Vegetation Community Responses

to Juniper Slash/Burn and Broadcast Burn

on A Semi-Desert Tobosa Grassland

by

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ABSTRACT

Modern management techniques to maintain rangelands and deter encroachment of juniper into grassland habitats currently includes fire prescription. Additionally, a large body of research has indicated that fire has multiple benefits to grasslands resulting in increased diversity of flora and fauna. In the semi-arid grassland of the Agua Fria National Monument, fire treatments may be able to provide similar advantages. This study considers two methods of fire prescription on the Agua Fria National Monument within central Arizona: 1) Juniper thinning with pile burning; 2) Broadcast burning.

The Agua Fria National Monument upland ecosystem has limited research focusing on semi-arid grassland and juniper stand's response to implemented treatments over time. The four year monitoring duration of this study aids in assessing the outcome of treatments and reaching the objectives of the management plan.

Vegetation in 981 quadrats was measured for species richness, cover, densities, height, and biomass during the fire prescription period from 2009 through 2013. The study was divided into two treatment types: 1) Juniper cutting and pile burn; 2) Broadcast burn areas in open grasslands.

Results of this study provide consistent examples of vegetative change and community movement towards positive response. Percent composition of overall vegetation is 5 – 30% with >50% of litter, bare ground and rock cover. Juniper sites have immediate consequences from tree thinning activities that may be beneficial to wildlife, particularly as connective corridors pronghorn antelope. Grass height was significantly reduced as well as forb density. Forbs that are highly responsive to environmental factors indicate an increase after the second year. Analysis results from grasslands indicated that cactus and unpalatable shrubs are reduced by fire but a return to pre-burn conditions occur by the third year after fire disturbance. Percent cover of perennial grasses has shown a slow increase. Wright's buckwheat, a palatable shrub, has increased in density and height, indicating fire adaptations in the species. Species richness was reduced in the first year but increase in density continues into the third year after burn.

This humbling work is dedicated to my family who has encouraged me

and endured my journey with undying patience.

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ACRONYMS

°C	Degrees Celsius
ArcGIS	ArcGIS is a geographic information system (GIS) for working with maps and geographic information
AFNM	Agua Fria National Monument
ANOVA	Analysis of Variance
BLM	The Bureau of Land Management
cm	centimeter(s)
GIS	Geographic Information System
GPS	Geospatial Positioning System
ha	hectares
m	Meter(s)
n	Statistical sample size
PBB	post-burn broadcast
PBJ	post-burn juniper
PCA	Principle Component Analysis
SPSS	SPSS Statistics 22 (IBM Corp. 2013)

0PBJ	0 year post-burn juniper
1PBJ	1 year post-burn juniper
	.
	.
	.
4PBJ	4 years post-burn juniper

0PBB	0 year post-burn broadcast
	.
	.
	.
3PBB	3 years post-burn broadcast

INTRODUCTION

Objective

The primary objective of this research is to determine how the Agua Fria National Monument's (AFNM) vegetative community responds to juniper thinning and broadcast burning through time. We address aspects of rangeland health and how changes in vegetation based on treatment types might help support management goals for rangeland resources.

Additionally, we provide monitoring of specific sites on the AFNM as a tool to evaluate the outcome of fire treatments used by managers. Efforts have been integrated into a management plan and include juniper thinning and prescribed fire treatments.

Simultaneously, the Arizona Game and Fish Department has been monitoring the movement of 25 pronghorn antelope using GPS collars. These movement data in combination with vegetation analysis for treatment units provided by the research results of this thesis, will support future management decisions for maintaining grassland habitat and improving antelope corridors (BLM 2010), as studies have suggested that vegetation associations preferred by the pronghorn can be maintained by seasonal grazing and intermittent fire (Loeser 2005; Briggs et al. 2007).

Background

Agua Fria National Monument's Record of Decision (BLM 2010) includes guidelines for approved application of prescribed burning that includes four phases:

1. Information/assessment,
2. Plan development,
3. Implementation,
4. Monitoring and evaluation

The monitoring and evaluation phase is the key purpose of the study at hand, with this information providing input to management planning as a secondary purpose.

The AFNM upland ecosystem has limited research focusing on semi-arid grassland and juniper stand's response to implemented treatments over time. Five year monitoring will aid in assessing the outcome of treatments and reaching the objectives of the management plan. Continued study of vegetation community response to juniper thinning and broadcast burning will facilitate management decisions in the future to help identify strategies for maintaining wildlife habitat (Huebner and Vankat 2003).

Long-term monitoring of rangelands facilitates conservation efforts that effect future biological resources. In the semi-arid grassland of the AFNM, fire treatments may be able to provide various advantages. A large body of research has indicated that fire has multiple benefits to grasslands resulting in increased diversity of flora and fauna. Under controlled conditions burning can release nitrogen, increase sunlight to organisms, stimulate growth, improve soil, increase palatable forbs, control woody encroachment, and maintain native species. Treatment frequency and effectiveness are two important considerations that determine management actions. Monitoring provides insight when evaluating responses of vegetation over time.

Region Management

Today's desert grasslands are plagued by encroachment of native woody species that threaten change toward juniper dominated landscapes. It is generally agreed that livestock grazing, fire suppression, and climate are responsible for accelerated vegetation change (Humphrey 1952, 1958; Buffington and Herbel 1965; Briggs et al. 2007). Increases in bare ground and decreases in native species richness have been attributed to increases in juniper population (Taft and Kron 2014).

The focus of this research, a large region around the main canyon of the Agua Fria River, was established in 2000 as a National Monument operated by the Bureau of Land Management (BLM) to protect and manage its valuable resources. The Agua Fria's topographical influence on fire spread and vegetative distribution is apparent: where fire breaks occur due to canyons, boulder fields, and riparian tributaries, grassland communities differ. Juniper stands integrated with other fire intolerant woody species are found on protected topographic environments.

Juniper control and removal is a practiced management tool on other southwest rangelands (Sharrow and Wright 1977), however, effective control varies with plant associations (Miller et al. 2000), frequency, season, and precipitation trends (Neuenschwander et al. 1978; Huebner and Vankat 2003). Studies have shown that juniper can be controlled with burning although mortality depends on tree size, species, and frequency of treatments (Bunting 1986).

There is no present research or documentation regarding pre-historical use of fire on the Agua Fria, but many studies suggest that fire played an important role in evolving grasslands (Humphrey 1958; Buffington and Herbel 1965; Wyckoff 1977; Bahre 1991; Denevan 1992; Roundy and Biendenbender 1995; McCann 1999b; Anderson 2006; McAdoo et al. 2013). Besides juniper control, prescribed burns are known as successful in maintaining grasslands from shrub encroachment and increasing grass production (Humphrey 1958; Ralphs and Busby 1979; Roberts et al. 1988; Sankey et al. 2012). Tobosa (*Hilaria mutica*) has been shown to increase biomass by three times the first year after a burn during a season of normal precipitation on a Texas plains study site (Ethridge et al. 1985). Grasslands have long been thought to evolve with natural fire regimes due to the nature of the vegetative materials present (Humphrey 1952, 1958). When fire is not suppressed and grassland conditions supply adequate fuel loads, fires from lighting storms can spread throughout a landscape maintaining an open structure and affecting plant species that have evolved with avoidance or tolerance to disturbance (Anderson 2006).

Early explorers recorded common fire use by indigenous people of North America. Manipulation with fire was one of the most powerful tools ancient people had to control their environment (McCann 1999a, 1999b; Allen 2002; Mohlenbrock 2012; McAdoo et al. 2013). Reliable knowledge about prehistoric fire use on the Perry Mesa and other semi-desert grasslands is presently limited because scientific evidence is most often unavailable (McPherson 1995). In similar grasslands, two studies of pollen and charcoal influxes in soil cores found less frequent large fire events occurred after abandonment of aboriginal villages (Morris 2010), showing frequent use of fire was likely used to maintain an open area. Many native desert shrubs are intolerant to high frequency fires because vegetation is more likely limited by lack of precipitation (Denevan 1992; McCann 1999b; Keely 2002). Velvet mesquite, for example, cannot resprout unless stems are larger than 1 cm when burned (Glendening and Paulsen 1955; Keely 2002). Mesquite and other intolerant species have long growth cycles and do not produce seed for 10 years or more (Humphrey 1952, 1958).

Environmental and disturbance factors interact to determine the outcome of plant community structure and stability. Where Arizona's mosaic of desert, chaparral, grassland, and woodland types converge, the balance of factors that influence species survival vary in importance (Huebner and Vankat 2003; Anderson 2006). Studies suggest that the factors affected by global change such as N deposition, atmospheric CO_2 concentrations, and warmer temperatures will favor community shifts toward juniper and other woody species (Dukes 1999; Briggs et al. 2007; Van Auken et al. 2000, 2009). More recent research into climate trends show that dramatic events both above and below the normal range may increase (Volder et al. 2013; Polley et al. 2013). Precipitation regimes will shift from summer to winter in the northern U.S. while the southwest will experience heavier less frequent rainfall with at least an annual 2.5% decrease by 2050 (Polley et al. 2013). Vegetation at the community level may represent multiple stable states within a landscape depending on the role of the disturbance factors (Huebner and Vankat 2003). If drought continues in the southwest then changes in vegetation communities on the AFNM are likely to occur as a response to changing environmental factors.

Human History of the Region

Human activity in the region effects plant distribution (Gumerman et al. 1975; Briggs et al. 2006; Kruze 2005, 2007). From the earliest evidence (A.D. 700 to present), human use of resources on the AFNM has been continuous. Evidence of pit houses and temporary camps near the river are from nomadic inhabitants occurring just after A.D. 700 (Stone 2008). An important pre-historic agricultural occupation, referred to as the Perry Mesa Tradition, emerged in 1200's. Over 450 archeological sites on the National Monument are found among the extended study units. Anthropologists date the regional villages from A.D. 1250 to around A.D. 1450. (Wilcox and Holmlund 2007; Stone 2008). Historical accounts from Spanish explorers in the mid 1500's describe early encounters with the Yavapai and Apache tribes (Stone 2008). Silver and gold mining were an active pursuit from 1896 to 1912 at the Richinbar mine near Black Canyon City Arizona, and a few other small mining claims dotting the area. The Agua Fria has accommodated grazing by Euro-American ranchers since the mid- 1800's and sheep herding by Basque immigrants in the 1930's. It was viewed as a good area for livestock grazing by early ranchers since its large flat surface was covered with grasses and permanent water was accessible in the canyons below (Briggs et al. 2006).

