8-12 Provisional
Wapi Park 1	McPan-Chijer	Silt Loam	1-6	Shallow	Well drained	Loamy 8-12 Provisional
Wapi Park 2	McPan-Chijer	Silt Loam	1-6	Shallow	Well drained	Loamy 8-12 Provisional
Southwest 1	Starbuck-McPan	Silt Loam	2-20	Shallow	Well drained	Shallow Loamy 8-12 ARTRT/PSSPS Loamy 8-12
Southwest 2	Starbuck-McPan	Silt Loam	2-20	Shallow	Well drained	Shallow Loamy 8-12 ARTRT/PSSPS Loamy 8-12

Table 3. Soil analysis results from samples collected from Minidoka Fuel Break study sites in 2012.

Location	Texture	pH	EC dS/m	Ca mmol(+)/L	Mg mmol(+)/L	K mmol(+)/L	Na mmol(+)/L	SAR
Bear Trap	Sandy Loam	6.06	0.35	3.4	1.2	0.75	1.6	1.1
Whiskey Butte-S	Silt Loam	7.24	0.84	1.7	1.2	0.56	9.4	7.8
Whiskey Butte-N	Silt Loam	7.17	0.54	2.7	1.7	0.64	3.9	2.7
Whiskey Butte	Silt Loam	7.10	0.64	1.4	1.1	0.44	7.6	6.8
Wapi Park 1	Silt Loam	7.38	3.9	3.4	4.1	0.57	26.0	13.0
Wapi Park 2	Silt Loam	7.32	4.2	1.6	1.3	0.66	2.0	1.7
Southwest 1	Silt Loam	6.77	0.61	1.5	1.1	0.72	5.7	5.0
Southwest 2	Silt Loam	6.59	0.48	1.3	1.0	0.40	5.3	5.0

Table 4. Canopy cover for *Bassia prostata* and vegetation life forms on all eight Minidoka sampling sites.

Location	Year	*Bassia prostata*	Perennial Grasses	Annual Grasses	Shrubs	Perennial Forbs	Annual Forbs
Bear Trap	**2012**	11.38	8.50	11.0a	1.24	2.77	0.01
	2013	16.04	8.06	0.160b	1.34	3.23	0.07
	2014	16.43	12.19	0.49b	2.13	3.61	0.00
	p-value	0.2101	0.1521	**0.0002***	0.6088	0.7790	0.2134
Whiskey Butte South	**2012**	4.25	8.09b	1.62b	3.87	1.91	.97b
	2013	9.46	12.47a	1.31b	5.53	1.47	1.62b
	2014	7.53	7.11b	9.610a	7.16	0.81	2.780a
	p-value	0.0665	**0.0154***	**<0.0001***	0.5343	0.4491	**0.0096***
Whiskey Butte North	**2012**	3.06	11.6a	0.86b	5.15	4.35	0.28b
	2013	3.71	8.31b	1.00b	5.77	6.48	0.47ab
	2014	3.61	5.86b	2.02a	8.20	3.24	0.97a
	p-value	0.8246	**0.0024***	**0.0546***	0.3385	0.1495	0.0870
Whiskey Butte	**2012**	2.46	3.41a	8.00	0.08	0.74a	1.66b
	2013	5.41	6.02a	8.52	0.62	0.73a	2.48b
	2014	5.02	4.77ab	9.23	0.68	0.18b	6.76a
	p-value	0.0879	**0.0079***	0.6350	0.0995	**0.0029***	**0.0447***
Wapi Park 1	**2012**	9.10b	9.39b	9.10a	1.02	0.20b	0.01b
	2013	18.0a	10.97b	1.77b	2.69	0.30b	0.07a
	2014	20.38a	16.02a	0.48b	2.11	1.23a	0.00b
	p-value	**0.0043***	**0.0002***	**0.0046***	0.5621	**<0.0001***	**0.0066***
Wapi Park 2	**2012**	7.44b	14.97	3.10	1.17	2.71a	0.01
	2013	8.53a	17.45	2.03	1.67	0.30b	0.02
	2014	10.35a	18.72	0.30	2.28	1.70a	0.01
	p-value	**0.0096***	0.2790	0.5323	0.2559	**0.0029***	0.7479
Southwest 1	**2012**	4.66	14.07	3.54b	0.00b	0.55	0.50
	2013	8.0	16.44	18.94a	4.12a	1.33	0.47
	2014	9.78	15.37	2.64b	6.810a	0.07	0.30
	p-value	0.2406	0.7787	**0.0002***	**0.0134***	0.2853	0.4556
Southwest 2	**2012**	6.16c	11.49a	3.08	0.10	0.40a	0.53
	2013	14.09b	19.94a	0.59	0.42	0.22ab	0.19
	2014	19.094a	9.910b	0.89	0.32	0.11b	0.06
	p-value	**<0.0001***	**0.0275***	0.5588	0.6586	0.0624	0.2854
All Sites	**2012**	6.064b	10.190	4.904	1.579b	1.704	0.52
	2013	10.405a	12.083	4.424	2.770ab	1.758	0.65
	2014	11.630a	11.244	3.208	3.711a	1.369	1.36
	p-value	**0.0002***	0.3059	0.4093	**0.0221***	0.6791	0.1004

*Significant at α=0.05

Table 5. Line point canopy cover for all eight Minidoka sampling sites.