Significant land modifications made by the Perry Mesa settlements continue to affect plant distribution within habitat types to this day. Soil alignments, field borders, and terraces were used to divert rainfall and direct storm runoff for crops in agricultural fields, altering soils and providing water (Briggs et al. 2006; Kruze 2007). Cleared plots, rock pile fields, and check dams are also found across the landscape of Perry Mesa (Gumerman et al. 1975; Briggs et al. 2006; Kruze 2005, 2007). Seven hundred years later, the distribution of rock piles continue to have an impact on the distribution of woody vegetation. Briggs et al. (2006) explained that the rocks allow less accumulated herbaceous fuels by reducing competition from grasses and reducing soil moisture loss; conditions that can protect shrubs from spreading fires and create a mosaic of fire free zones. There remains a visible difference in species composition between fields that have been cleared and those littered with rock piles.

Region Vegetation

The Agua Fria River flows north to south intermittently during summer monsoons and winter storms fed by mid-elevation creeks and tributaries with a few natural springs. Prehistorically its flow carved deep canyons through the basin of an ancient volcano forming Black Mesa on the west and Perry Mesa to the east. The result is an ecologically rich landscape hosting diverse southwestern vegetation types atop basalt and granite-derived soils. Riparian vegetation along the river, tributaries, and washes are a valuable ecological resource. Sonoran Desert scrub transitions to semi-desert grassland on mesa tops and interior chaparral on canyon terraces. In the northern hills there is a mosaic of montane conifer woodland and Great Basin conifer woodland within the semidesert mixed grass/scrub.

Among the dominant vegetation, tobosa grass (*Hilaria mutica*) is associated with several woody shrubs and juniper (*Juniperus monosperma*) on the AFNM. Similar communities exist on much of the southwest desert grasslands extending into the Sonoran and Chihuahuan deserts bordered and interspersed by mountainous chaparral, pinion/juniper woodlands and riparian ecosystems (Humphrey 1958; Neuenschwander et al. 1978; McClaren and Van Devender 1995). They are characterized by high temperatures, low precipitation, 900-1200 m elevations with broad basins, gentle slopes and important grass associations (Humphrey 1958). Dominant plant species are not always grasses, vegetation mosaics include a variety of succulents, shrubs, and trees adapted to disturbance by fire, extreme temperature, and precipitation trends. The large variety of wildlife they support are dependent on diversity of native plant species (Steidl 2013).

Region Wildlife & Habitat

One concern for degraded grassland is related to loss of habitat and diversity for grassland species (Bright 2000). The wildlife of grasslands are dependent on the mosaic effect of vegetation that exists due to climate, geology, and natural events (Bahre and Shelton 1993). On the Agua Fria, non-native plant distribution is of concern in riparian communities along stream banks, and with invasive non-native grasses along roadways ([BLM 2014). Wild oats (*Avena fatua*), a non-native species found on the Agua Fria, creates large dense stands that outcompete other species. The exotic red brome (*Bromus rubens*) has had successful recruitment in areas where soil moisture is more readily available, as understory to shrubs and within rocky fields and outcroppings. On mesa tops, there has been weedy invasion of black mustard (*Brassica nigra*) that creates monocultures degrading habitat and lowering species diversity. McLaughlin and Bowers (2006) found lower richness for grass species on exotic dominated mesa tops in southeastern Arizona and significantly higher species richness on native oak savanna in adjacent plots. On old-field tallgrass prairie it was found that a species rich diverse community of plants did not outcompete or slow the success of juniper seedlings and was decreased after encroachment success of juniper (Ganguli et al. 2008). A switch in vegetation dominance to woody species, whether native or introduced, involves species and functional group attrition (McLaughlin and Bowers 2006; Scherber et al. 2010) and may reduce resources for sustainable multi-use management plans.

Currently there are eight special status animal species within the management area (BLM 2014). Sensitive wildlife species that inhabit the area include the lowland leopard frog (*Lithobates yavapaiensis*), Mexican garter snake (*Thamnophis eques megalops*), common black hawk (*Buteogallus anthracinus*), and the desert tortoise (*Gopherus agassizii*). Diverse, small mammals, reptiles, amphibians, fish, and 196 bird species also are found on the AFNM (BLM 2014). The Agua Fria provides wildlife habitat for game species such as white tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), pronghorn antelope (*Antilocapra americana*), javelina (*Pecari tajacu*), and mountain lion (*Puma concolor*).

Pronghorn antelope, obligate with grassland ecosystems, is of special concern to managers of the AFNM. Juniper encroachment into open grassland habitat may have negative impacts on pronghorn populations by interrupting corridors between integral fawning habitat and providing hiding cover for predators. On arid grasslands, juniper thinning and prescribed fire treatments have been used to improve wildlife habitat and increase perennial grasses and other native herbaceous species (Roberts et al. 1988;

Bahre 1991; Miller et al. 2000; Sankey et al. 2012). Thinning and burning dense stands of juniper open wildlife corridors, reduce predator hiding cover, and improve forage for wildlife (BLM 2014). These measures are intended to benefit pronghorn inhabiting the area, and maintain 6800 ha of grasslands on the AFNM as integral habitat for fawning (BLM 2014).

Pronghorn antelope benefit the rangelands where they occur, maintaining grasses and lowering the density of shrubs. Pronghorn's diet selection can help minimize growth of undesirable plant species (BLM 2015). A major portion of the pronghorn's diet is composed of cactus, forbs, and browse plants, but normally little grass. While little grass is consumed as food it is an important habitat characteristic as pronghorn prefer average ground cover of 50% and 15 cm in height (Yoakum 1980). Cactus and forb use vary by season but appear to be the most important components of the pronghorn diet, primarily prickly pear species which made up 40% of non-grass diet in a Kansas study with shrubs and seasonal forbs being 38% (Hlavachick 1968). Sexson et al. (1981) found 95% of pronghorn diet during summer months consisted of non-grass species. Most common and highly utilized on his Kansas study site were prickly pear cactus (*Opuntia* sp.), globemallow (*Sphaeralcea* sp.), and broom snakeweed (*Gutierrezia sarothrae*) which are all abundant on the AFNM.

METHODS

Study Area

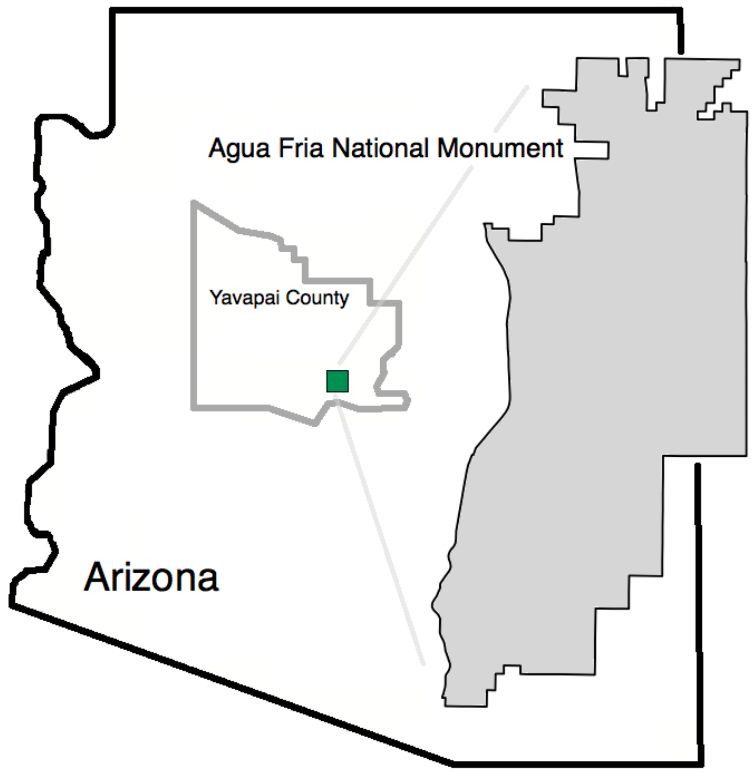

Figure 1. Location of the Agua Fria National Monument within Yavapai County, Arizona USA.

The AFNM includes 28,600 hectares in southeastern Yavapai County, approximately 64 km north of Phoenix, Arizona (Appendix A-1). It is bounded on the south by Black Canyon City, the west by Interstate Highway 17, on the east and north by the Tonto and Prescott National Forests, and on the northwest corner by state and private lands of Cordes Junction, Arizona (Appendix A-2). Elevations range from 655 m at the lower canyon floor to 1400 m in the northern hills and plateaus. Our study area is 4042 ha stratified into eight treatment units in two upland habitat types, the mesa tops are dominated by tobosa grass (Fig. 2) and juniper woodland sites in the northern hills characterized by scattered juniper on hillsides and in canyons (Fig. 3).

Figure 2. Pre-burn grassland site on the Agua Fria National Monument, facing southeast from Perry Mesa. In the background are the New River Mountains, Tonto National Forest. Banana yucca, buckhorn cholla, and cactus apple are interspersed among wild oats and tobosa grass. Cordes Junction, Arizona USA.

Figure 3. Juniper trees on the hillside of Sycamore canyon. A typical juniper site in the northern hills of the Agua Fria National Monument. Shrubs in the foreground are catclaw acacia, velvet mesquite, and cactus apple. Cordes Junction, Arizona USA.

Soil and surface features are formed from ancient volcanic activity and fine material deposition. Two dominant soil complexes that are found on the upland plains and hills of the study units. Springerville-Cabezon soil complex features 3–30% slopes and 0-10 cm of cobbly clay with 10–89 cm underlying silty clay and 71–178 cm to lithic bedrock. Springerville soil series is classified as fine, smectitic, mesic Aridic Haplusterts . The textures are clay and silty clay. Intermixed 15–30% slopes of cobbles or boulders and shallow clay loam to 3 cm comprise the Cabezon soil profile with 18–51 cm to lithic bedrock. Cabezon is classified as clayey, smectitic, mesic Ardic Lithic Argiustolls. An unburned unit on the southern-most plains of the AFNM's broadcast burn group is 65% Rimrock-Graham complex, well drained with 3–15% slopes. Surfaces consist of stony and cobbly clay with underlying clay layers of 5–86 cm of residuum or colluvium (NRCS 2014). Rimrock is a vertisol with classification of fine , smectitic thermic Leptic Haplotorrents. Graham is an Aridisol classified as clayey, smectitic, thermic, Lithic Ustic Haplargrids.

The dominant plant of our vegetative community is tobosa grass, intermixed with other perennial grasses, particularly curly mesquite (*Hilaria belangeri*), grama grasses (*Bouteloua* spp.), and perennial three awn grasses (*Aristida* spp.). Annual grasses include some invasive species such as wild oats (*Avena fatua*), little barley (*Hordeum pusillum*) and red brome (*Bromus rubens*). Hundreds of annual forbs produce ground cover in the spring and late summer after monsoon rains. Overstory vegetation consists of one-seed Juniper (*Juniperus monosperma*), velvet mesquite (*Prosopis velutina*), catclaw acacia (*Acacia greggii*), and succulent species, Parry's agave (*Agave parryii*), yucca (*Yucca* spp.). Three commonly encountered species of cacti, among others, are Engelmann's prickly pear (*Opuntia engelmannii*), hedgehog cactus (*Echinocereus engelmannii*), and buckhorn cholla (*Cylindropuntia acanthocarpa*). Woody shrubs that are often densely established, broom snakeweed (*Gutierrezia sarothrae*), Wright's buckwheat (*Eriogonum wrightii*), and littleleaf range ratany (*Krameria erecta*) are abundant on volcanic rocky sites. Chaparral species such as scrub oak (*Quercus turbinella*), desert ceanothus (*Ceanothus greggii*), lotebush (*Ziziphus obustifolia*), and mountain mahogany (*Cercocarpus montanus*) are found on rocky slopes in transitional communities between riparian and desert scrub associations (Appendix B).

Sampling Design

In advance of our research, the BLM identified key management unit locations for either juniper removal/pile burns, or plains grassland broadcast burns (prescription and natural fire event) (Appendix A-3). The total area of the management units is 4042 ha with treatments conducted between years 2009 to 2013. Treatments took place during winter months, measured after 1st growth period except management unit J1 which was measured following juniper cutting and J3 measured in May immediately after pile burning in Aril 2012 (Table 1). Four sites totaling 519 ha received the juniper slash/pile burns and four plains grassland sites of 3856 ha received broadcast burns. One grassland site was unburned since at least the requisition of the monument in 2000 and serves as a control for broadcast burn units. All plots were measured annually May through August. Juniper pile burn data from 2012, 2013, 2014 and broadcast burn data from 2012 and 2013 were used to characterize vegetation changes by years post-burn. Sample sizes range from 15 – 263 plots in gradients from 0 to 4 years post-burn shown in Tables 1 and 2.

Table 1. Juniper treatment sites in gradients of year post-burn on the Agua Fria National Monument, Arizona.

Treatment gradient		plots/ site	year burned	Study site	*n*	year collected
cut/pre-burn juniper	0PBJ	18	2013	J1	57	2012
		19	2013	J1		2013
0 yr post-burn juniper	0PBJ	20	2012	J3		2012
1 yr post-burn juniper	1PBJ	20	2011	J2	72	2012
		32	2012	J3		2013
		20	2013	J1		2014
2 yrs post-burn juniper	2PBJ	18	2011	J2	18	2013
3 yrs post-burn juniper	3PBJ	15	2010	Syc	33	2013
		18	2011	J2		2014
4 yrs post-burn juniper	4PBJ	15	2010	Syc	15	2014

Table 2. Broadcast burn treatment sites in gradients of year post-burn on the Agua Fria National Monument, Arizona.

Treatment gradient		plots/ site	year burned	Study site	*n*	year collected
pre-burn broadcast	0PBB	50	–	B	50	2012
1 yr post-burn broadcast	1PBB	219	2011	E	219	2012
2 yrs post-burn broadcast	2PBB	136 127	2010 2011	H E	263	2012 2013
3 yrs post-burn broadcast	3PBB	151 107	2009 2010	I H	258	2012 2013

Vegetative characteristics were measured by treatment type, stratified by time using randomly located sampling units generated at a density of 1 per 6 ha. 0PBJ plots were pre-fire but not pre-treatment because the cutting process had taken place before the time we collected data. However, a growing season had not passed at the time of sampling. Sampling was replicated each year after treatment within the same management units with a new set of random plots.

Macro plots were generated with ArcGIS 10 and locations were restricted to management unit boundaries. We used handheld Garmin Geospatial Positioning System (GPS) units to locate plots within treatment areas. Each macro-plot was configured with a 25 m tape radiating from the plot coordinates in a random compass direction constituting the center line of a 4 x 25 m belt transect (Figure 4).

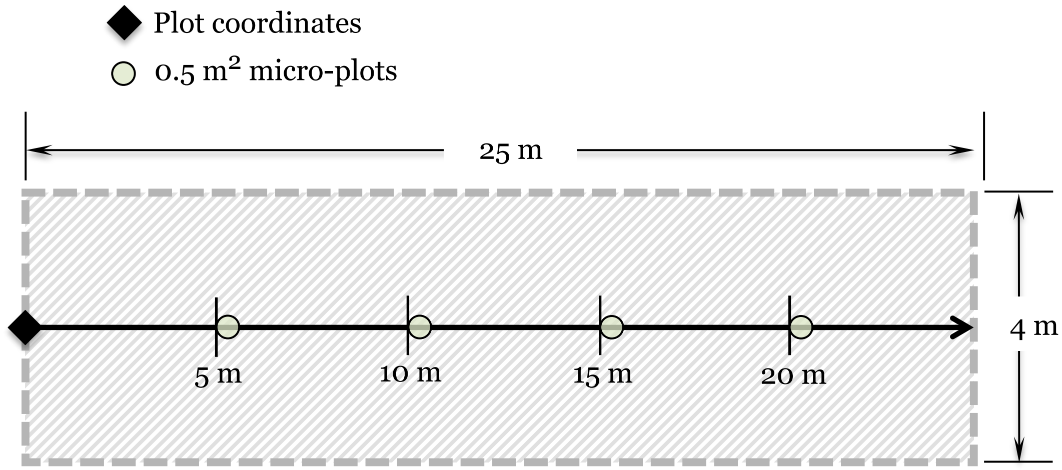

Figure 4. Diagram of macro-plot geometry and placement of 0.5 m² micro-plots. Transect line radiated in a random direction 25 m from each plot coordinate forming a belt transect.

At each location we recorded: canopy cover (%), which included all living plant taxa and non-vegetative covers, rock, gravel, bare ground, litter; perennial shrub densities (including succulents) and average height; annual and perennial forb and grass densities, average height, and biomass. Canopy cover was measured in 10 cm intervals along the central transect line, following a traditional line-intercept sampling method (Kaiser 1983). For tree density, we counted species over 2 m in height, any part of which was within the macro-plot. Shrubs were recorded by density, counting every perennial shrub by species as well as recording the average height within the macro-plot. Grasses and forbs were recorded by density, height, and biomass of each species within a circular micro-plot of 0.5 m² placed at five meter intervals, as shown in Figure 4. When bunch grasses "appeared" as one individual, any part of which was within the hoop, they were counted as such. Grass and forb densities, height, and biomass on all four micro-plots were averaged by species to use for analysis.

We used a double sampling technique to obtain a feasible measurement of biomass throughout the large number of plots sampled (Pitt 1990). Grasses and forbs within each micro-plot were estimated by species in 0.10 increments of handfuls and subsamples of plant material were collected on every fifth plot. Above ground biomass was clipped at ground leve by species within the micro-plots and stored off site in brown paper bags. The clippings were oven dried for 24 hours at 65°C then weighed.

Statistical Analysis

The two treatment types - broadcast burn (grassland) and pile burn (juniper) were analyzed separately. Descriptive attributes (density, height, biomass, and cover) of each taxonomically distinct species as well as abiotic factors (rock, bare ground, and gravel) comprised the data set and were treated as variables. Species richness was expressed as the number of species present in each macro-plot and was analyzed for both treatment types. Cover was calculated as a percentage of the transect length. Biomass estimates were converted to weight in grams from the double sampling method for plots that were not clipped. In order to calculate a conversion from handfuls to weight, a linear regression equation was calculated between each species handful estimate and biomass weight. Species that were not collected in adequate quantities for predictive linear conversion were assigned a regression equation from a species with similar weight and foliage type. All other measurements were spatial (meters) and quantitative (densities). SPSS Statistics 22 (IBM Corp. 2013) was used for all data analysis.

The raw data included 556 total variables from 128 unique taxon (Appendix B). Because of the large number of dependent variables that composed the data set, variables in both treatment units were significantly reduced to eliminate noise from rare or infrequent species with less than 10% occurrence in all plots. In the PBJ units, 103 variables remained, whereas broadcast burned units retained 82 dependent variables.

To find statistical contributors, a principle component analysis (PCA) was conducted on variables within each treatment type. New components of related taxa were summed to create new variables based on life form. These composites represent related variables to allow more conclusive results within all the components of the PCA .

While many of these variables show some trend in variation over time it was prudent to limit the analysis to variables that were most descriptive of changes throughout the study. Specific taxa of interest with important component scores from PCA were included in individual analyses. Components with eigenvalues > 1 in the PCA are ranked by loading scores in order to interpret essential components. Variables with loading scores < 0.5 were not considered primary contributors and were dropped from further analyses. Remaining variables means were compared between post-burn years using 1-way analysis of variance (ANOVA) and Tahmane's post-hoc comparisons. Those that were significant at the 0.05 level were compared to years post-burn with quadratic regression for further analyses.