Location	Year	Bear Ground	Litter	*Bassia prostata*	Perennial Grasses	Annual Grasses	Shrubs	Perennial Forbs	Annual Forbs
Bear Trap	**2012**	26.5b	67.0	6.0a	11.5	21.0	1.0	2.5	4.5
	2013	47.0a	50.0	0.3b	20.0	16.0	0.0	3.5	5.5
	2014	50.0a	67.5	7.0a	15.0	29.5	1.5	6.0	3.5
	p-value	**0.0557***	0.5220	**0.0045***	0.2277	0.3511	0.4355	0.2414	0.8265
Whiskey Butte South	**2012**	66.5a	27.0b	6.0a	8.5	15.0a	1.5	4.5	4.0a
	2013	54.5b	43.0a	1.0b	10.5	5.5ab	1.5	3.5	0.0b
	2014	60.0ab	35.5ab	3.0ab	6.5	1.5b	0.5	4.0	0.5b
	p-value	**0.0576***	**0.0169***	**0.0140***	0.6878	**0.0346***	0.7049	0.9316	**0.0192***
Whiskey Butte North	**2012**	57.5	37.0	4.5	3.0	20.0a	1.5	5.0	2.5
	2013	55.5	41.5	3.0	3.5	3.0b	0.5	7.5	6.0
	2014	62.0	32.0	5.5	3.5	1.0b	2.5	11.0	2.5
	p-value	0.6360	0.3895	0.6411	0.9163	**0.0002***	0.3765	0.2640	0.4456
Whiskey Butte	**2012**	60.5a	38.0b	1.5b	5.5b	5.5a	14.5	0.5	0.5
	2013	46.5ab	50.5a	3.0a	11.0a	2.5b	9.0	1.0	1.0
	2014	54.5b	44.0ab	0.0c	5.5b	0.0b	10.5	0	0
	p-value	**0.0165***	**0.0449***	**0.0033***	**0.0458***	**0.0026***	0.6000	0.3227	0.3227
Wapi Park 1	**2012**	43.5	55.0	0.0	14.0	8.5b	12.5a	3.5	0.0
	2013	39.5	60.0	0.5	19.5	19.0a	0.0b	3.0	0.0
	2014	43.5	51.0	1.5	17.5	19.0a	0.5b	3.0	0.0
	p-value	0.7190	0.3441	0.5217	0.7164	**0.0020***	**0.0154***	0.9432	0
Wapi Park 2	**2012**	33.5	65.0	1.5b	5.0b	30.0	3.0	2.0	0.5
	2013	39.0	60.0	1.0b	5.0b	29.0	0.0	2.5	0.0
	2014	41.0	50.5	8.5a	13.5a	35.5	0.0	3.0	0.0
	p-value	0.4266	0.1060	**0.0145***	**0.0540***	0.7538	0.1004	0.7985	0.4053
Southwest 1	**2012**	32.4	64.0	3.6	4.8	10.4a	2.4	0.0b	0.0
	2013	23.2	71.2	5.6	5.2	12.8a	7.2	0.8b	2.0
	2014	28.8	66.8	4.8	4.8	0.8b	13.2	5.6a	0.8
	p-value	0.5218	0.6425	0.7288	0.9929	**0.0314***	0.5041	**0.0520***	0.3966
Southwest 2	**2012**	30.8	67.6	1.6	6.8	10.4a	0.0	0.0	0.0
	2013	29.6	64.4	5.6	16.0	7.2a	2.4	0.0	0.4
	2014	36.0	59.2	4.8	17.6	0.8b	2.4	2.8	0.0
	p-value	0.7905	0.6936	.0.1069	0.1666	**0.0074***	0.4863	0.3966	0.3966
All Sites	**2012**	44.9	54.3	3.2ab	7.9	15.3	4.4	2.3	1.6
	2013	42.9	57.3	2.4b	12.0	12.2	1.6	2.8	1.9
	2014	48.4	49.1	4.6a	11.2	9.7	2.5	4.3	0.9
	p-value	0.2499	0.3889	**0.0240***	0.0866	0.1440	0.0955	0.0813	0.3766

*Significant at α=0.05

Table 6. Percent frequency for *Bassia prostrata* for the eight Minidoka sampling sites.

Year	**Bear Trap**	**Whiskey Butte South**	**Whiskey Butte North**	**Whiskey Butte**	**Wapi Park 1**	**Wapi Park 2**	**Southwest 1**	**Southwest 2**	**All sites**
2012	67	33	25	8	56	72	20	38	39.9
2013	72	42	24	20	66	73	29	60	48.3
2014	78	69	42	36	61	64	29	70	57.4
Chi-square	3.0315	28.125	9.6851	23.5169	2.1017	2.3030	8.7157	21.7532	49.0742
p-value	0.2196	**<0.0001***	**0.0079***	**<0.0001***	0.3496	0.3162	**0.0128***	**<0.0001***	**<0.0001***

*Significant at $\alpha=0.05$

Table 7. Species richness and diversity calculated from canopy cover for the treated (1-4) and untreated (5) transects and the statistical comparison between the treated and untreated transects.