RESULTS

Pile Burn Juniper Results and Discovery of Contributing Variables

In the PCA, seven components described 73.8% of the total vegetative changes between burn years on PBJ sites. Components 1 & 2 contributed 33% of the total variation, consisting of all grass height and shrub density variables. Grass density, primarily annuals, describes 10% of the variation as the third component, while the remaining components are each less than 10% (Table 3).

Table 3. Pattern matrix from principle component analysis using varimax rotation for interpretation of primary components of juniper pile burn treatment units. Variables with <0.30 component scores were suppressed and scores ≥0.50 were considered important variables for further analysis with quadratic regression.

	Component						
	C1	C2	C3	C4	C5	C6	C7
Variable	Grass height	Shrub density	Grass density	Increaser shrub height	Cactus density/ height	Forb height/sp. richness	Palatable shrub ht/ forb density
Grass height, cm	**0.986**						
Perennial grass height, cm	**0.948**						
Annual grass height, cm	**0.751**						
Shrub density		**0.987**					
Increaser shrub density		**0.847**					
Palatable shrub density		**0.689**					
Annual grass density			**0.981**				
Grass density			**0.968**				
Shrub height, cm				**0.891**			0.428
Increaser shrub height, cm				**0.87**			
Perennial grass density	0.352			-0.38			
Velvet mesquite density				0.322			
Cactus height, cm					**0.902**		
Cactus density					**0.833**		
Forb height, cm						**0.811**	
Species richness						**0.731**	
Average precipitation, cm						**-0.508**	
Palatable shrub height, cm							**0.894**
Forb density	0.371						**0.508**
Eigenvalues	3.48	2.792	2.024	1.748	1.6	1.287	1.097
% of Variation explained	18.316	14.696	10.654	9.199	8.422	6.774	5.774
cumulative % variation	18.316	33.013	43.666	52.866	61.288	68.061	**73.835**

The seven components identified by PCA included 17 variables, composites of grass, shrubs, cactus, forbs, and also species richness. Within the pile burn treatment areas specific epithets did not contribute to significant changes of vegetation over time. Variables that were redundant within the PCA were dropped. Composite variables were used for further analysis where components included all sub categories of the same variable. For example, grass height components (C1 in Table 3) life cycle variations ranked in the same category. As a result, only inclusive components were retained for similar rankings of life forms. Also, species richness met specific objectives for analysis and was identified as important in PCA. Ten variables shown in Appendix C were retained for continued analysis. In a 1-way analysis of variance (ANOVA), all composite variables were found significantly different between years post-burn except cactus height.

Quadratic regression analysis indicated predictive responses post-burn for variables that were statistically different between years (Table 4). Results of the regression analysis found shrub density was the only variable not predictable over time ($\alpha = 0.05$, $p = 0.846$). Years post-burn explained less than 10% ($R^2 < 0.1$) variation of forb height, species richness, and palatable shrubs. Forb densities were the most predictive ($R^2 = 0.218$, $F = 26.7$, $p < 0.005$). Other variables that showed some predictability ($R^2 \geq 0.1$) were grass height and density, cactus density, and increaser shrub height. Regression models of linear and quadratic curves are shown in Appendix D.

Table 4. Pile burn juniper results from quadratic regression with post-burn years for statistically significant variables.

Dependent Variable	R Square	F	*p*
Grass height, cm	0.165	18.904	**0.000**
Shrub density	0.002	0.167	0.846
Grass density	0.118	12.868	**0.000**
Increaser shrub height, cm	0.100	10.631	**0.000**
Cactus density	0.151	17.058	**0.000**
Palatable shrub height, cm	0.076	7.921	**0.000**
Forb density	0.218	26.749	**0.000**
Forb height, cm	0.056	5.728	**0.004**
Species richness	0.081	8.452	**0.000**

Cover composition shows the high percentage of litter, rock and bare ground (75 – 84%) as compared to vegetative cover (12 – 25%). Percent composition of forbs fell from 13% to 1% the first year after burning (Appendix D-10). Litter made up the highest composition of cover classes and exhibited the highest variability (Appendix D-14, D-19). An unexpected variability in rock composition illustrated variation in random plot selection within the data (Table 5).

Table 5. Pile burn juniper results of percent cover composition.

Years Post Burn	% Forb Cover	% Grass Cover	% Shrub Cover	% Cactus Cover	% Litter Cover	% Rock Cover	% Bare Ground Cover	% Gravel Cover	% Tree Cover
0 Yrs	13	3	4	4	25	18	26	7	0
1 Yrs	1	5	5	3	39	16	24	5	1
2 Yrs	1	6	5	3	35	21	28	0	1
3 Yrs	1	4	4	3	50	16	21	0	1
4 Yrs	1	6	11	3	35	31	12	0	1

Trees did not contribute to variation in the analysis because juniper was the target for treatment on PBJ units and mesquite over 1 m in height were rarely encountered. The most descriptive components - grass height, grass density, cactus density, and forb density - all showed a decrease after burn treatment compared to unburned conditions. Following the initial decease after burn, forb density and grass height, but not grass density, began an increase by the third year after treatment but did not reach the same levels as the first year measured. Forb height increased marginally throughout the four years. Unpalatable (increaser) and palatable (decreaser) shrub height slightly increased throughout the first three years of the study, though shrub density showed no change, indicating new recruits were not initiated during the study period. Species richness increased up to the second year but the mean number of species dropped to the initial level by year four.

Broadcast Burn Results And Discovery of Contributing Variables

Results of the PCA for broadcast burn sites identified 7 important components explaining 67.4% of the variation in the data. Cactus species dominated by Engelmann's prickly pear had the highest loading scores comprising component 1, carrying 21% of the total variation. Increaser shrubs, primarily influenced by broom snakeweed density and cover describes 12% more variation in C2. Some species were more descriptive of changes in the vegetation community than the composite variable of the general life form, broom snakeweed, Wright's buckwheat, and velvet mesquite variables loaded with >0.80 in components 2, 3, and 4 (Table 6). Perennial grass, all grass heights, and bare ground were most descriptive of components 5 and 6. Although an important component of pronghorn habitat characteristics, bare ground cover, was not included in analysis of vegetation changes. Species richness had cumulative scores in C1 and C3 and was retained to examine the effects of time. Eighteen variables from composites and individual species were compared between years to evaluate changes in the vegetation community from broadcast burn treatments.

Table 6. Results of broadcast burn principle component analysis (PCA). Pattern matrix from PCA using varimax rotation to simplify interpretation into seven primary components of broadcast burn treatment units. Variables with <0.30 component scores were suppressed and cumulative scores ≥0.50 were considered important variables for further analysis.

	Component						
	C1	C2	C3	C4	C5	C6	C7
	Cactus/ prickly pear sp.	Broom snakeweed	Wright's buckwheat/ sp. richness	Velvet mesquite	Perennial grass	Grass height/bare ground	Forbs
Eng. prickly pear height,	**0.887**						
Eng. prickly pear density	**0.881**						
Cactus height, cm	**0.872**						
Cactus density	**0.838**						
Eng. prickly pear % cover	**0.788**						
Broom snakeweed den.		**0.991**					
Increaser shrub den.		**0.978**					
Broom snakeweed % cover		**0.835**					
Wright's buckwheat % cover			**0.948**				
Wright's buckwheat den.			**0.903**				
Shrub % cover		0.318	**0.655**				
Species richness	**0.383**		**0.441**				
Velvet mesquite height, cm				**0.922**			
Increaser shrub height				**0.825**			
Velvet mesquite density				**0.819**			
Tobosa % cover					**0.839**		
Perennial grass density					**0.766**	0.301	
Tobosa biomass, g					**0.631**	-0.457	
Perennial grass height, cm						**0.758**	
Annual grass height, cm						**0.648**	
Bare ground % cover						**-0.511**	
Forb height, cm							**0.683**
Forb density, cm						0.46	**-0.53**
Annual grass density							0.321
Eigenvalues	5.042	2.983	2.04	1.928	1.671	1.476	1.045
% of Variation explained	21.008	12.428	8.498	8.031	6.961	6.149	4.354
cumulative % variation	21.008	33.436	41.934	49.965	56.926	63.075	**67.429**

The remaining variables were analyzed with quadratic regression to determine what type of changes may continue to take place over time. Linear and quadratic plots against time since burn for each variable are illustrated in Appendix E. In Table 7 most groups show weak predictive values, $R^2 < 0.10$, where less than 10% of the variation in the data are explained by time. Engelmann's prickly pear was the most predictive in all three variables, followed by annual grass height and species richness.

Table 7. Broadcast burn treatment results from quadratic regression with post-burn years for variables that were found significantly different ($p < 0.05$) in a 1-way ANOVA. All variables have predictable values of R^2. Weakly predictable values for variables have < 10% variation ($R^2 < 0.10$) explained by time.

Dependent Variable	R Square	F	*p*
Engelmann's prickly pear density	0.328	192.242	**0.000**
Engelmann's prickly pear height, cm	0.19	92.035	**0.000**
Engelmann's prickly pear % cover	0.179	85.981	**0.000**
Wright's buckwheat % cover	0.017	6.663	**0.001**
Shrub % cover	0.029	11.692	**0.000**
Broom snakeweed % cover	0.029	11.906	**0.000**
Broom snakeweed density	0.043	17.673	**0.000**
Tobosa cover	0.047	19.552	**0.000**
Tobosa biomass, g	0.074	31.473	**0.000**
Perennial grass density	0.011	4.463	**0.012**
Perennial grass height, cm	0.07	29.46	**0.000**
Annual grass height, cm	0.193	93.848	**0.000**
Velvet mesquite height, cm	0.057	23.671	**0.000**
Velvet mesquite density	0.02	7.89	**0.000**
Forb density	0.026	10.313	**0.000**
Species richness	0.171	80.951	**0.000**

Engelmann's prickly pear was markedly lower than the unburned site (0 years post-burn) in density, height, and cover. After three years the increase in all attributes return to pre-burn conditions. This species reflected the highest predictability in regression analysis and was markedly affected by the treatments.

Shrub cover, which is a composite influenced by buckwheat and broom snakeweed also decreased in first year post-burn but thereafter increased to above unburned conditions. Alternately, buckwheat was substantially higher in density at one year post-burn than the unburned unit, but did not show a statistically significant change between years in an ANOVA (Appendix E). The other primarily contributing shrub, broom snakeweed, has a consistent rise in density throughout all years post-burn. Velvet mesquite has a prominent presence in the broadcast burn sites as a shrub under 2 m; the data reflects a decrease in both height and density from unburned conditions but nearly reaches those conditions by the third year.

Grasses that were included as substantial for analysis by PCA are perennial species, tobosa – cover and biomass, and composite perennial grass height and density which included tobosa and curly mesquite. Data from both tobosa variables decreased from unburned in first year, but increased to well above the control site by the third year after burn. The perennial grass composite for density increased two-fold from unburned within one year after burn and continued an increase thereafter while perennial grass heights were decreased throughout. Annual grasses that were included in the composite for height were wild oats, red brome, and little barley, and responded with an almost linear regression of decline throughout the three years post-burn, falling below unburned conditions.

Forb height responses were in contrast to forb density but not found statistically significant at a 95% level with ANOVA, ($F = 0.682$, $p = 0.563$). Forb density response increased one year after burn and shows a convex regression curve that ends with similar densities to unburned conditions after three years post-burn (Appendix F-15).

The mean number of unique species on units of broadcast burn was lower in the first year after burn. The regression curve for species richness that explains the changes post-burn is a convex curve that returns to unburned conditions by the third year (Appendix F-16).

Vegetative composition dropped from 14% to 5% after the first year but returned to 14% 3 years after burn. As in the Juniper treatment units, ground litter composition was substantially higher than all other cover classes (Table 8) with rock and bare ground composing the next highest percentages (Appendix F-25). Vegetation cover classes all show a slight increase throughout the study which is consistent with regression analysis from broadcast burn variables (Appendix F-17 – F-20).

Table 8. Broadcast burn treatment results of percent cover composition.

Years Post Burn	% Forb Cover	% Grass Cover	% Shrub Cover	% Cactus Cover	% Litter Cover	% Rock Cover	% Bare Ground Cover	% Gravel Cover
0 Yrs	1	3	4	6	54	20	10	2
1 Yrs	0	2	2	0	60	26	9	1
2 Yrs	0	4	3	0	65	14	10	3
3 Yrs	1	7	5	1	45	16	14	11

DISCUSSION

Juniper Pile Burn Response

It is well known that juniper invasion shifts community structure and effects understory grasses and forbs by competition for water and sunlight (Humphrey 1952, 1958; Miller et al. 2000; Van Auken 2009). Removal of juniper by mechanical, fire or other treatment methods has been found to increase herbaceous vegetation in semi-arid grasslands and increase grass production (Wright 1969; Sharrow and Wright 1977; Neuenschwander et al. 1978; Ralphs and Busby 1979; Ethridge et al. 1985; Roberts et al. 1988; Miller et al. 2000; White and Loftin 2000; Brockway et al. 2002; Ansley et al. 2006; Bock et al. 2007; Stoddard et al. 2008; Sankey et al. 2012; Miller et al. 2014). Removal of canopy cover directly affects soil temperature and organic carbon levels which change biotic relationships (Debnar 2007). Without juniper competition, water and nutrients become available to increase foliar growth and species richness (Brockway et al. 2002). Removal of allelopathic juniper liter allows new or suppressed species in the community to germinate. The time span for changes to occur is widely variable depending on the ecological process involved. This study found decreases in densities of forbs, grass, and cactus with recovery by forb recruitment only after the third year, as shown in Appendix D-3, D-5 and D-7. The recovery of grass heights would be caused by elimination of litter that reduces available light, allowing new growth to increase before recruitment. In the case of tobosa grass, a parent plant will increase the number of culms but seeds that were burned in the litter reduces recruits and allows increase from rizomes (Neuenschwander et al. 1978). In Miller et al. (2014) it was noted that increased cover by the third season after burning was from residual vegetation but not new recruits. Recovery of forb density was most likely a product of increased available light, moisture and nutrients. Other studies of juniper removal have found decreases in perennial grass, forb, and non-native grass cover in the first growing season after mechanical treatments with fire (Ansley et al. 2006; Miller et al. 2014). Other studies have shown that a rise in species richness due to newly available resources generally returns to pre-treatment conditions within two to three years (Van Auken 2009), as confirmed by this study as shown in Appendix D-9.

Scattered unburned slash was observed to create increased patches of herbaceous vegetation during 2013 and 2014 in unit J1 and surrounding non-study areas were the pile burn treatment was not employed. Course debris from masticated juniper provides protection from soil erosion and aids in water retention (Evans 1988). Where pile burns had taken place within the study unit this effect was not present.

It is assumed that other factors were also effecting new growth and species recruitment. Besides juniper removal and fire, it is intuitive that other variables as a result of activity would cause a transitory change in community response. Due to the activity necessary to cut larger juniper trees and either pile, burn, or scatter slash, the area would undergo some amount of disturbance that causes cessation of growth. Cactus density had a marked decrease throughout the juniper removal portion of this study (refer to Appendix D-5). These decreases are due to disturbance of vegetation adjacent to the juniper cut rather than fire in the first years as observed during the measurement process.

Broadcast Burn Response

Within the broadcast burn treatments, the control unit allows us to look at the difference over time after treatments comparative to the unburned site that has not been grazed since 2005 and has not burned since 2001.

Prickly pear data shows little response to burn in the first through third years after burn application as reflected in the variable plots for height, density and percent cover as shown in Appendix F-1, F-2, and F-3. If burn damage was evident, it would most likely be illustrated by a reduction in cover due to low growth patterns of Engelmann's prickly pear species, but this was not observed in the data. This study's findings are consistent with Forest Service observations which describe prickly pear as tolerant to fire as long as the heat intensity provided by fine fuels do does not rupture plant cells. Plants are known to return to original size within three to five years if damage does occur (USFS 2014).

Shrub cover data illustrates little linear or quadratic change but the data plots show an increase over time throughout the study period when compared to the unburned treatment unit (refer to Appendix F-5). Appendix F-4, F-5 and F-6 show that shrub cover is primarily influenced by the species data from Wright's buckwheat and broom snakeweed since they all show similar trends. Broom snakeweed also demonstrated an increase in density showing recruitment was not limited by fire, while change in buckwheat density was not statistically significant as seen in Appendix E. This indicates possible adaptations or unresponsiveness to fire by broom snakeweed.

Velvet mesquite is another shrub that demonstrates little response to fire treatments. While density data plot Appendix F-14 indicate a slight increase, heights after burn are decreased in the first year followed by return to pre-burn conditions as shown in Appendix F-13. This is consistent with findings which show that mesquite quickly recovers from fire in grasslands by re-sprouting and new growth, and that it takes high intensity, frequent fires to control encroachment into grasslands (Bock et al. 2007).

Since tobosa grass is the primary community species on the Agua Fria plains, it was subjected to analysis with regression even though it was included within the overall perennial grass composite. All perennial grass density shows slight increase over the study period (see Appendix F-10); however, the lack of tobosa grass density as a PCA component indicates that tobosa grass density by itself had no statistically significant change . Measurements were made in the summer months before the growing season resulting in seed heads mostly not being present, so overall height was determined using grass leaf growth. Because perennial grass height was decreased two successive years after burn, we might assume that residual vegetative growth after fire is concentrated on expanding plant size and number of culms. Appendix F-8 and F-9 show the data for both grass biomass and cover increased over the study period, reinforcing previous research on tobosa's adaptation to fire (Humphrey 1952, 1958; Neuenschwander et al. 1978; Roberts et al. 1988) and perennial grass recovery periods (White and Loftin 2000).

Contrary to the findings of the juniper pile burn sites, Appendix F-15 shows forb density increased rather than decreased in the first year after treatments with the broadcast burn sites. Previous discussion about residual disturbance due to human activity as an outcome for reduced growth of surrounding vegetation in juniper treatments likely explains this difference. In a grassland burn, less disturbance by foot traffic and a renewal of resource availability including, sunlight, nutrients, and moisture are contributing factors to increased growth of forbs, and recruitment of new species (Appendix F-15 and F-16).

One outcome of increased forb density and species richness was a decrease in annual grass height as compared to the unburned site. Alred (2008) found increased nitrogen content in soils immediately after burn, which would typically increase growth in annuals but the low precipitation during spring could have inhibited growth (Wright

1969). It is unknown whether the annual grasses are outcompeted by growth in forb species density or affected by other factors relating to weather or fire recovery.

Climate conditions

Climate and precipitation were also considered in this study. Weather data was obtained from the nearest weather station in Cordes Junction, Arizona lat. 34°18' N, long. 112°10' W, altitude 1148 m, approximately 4 km north of the Agua Fria's central plains region. The typical precipitation regime is bimodal with summer monsoonal rains in July and August and in winter, frontal storms during January and February. Average monthly long-term (1926 – 2014) compared to average monthly treatment years (2009 – 2013) are illustrated in Figure 3. The long-term annual mean temperature is 16.3 °C with annual mean precipitation of 36.8 cm. Highs occur in July with a mean maximum temperature of 35.4 °C with mean minimum temperatures lowest in January at 7° C. Treatment years 2009 – 2013, had a mean annual temperature of 16.9 °C and a mean annual rainfall of 32.5 cm (WRCC 2014).