Location	**Year**	**Species Richness**			**Shannon-Wiener Index (SWI)**		
		Treated	**Untreated**	**p-value**	**Treated**	**Untreated**	**p-value**
Bear Trap	**2012**	16	13	**0.0437***	1.72	1.32	0.7582
	2013	14	9		1.25	1.34	
	2014	14	10		1.44	1.59	
	mean	14.67	10.67		1.47	1.42	
	p-value	0.3333	0.4878		0.5966	0.2910	
Whiskey Butte South	**2012**	17	11	**0.0353***	2.23	1.01	0.0817
	2013	13	9		1.74	1.30	
	2014	13	8		1.85	1.73	
	mean	14.33	9.33		1.94	1.35	
	p-value	0.3333	0.1210		0.4706	0.0712	
Whiskey Butte North	**2012**	13	8	**0.0158***	2.05	1.08	**0.0113***
	2013	12	10		1.91	1.43	
	2014	12	10		1.92	1.51	
	mean	12.3	9.33		1.96	1.34	
	p-value	0.3333	0.3333		0.3741	0.2214	
Whiskey Butte	**2012**	13	9	**0.0161***	1.53	0.43	0.3250
	2013	11	9		1.53	1.24	
	2014	12	10		1.54	1.69	
	mean	12.0	9.33		1.53	1.12	
	p-value	0.6667	0.3333		0.3333	0.1041	
Wapi Park 1	**2012**	12	8	**0.0022***	1.63	1.27	0.4629
	2013	14	8		1.21	1.24	
	2014	12	8		1.24	1.24	
	mean	12.67	8		1.36	1.25	
	p-value	1.00	?		0.3741	0.3333	
Wapi Park 2	**2012**	10	12	1.0000	1.45	1.78	**0.0082***
	2013	13	12		1.15	1.95	
	2014	10	9		1.17	1.74	
	mean	11.0	11.0		1.26	1.82	
	p-value	1.0	0.3333		0.3713	0.8852	
Southwest 1	**2012**	10	4	**0.0534***	1.35	0.60	**0.0163***
	2013	10	6		1.47	0.77	
	2014	19	4		2.14	0.51	
	mean	13	3.3		1.65	0.63	
	p-value	0.3333	1.000		0.2433	0.7786	
Southwest 2	**2012**	9	2	**0.0048***	1.23	0.06	0.3107
	2013	9	5		0.94	1.04	
	2014	8	3		0.91	0.87	
	mean	8.67	4.67		1.03	0.66	
	p-value	0.3333	0.7877		0.2792	0.4371	
All Sites	**p-value**	0.0921	**<0.0001***	**0.0001***	**0.0016***	**0.0088***	0.0583