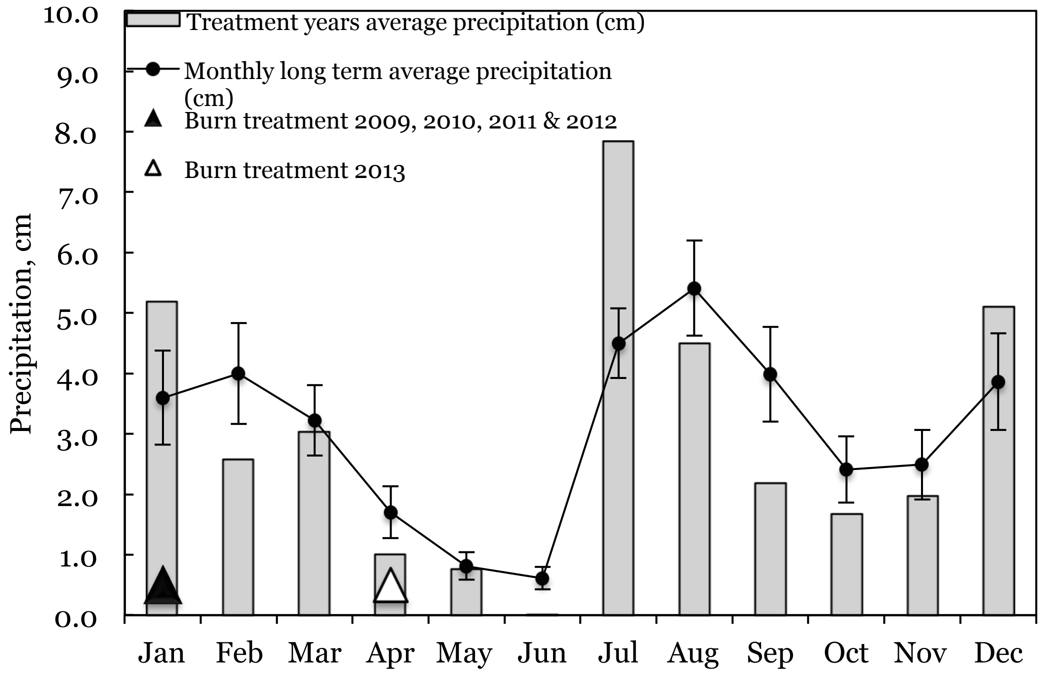

Figure 5. Average monthly long-term precipitation compared to average precipitation from treatment years, 2009 – 2013. Winter treatments occurred in January and one in spring, April 2013. Weather data obtained from the station in Cordes Junction, Arizona USA.

Mean monthly and annual precipitation and temperature were introduced as possible predictors. Temperature was not correlated with vegetation changes between years post-burn in PBJ or PBB units, and consequently, no further analysis was conducted using this variable. It is notable that during treatment years, monthly precipitation was higher than the long-term monthly average during typical rainy periods - January, July, and December, but lower precipitation occurred during all other months (Fig. 5). A negative correlation in the sixth component of the PCA (-0.508) (Table 3) and a subsequent t-test ($t = 51.3_{(2, 194)}$, $p = < 0.005$) found that precipitation data was confounding the main factor – time, and was dropped from the rest of the analysis. This lack of correlation is possibly due to the timeframe of this study. The 4 year duration tends to lessen the effects of precipitation and climate anomalies, averaging out variances that occur over the individual seasons. Since the factor of time is not relative between treatment units, analysis of climate condition variables was not meaningful for this study. In a continuing a trend of warmer and drier conditions for the area, annual average precipitation during treatment years was lower than the annual long-term mean with higher annual long term temperatures. Subsequent years of study data will continue to minimize the effects of short term weather events on the analysis of treatment response.

Effect on Responses Due to Livestock Activity

During data collection, there was observed negative effects to vegetation in areas subjected to grazing pressure concentrated at water features. It would be helpful for future studies to map a study exclusion area around the active water features that have been impacted as a result of cattle by trampling and intensive grazing in high use areas. Excluded from future analysis, this may prevent unbalanced negative results within the generated random plots. Grazing on the Agua Fria National Monument is part of the multiuse management objectives and is monitored to maintain overall range health. Minimal impacts were observed on surrounding grazing allotments on both juniper encroached hills and plains dominated by native grasses.

Conclusion

Cover composition clearly shows that vegetation presently makes up the smallest percentage of ground cover on the study sites. Litter is the primary cover and functions as significant protection from runoff and soil erosion. Changes in vegetative cover are minimal over the relatively short study period. It has been shown that community composition changes slowly (Humphrey 1958; Roundy and Bienbender 1995; Loeser 2005). Throughout the study the results provide consistent examples of vegetative change on a small scale and community movement towards positive response which is consistent with a large body of research (Sharrow and Wright 1976; Ralphs and Busby 1979; Ethridge et al. 1985; White and Loftin 2000; Ansley et al. 2006; Sankey et al. 2012). It has been relevant for evaluation of post-fire changes in response to management plans for habitat improvement and cost effective means to reach proposed goals.

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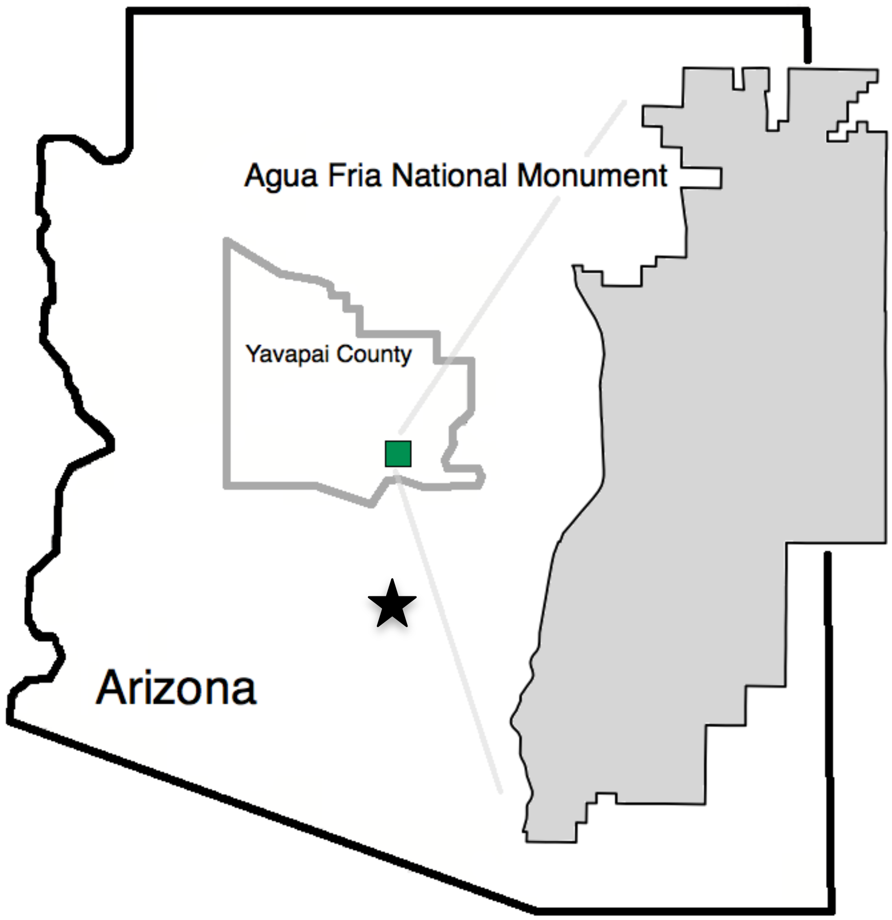
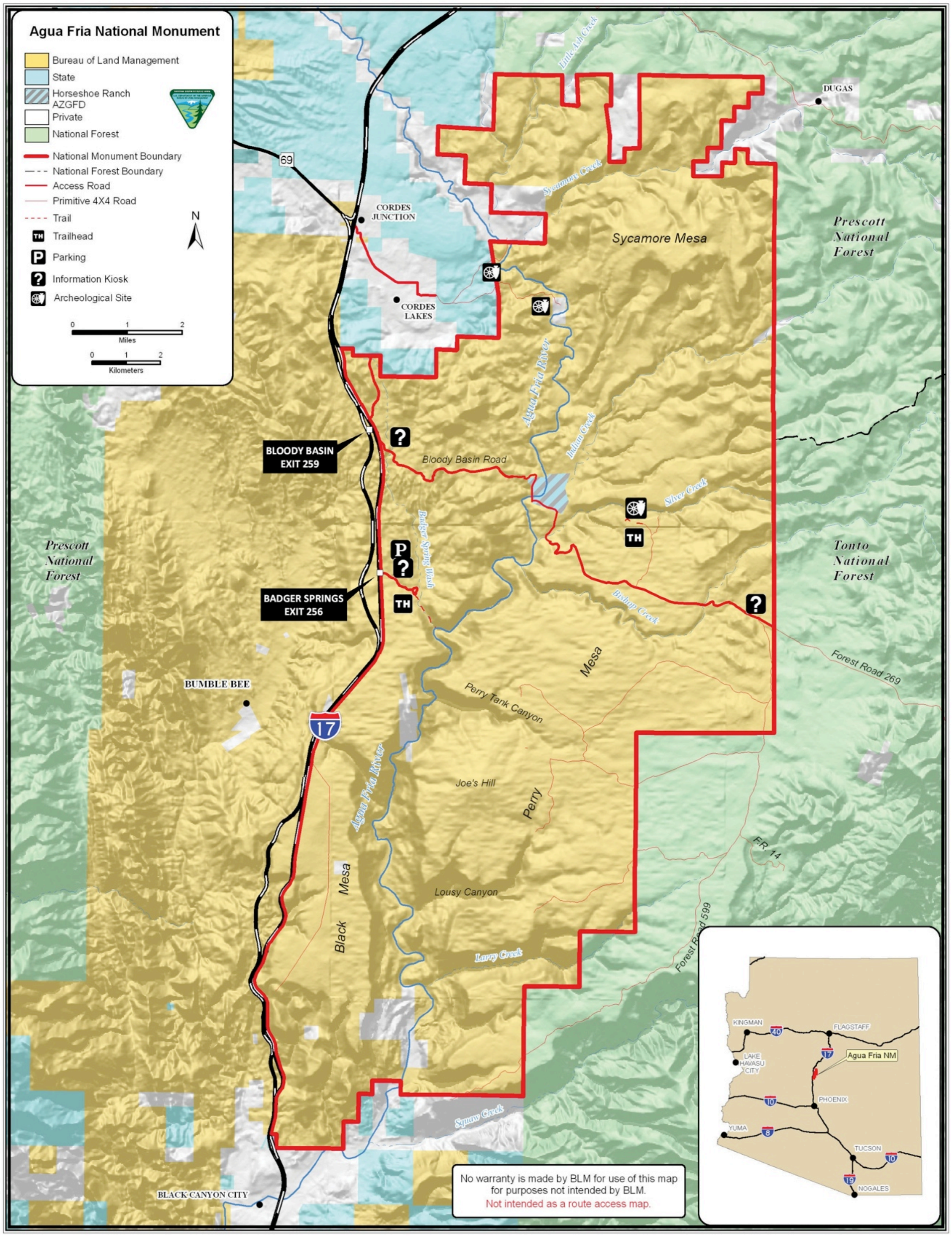
APPENDIX A

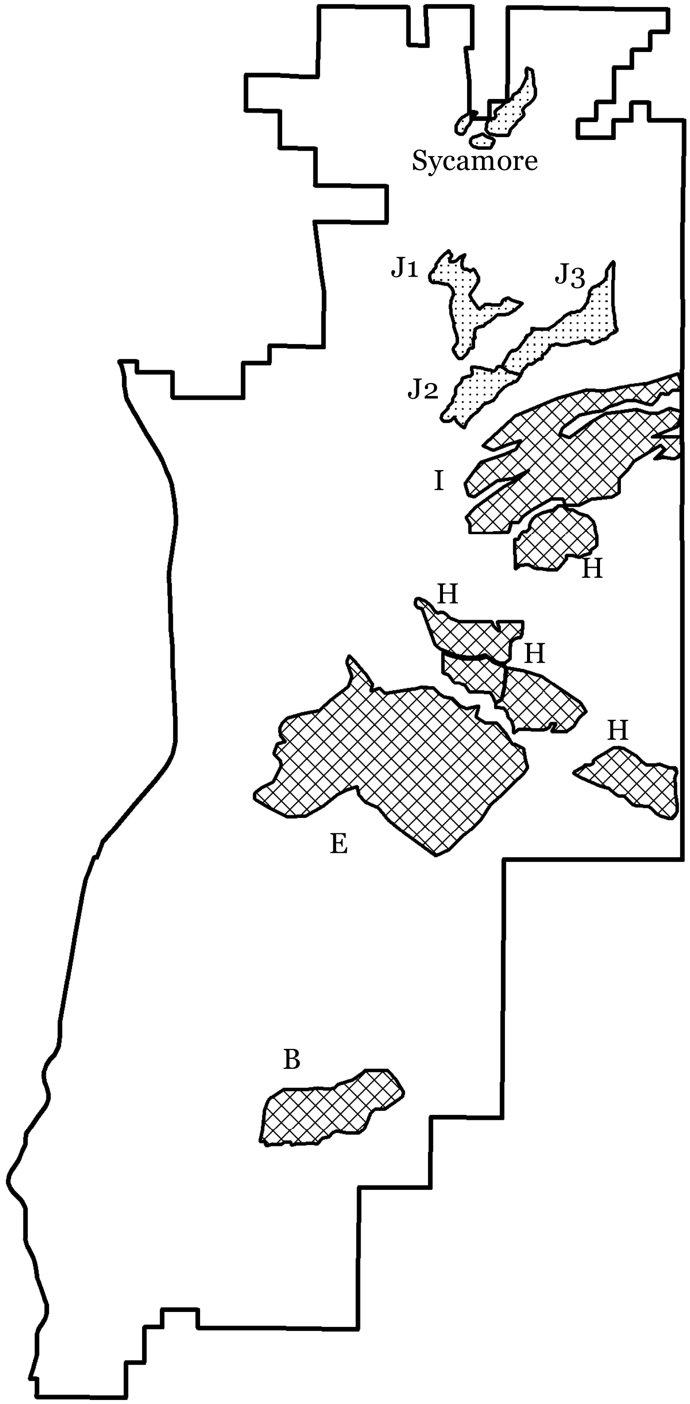
STUDY SITE, AGUA FRIA NATIONAL MONUMENT MAPS AND BLM DESIGNATED TREATMENT UNITS



Appendix A-1. Location of the Agua Fria National Monument within Yavapai County, Arizona USA.



Appendix A-2. Borders of the Agua Fria National Monument, associated roadways, and property (BLM 2014).



Appendix A-3. Treatment units designated by the Bureau of Land Management. Juniper pile burn treatments on the northern units are labeled as Sycamore and J1-3. The remaining plots (B, E, H, I) are broadcast burn treatments; unit B was unburned.

APPENDIX B

PLANTS IDENTIFIED IN 2012 AND 2013 ON THE AGUA FRIA NATIONAL MONUMENT STUDY PLOTS IN CENTRAL ARIZONA USA

Plant Taxonomy information taken from
Southwest Environmental Information Network (2013)

Family	ScientificName	CommonName
Amaryllidaceae	*Allium macropetalum*	largeflower onion
	Nothoscordum bivalve	crowpoison
Apiaceae	*Daucus pusillus*	American wild carrot
Apocynaceae	*Asclepias asperula*	spider milkweed
Asparagaceae	*Agave chrysantha*	goldenflower century plant
	Agave parryi	Parry's agave
	Dichelostemma capitatum	bluedicks
	Nolina microcarpa	sacahuista
	Yucca baccata	banana yucca
Asteraceae	*Acourtia wrightii*	brownfoot
	Ambrosia confertiflora	slimleaf bursage
	Artemisia ludoviciana	silver sage
	Baccharis pteronioides	yerba de pasmo
	Baccharis salicifolia	water wally
	Baccharis sarothroides	desertbroom
	Baileya multiradiata	desert marigold
	Bebbia juncea	sweetbush
	Dieteria asteroides	fall tansyaster
	Encelia farinosa	brittlebush
	Encelia frutescens	button brittlebush
	Ericameria laricifolia	turpentine bush
	Erigeron divergens	spreading fleabane
	Gutierrezia sarothrae	broom snakeweed
	Machaeranthera tanacetifolia	tanseyleaf tansyaster
	Porophyllum gracile	slender poreleaf
	Pseudognaphalium canescens	Wright's cudweed
	Rafinesquia californica	California chicory
	Rafinesquia neomexicana	New Mexico plumeseed
	Sonchus oleraceus	common sowthistle
	Stephanomeria pauciflora	brownplume wirelettuce
	Uropappus lindleyi	silver puffs
Berberidaceae	*Berberis haematocarpa*	bloodberry barberry
Boraginaceae	*Amsinckia menziesii*	Menzies's fiddleneck
	Cryptantha barbigera	bearded cryptantha
	Cryptantha micrantha	redroot cryptantha
	Cryptantha pterocarya	wingnut cryptantha
	Cryptantha recurvata	curvenut cryptantha
Brassicaceae	*Boechera perennans*	perennial rockcress

Family	ScientificName	CommonName
	Brassica tournefortii	Asian mustard
Brassicaceae	*Capsella bursa-pastoris*	shepherd's purse
	Caulanthus lasiophyllus	California mustard
	Chorispora tenella	blue mustard
	Descurainia pinnata	western tansymustard
	Descurainia sophia	herb sophia
	Draba cuneifolia	wedgeleaf draba
	Lepidium thurberi	pepperweed
	Physaria gordonii	bladderpod
	Sisymbrium altissimum	tall tumblemustard
	Sisymbrium irio	London rocket
	Thysanocarpus curvipes	sand fringepod
Cactaceae	*Cylindropuntia acanthocarpa*	buckhorn cholla
	Cylindropuntia bigelovii	teddybear cholla
	Cylindropuntia leptocaulis	Christmas cholla
	Cylindropuntia whipplei	Whipple cholla
	Echinocereus engelmannii	Engelmann's hedgehog cactus
	Echinocereus fasciculatus	strawberry hedgehog
	Ferocactus cylindraceus	California barrel cactus
	Mammillaria grahamii	Graham's nipple cactus
	Opuntia chlorotica	dollarjoint prickly pear
	Opuntia basilaris	beavertail prickly pear
	Opuntia engelmannii	Engelmann prickly pear
Cannabaceae	*Celtis pallida*	spiny hackberry
Cupressaceae	*Juniperus monosperma*	oneseed juniper
Ephedraceae	*Ephedra trifurca*	longleaf jointfir
Euphorbiaceae	*Chamaesyce albomarginata*	whitemargin sandmat
	Chamaesyce arizonica	Arizona sandmat
	Chamaesyce capitellata	head sandmat
Fabaceae	*Acacia greggii*	catclaw acacia
	Astragalus arizonicus	Arizona milkvetch
	Astragalus nuttallianus	smallflowered milkvetch
	Astragalus tephrodes	ashen milkvetch
	Calliandra eriophylla	fairyduster
	Lotus humistratus	foothill deervetch
	Lotus rigidus	shrubby deervetch
	Melilotus officinalis	yellow sweetclover
	Prosopis juliflora var. velutina	velvet mesquite
	Senna bauhinioides	twinleaf senna
	Quercus turbinella	Sonoran scrub oak

Family	ScientificName	CommonName
Fouquieriaceae	*Fouquieria splendens*	ocotillo
Geraniaceae	*Erodium cicutarium*	redstem stork's bill
Krameriaceae	*Krameria erecta*	littleleaf ratany
Lamiaceae	*Salazaria mexicana*	Mexican bladdersage
Malvaceae	*Malva parviflora*	cheeseweed mallow
	Sida abutifolia	spreading fanpetals
	Sphaeralcea ambigua	desert globemallow
	Sphaeralcea coulteri	Coulter's globemallow
	Sphaeralcea rusbyi	Rusby's globemallow
Nyctaginaceae	*Allionia incarnata*	trailing windmills
	Boerhavia coccinea	scarlet spiderling
	Boerhavia erecta	erect spiderling
	Boerhavia intermedia	fivewing spiderling
Oleaceae	*Menodora scabra*	rough menodora
Onagraceae	*Gaura coccinea*	scarlet beeblossom
Plantaginaceae	*Plantago patagonica*	woolly plantain
Poaceae	*Aristida purpurea*	Fendler's threeawn
	Aristida ternipes	spidergrass
	Avena fatua	wild oat
	Bothriochloa barbinodis	cane bluestem
	Bouteloua aristidoides	needle grama
	Bouteloua barbata	sixweeks grama
	Bouteloua curtipendula	sideoats grama
	Bouteloua eriopoda	black grama
	Bromus carinatus	Arizona brome
	Bromus japonicus	Japanese brome
	Bromus rubens	red brome
	Elymus elymoides	squirreltail
	Eragrostis lehmanniana	Lehmann lovegrass
	Hilaria belangeri	curly-mesquite
	Hilaria mutica	tobosa grass
	Hordeum pusillum	little barley
	Sporobolus airoides	alkali sacaton
	Sporobolus contractus	spike dropseed
	Sporobolus cryptandrus	sand dropseed
	Vulpia microstachys	small fescue
	Vulpia octoflora	sixweeks fescue
Polemoniaceae	*Eriastrum diffusum*	miniature woollystar
Polygonaceae	*Eriogonum wrightii*	Wright's buckwheat
Rhamnaceae	*Ceanothus greggii*	desert ceanothus