*Significant at α=.05

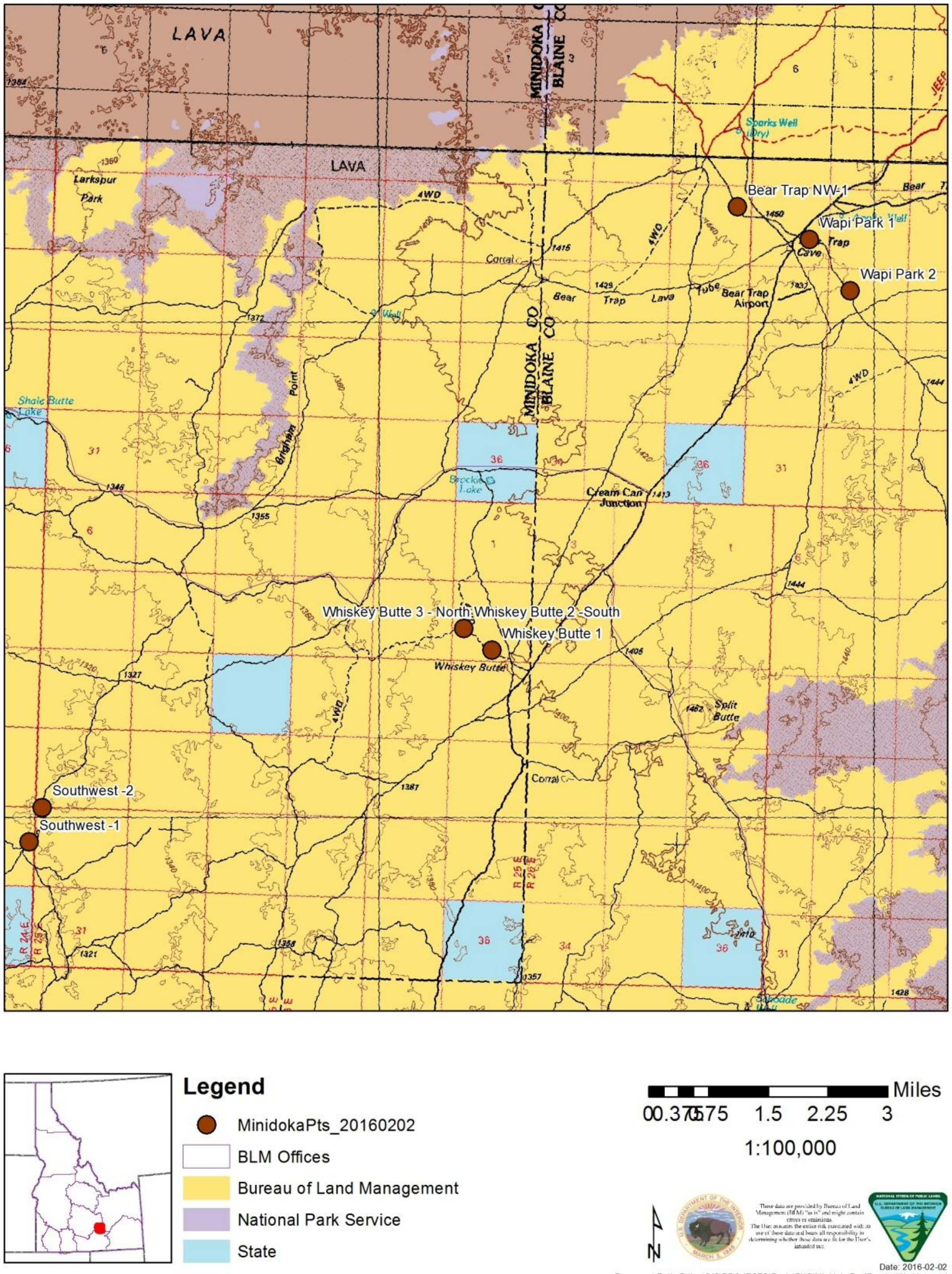


Figure 1. Map of the Minidoka Fuel Break project area with the eight study sites.

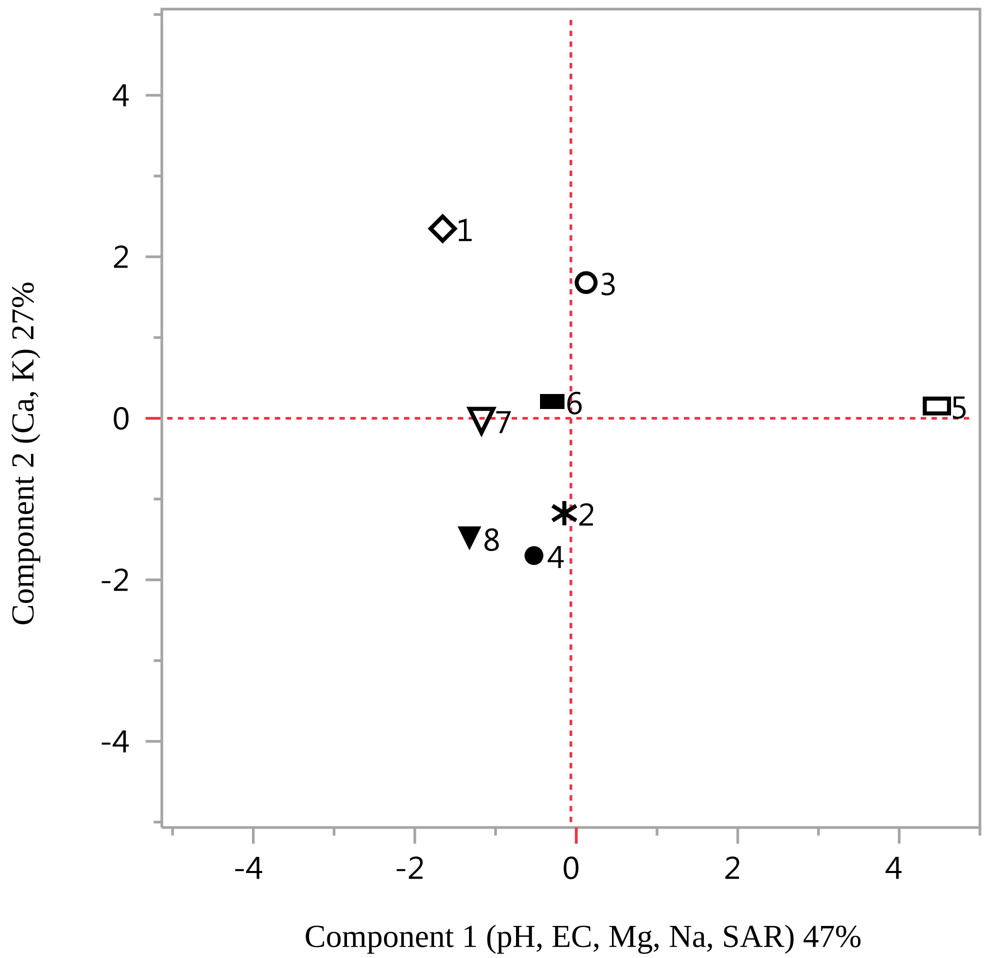


Figure 2. Principle Components Analysis based on the soil components of the Minidoka study sites 1) Bear Trap, 2) Whiskey Butte South, 3) Whiskey Butte North, 4) Whiskey Butte, 5) Wapi Park 1, 6) Wapi Park 2, 7) Southwest 1 and 8) Southwest 2.

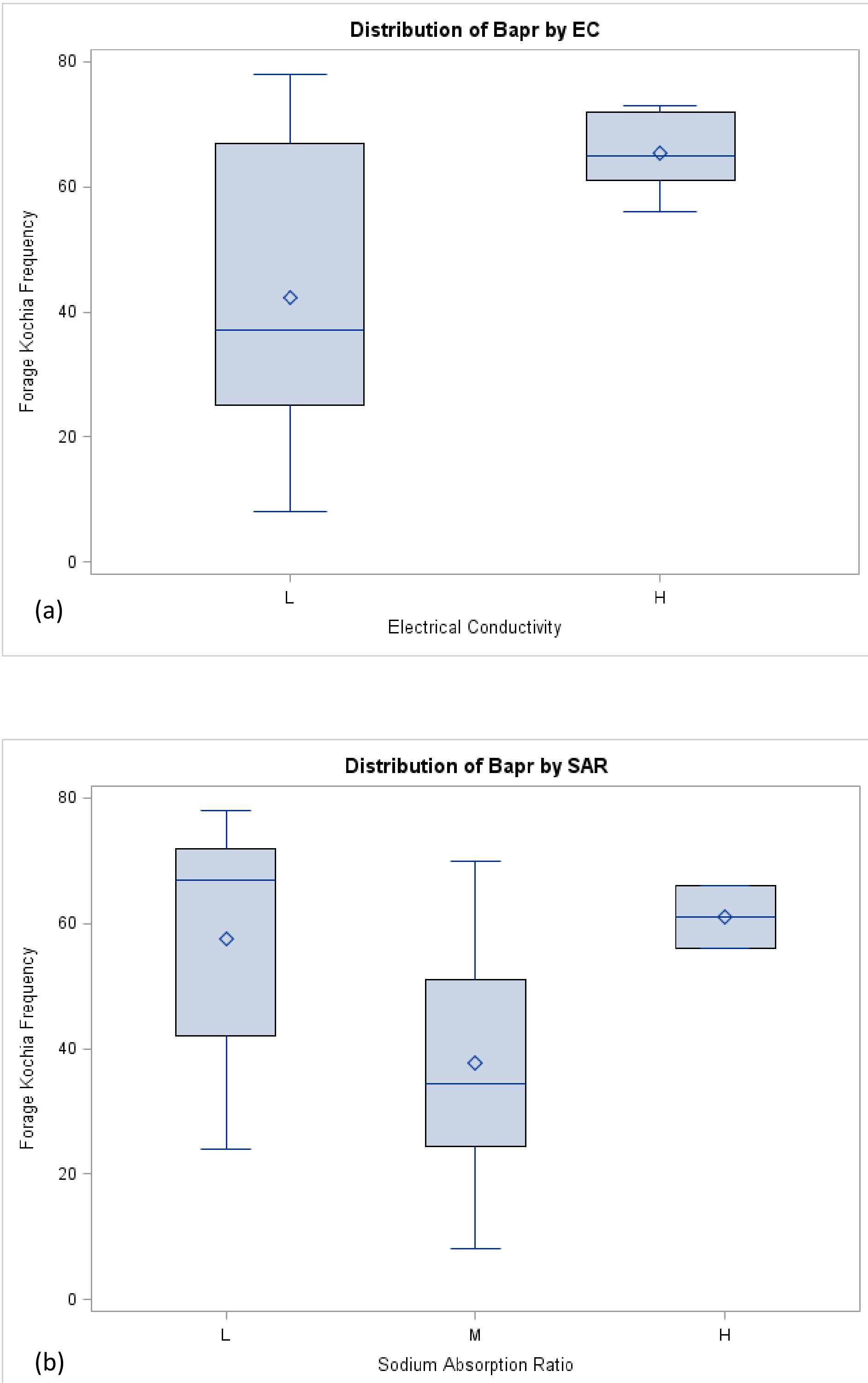
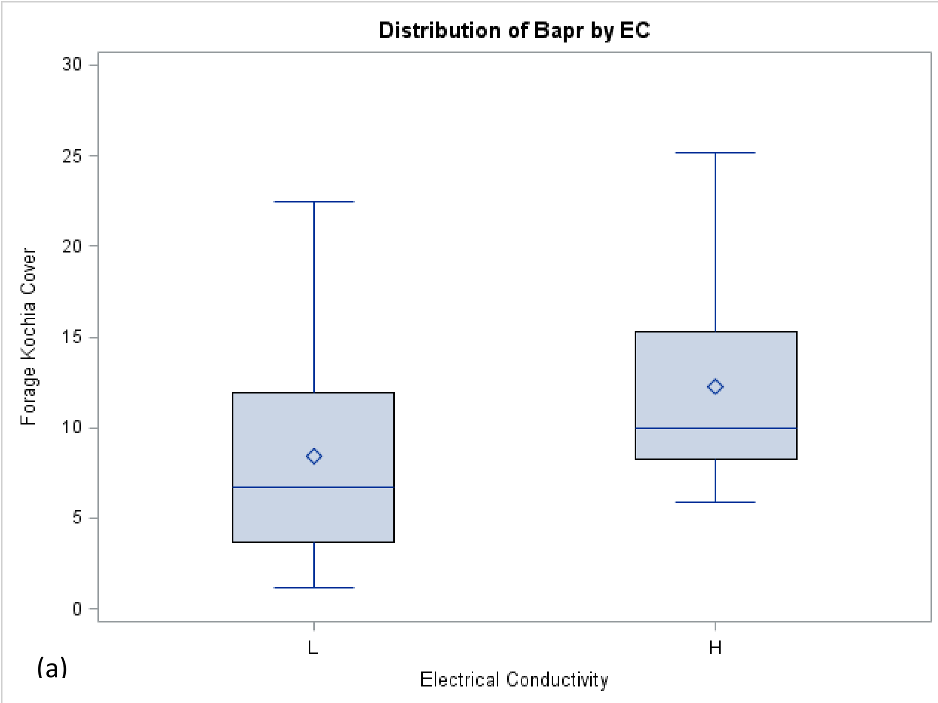


Figure 3. Forage kochia frequency distribution by a). low (L) <1.0 dS/m, and high (H) 3.9-4.2 dS/m soil salinity levels (EC) and b). low (L) 1.0-3.99, medium (M) 4.0-7.99 and high (H) 8.0-13.0 soil sodium absorption ratio (SAR) values.



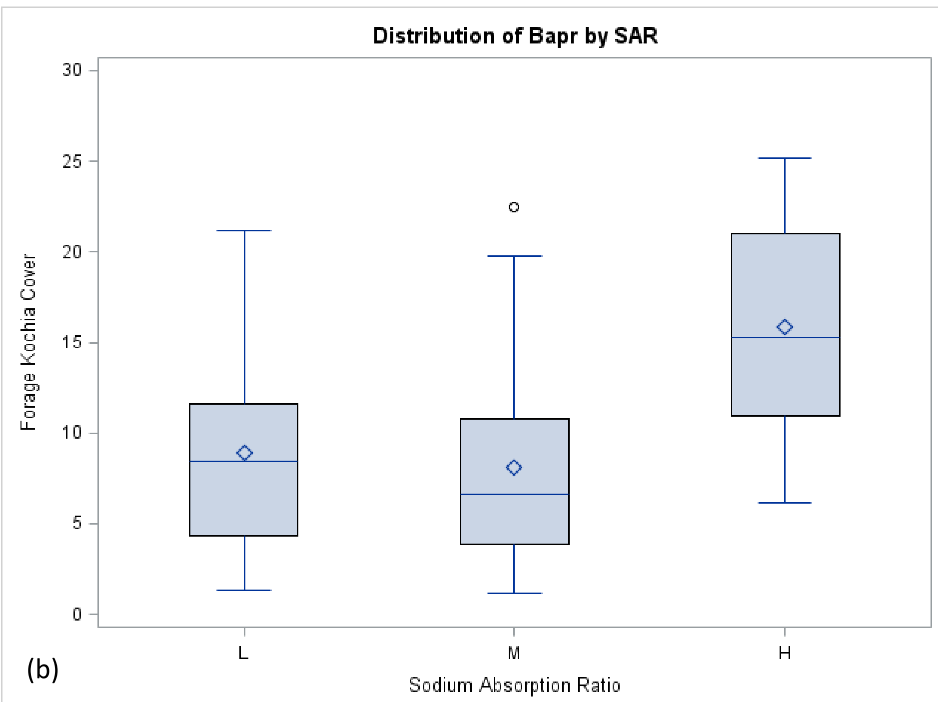


Figure 4. Forage kochia cover distribution by a). low (L) <1.0 dS/m, and high (H) 3.9-4.2 dS/m soil salinity levels (EC) and b). low (L) 1.0-3.99, medium (M) 4.0-7.99 and high (H) 8.0-13.0 soil sodium absorption ratio (SAR) values.

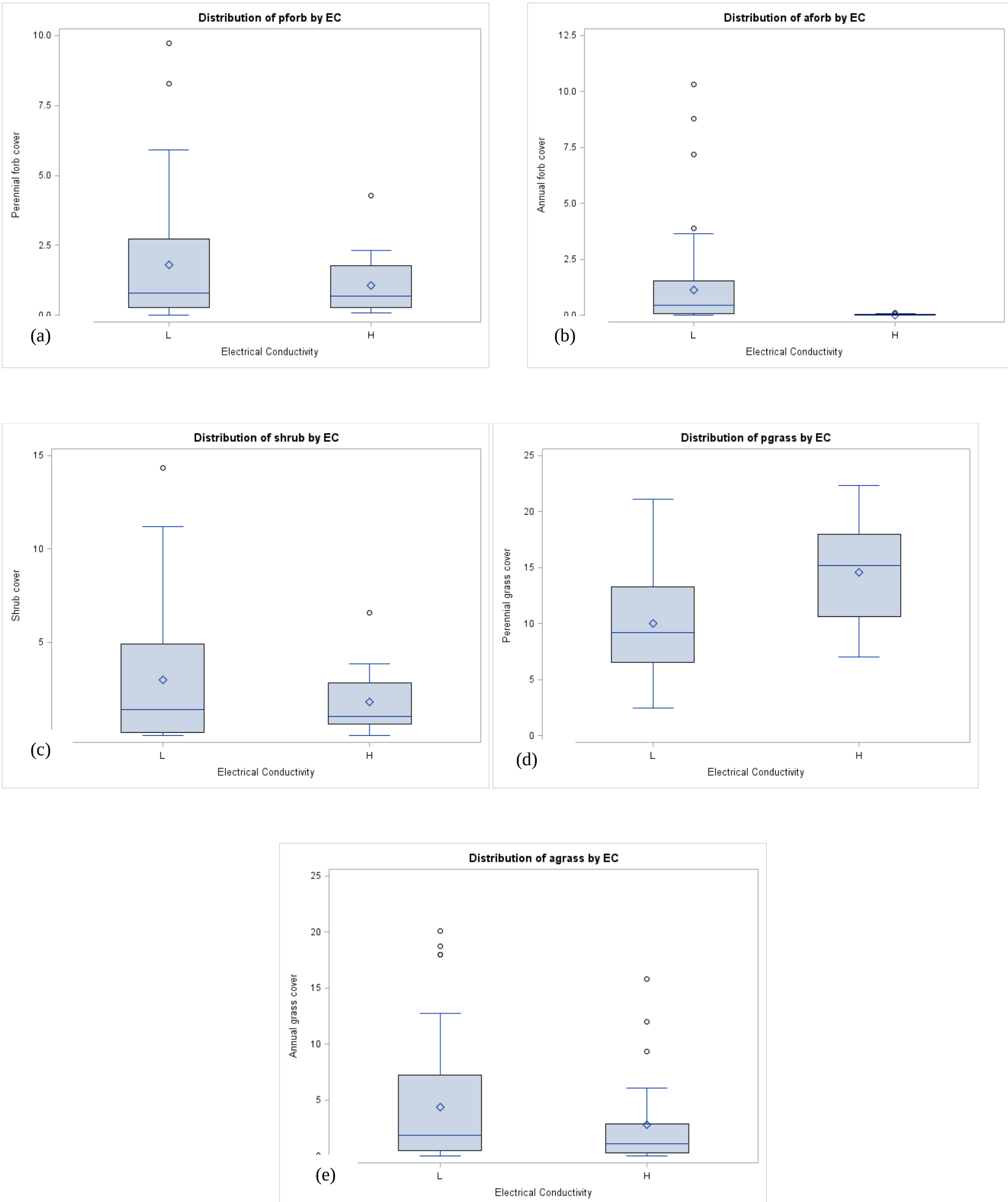


Figure 5. Canopy cover distribution for (a) perennial forbs, (b) annual forbs, (c) shrub, (d) perennial grass, and (e) annual grass by low (L) <1.0 dS/m, and high (H) 3.9-4.2 dS/m soil salinity levels (EC).

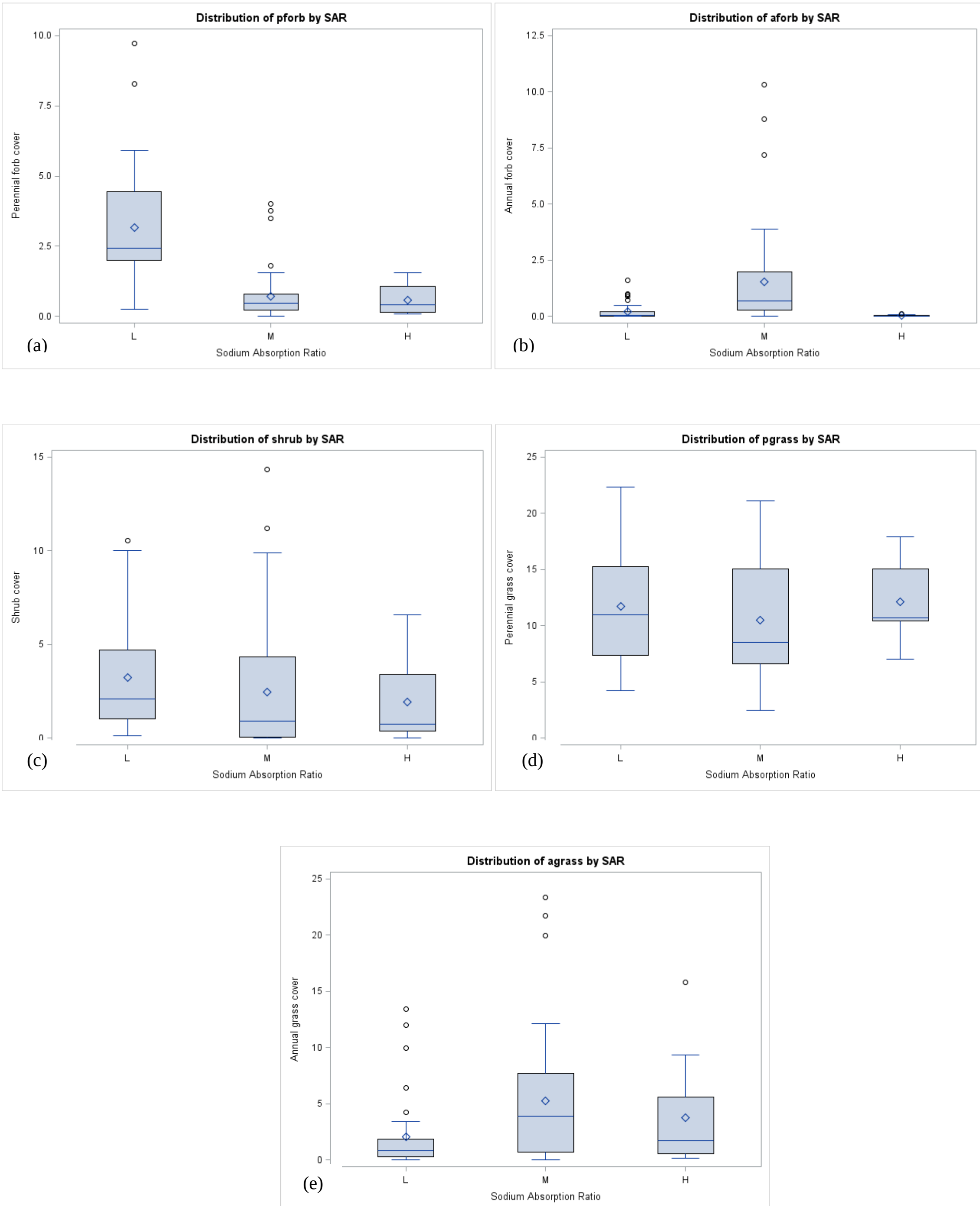


Figure 6. Canopy cover distribution for (a) perennial forbs, (b) annual forbs, (c) shrub, (d) perennial grass, and (e) annual grass by low (L) 1.0-3.99, medium (M) 4.0-7.99 and high (H) 8.0-13.0 soil sodium absorption ratio (SAR) values.

Appendix 1. Plant species list. Nomenclature follows the United States Department of Agriculture, Natural Resources Conservation Services Plant Database. Available at http://plants.usda.gov. Accessed January 2016.

Scientific Name	**Species Symbol**	**Common Name**
Achnatherum thurberianum	ACTH7	Thurber's needlegrass
Agropyron cristatum	AGCR	crested wheatgrass
Allium ascalonicum	ALAS	wild onion
Artemisia tridentata ssp. wyomingensis	ARTRW8	Wyoming big sagebrush
Artemisia tripartita	ARTR4	threetip sagebrush
Astragalus spp.	ASTRA	milkvetch spp.
Bassia prostrata	BAPR	forage kochia
Bromus tectorum	BRTE	cheatgrass
Chrysothamnus viscidiflorus	CHVI8	green rabbitbrush
Draba spp.	DRABA	Draba spp.
Elymus elymoides	ELELH	squirreltail
Erigeron spp.	ERIGE2	fleabane spp.
Halogeton glomeratus	HAGL	saltlover
Koeleria macrantha	KOMA	prairie Junegrass
Lactuca serriola	LASE	prickly lettuce
Lepidium perfoliatum	LEPE2	clasping pepperweed
Leymus cinereus	LECI4	basin wildrye
Linum lewisii	LILE3	Lewis flax
Lupinus spp.	LUPIN	lupine spp.
Pascopyrum smithii	PASM	western wheatgrass
Phlox spp.	PHLOX	phlox spp.
Phlox hoodii	PHHO	spiny phlox
Phlox longifolia	PHLO2	longleaf phlox
Poa bulbosa	POBU	bulbous bluegrass
Poa secunda	POSA12	Sandberg bluegrass
Pseudoroegneria spicata	PSSP6	bluebunch wheatgrass
Salsola kali	SAKA	Russian thistle
Sisymbrium altissimum	SIAL2	tall tumblemustard
Sphaeralcea ambigua	SPAMM	desert globemallow
Symphoricarpos albus	SYAL	common snowberry
Thinopyrun intermedium	THIN	intermediate wheatgrass
Tragopogon dubius	TRDU	yellow salsify / goatsbeard
Vulpia octoflora	VUOC	sixweeks fescue

Appendix 2. GPS coordinates, UTM zone 11, for the eight Minidoka study sites.

Study Site	Northing	Easting
Bear Trap	4762530	12T307186
Whiskey Butte-South	4754015	12T301653
Whiskey Butte-North	4754015	12T301653
Whiskey Butte	4753578	12T0302226
Wapi Park 1	4761874	12T0308634
Wapi Park 2	4760837	12T0309461
Southwest 1	4749708	12T0292876
Southwest 2	4750405	12T0293140