Family	ScientificName	CommonName
	Frangula californica	California buckthorn
	Rhamnus crocea	redberry buckthorn
Rhamnaceae	*Ziziphus obtusifolia*	lotebush
Rosaceae	*Cercocarpus montanus*	alderleaf mountain mahogany
Sapindaceae	*Dodonaea viscosa*	Florida hopbush
Solanaceae	*Lycium spp.*	
	Solanum elaeagnifolium	silverleaf nightshade
Verbenaceae	*Aloysia wrightii*	Wright's beebrush
Violaceae	*Hybanthus verticillatus*	babyslippers
Zygophyllaceae	*Larrea tridentata*	creosote bush

APPENDIX C

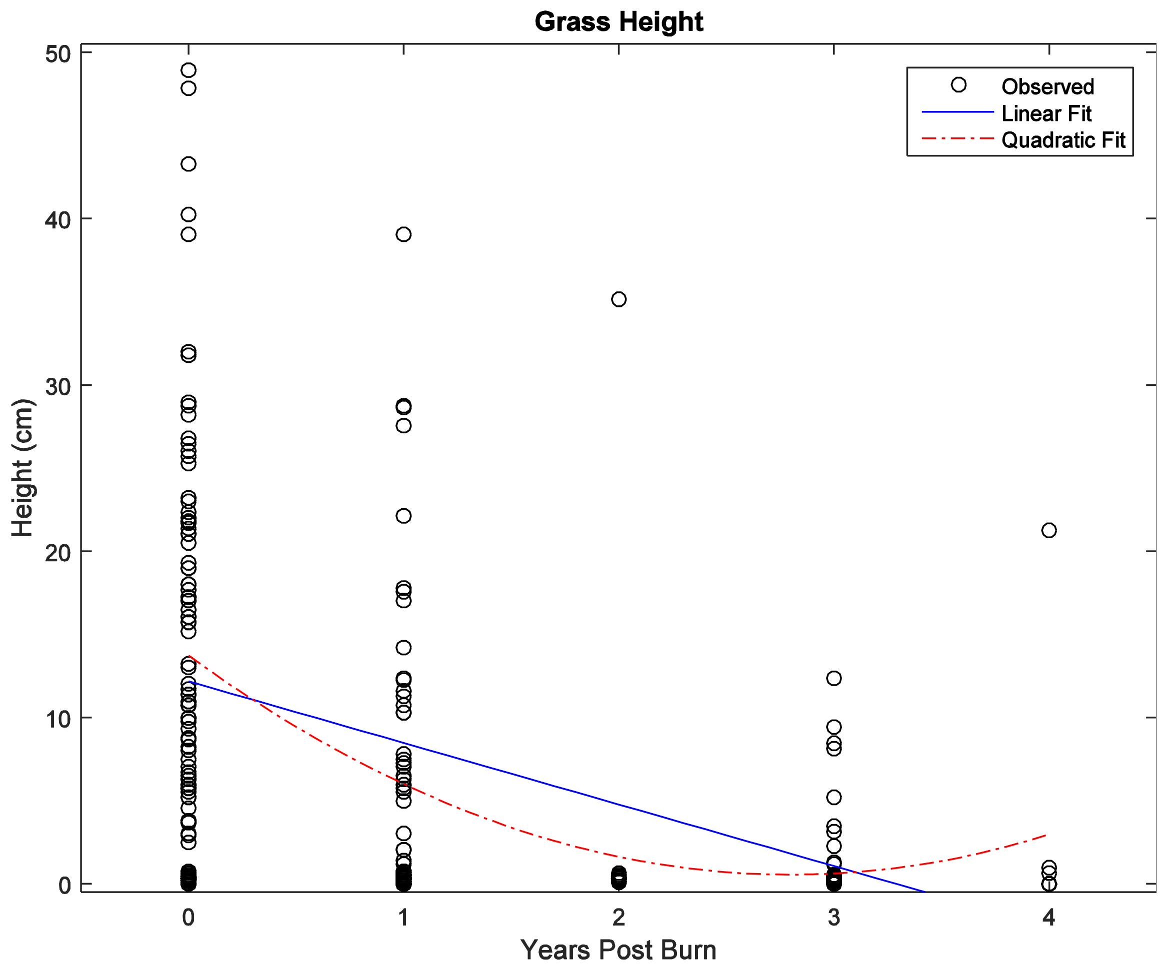
PILE BURN JUNIPER TREATMENT RESULTS FROM ANALYSIS OF VARIANCE FOR SIGNIFICANT FACTORS BY YEARS POST-BURN

Appendix C. Pile burn juniper treatment results from 1-way ANOVA for significant variables by years post-burn. Variables at $p \leq 0.05$ were used to further analyze the predictability of vegetation changes in years post-burn. All variables except cactus height showed significant differences between years.

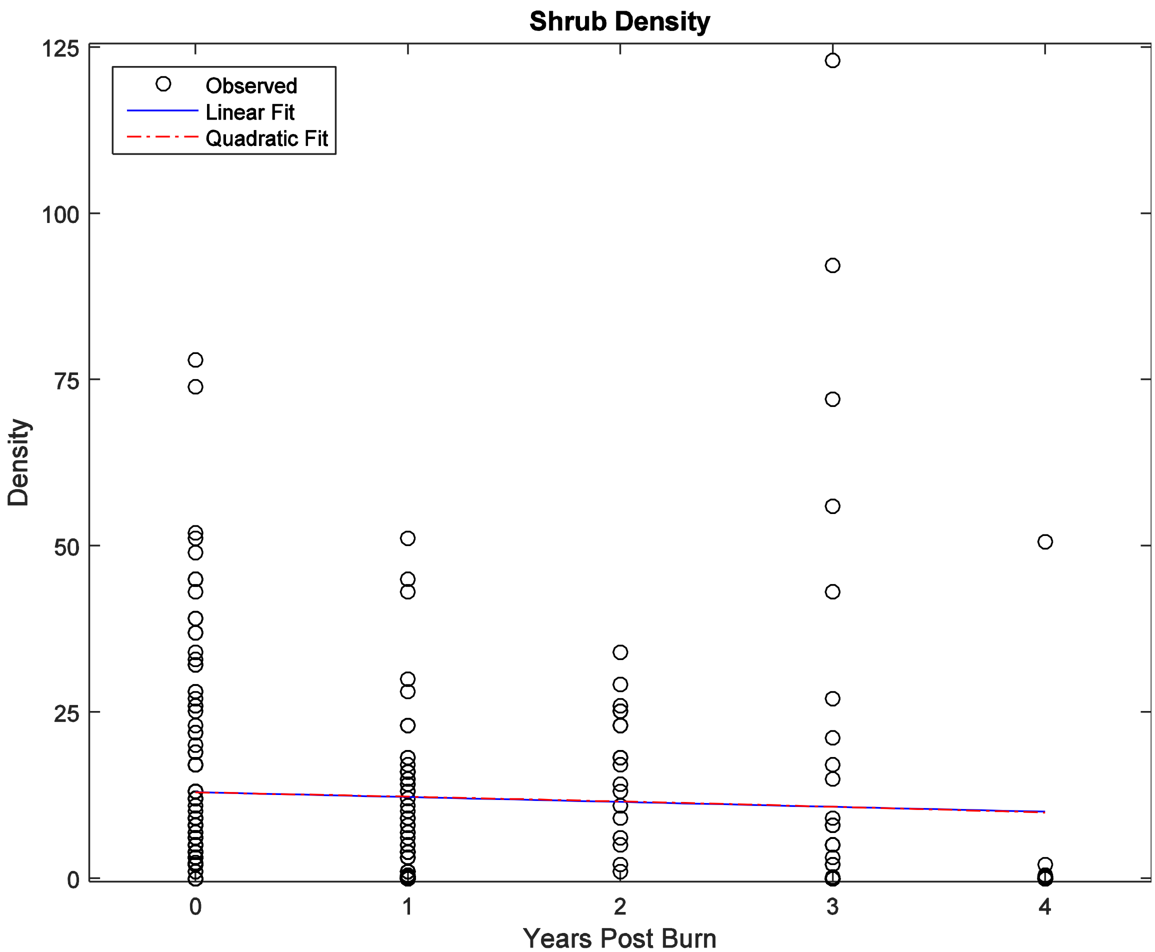
Variable	Years post-burn	Sum of Squares	df	Mean Square	F	Sig.
Grass height, cm	Between Groups	3317.207	4	829.302	9.543	**0.000**
	Within Groups	16510.547	190	86.898		
	Total	19827.754	194			
Shrub density	Between Groups	2795.957	4	698.989	2.461	**0.047**
	Within Groups	53960.394	190	284.002		
	Total	56756.35	194			
Grass density	Between Groups	8558.448	4	2139.612	6.835	**0.000**
	Within Groups	59476.080	190	313.032		
	Total	68034.528	194			
Increaser shrub height, cm	Between Groups	774.601	4	193.65	7.408	**0.000**
	Within Groups	4966.895	190	26.142		
	Total	5741.495	194			
Cactus density	Between Groups	1321.869	4	330.467	15.721	**0.000**
	Within Groups	3994.050	190	21.021		
	Total	5315.920	194			
Cactus height, cm	Between Groups	6.648	4	1.662	2.043	0.09
	Within Groups	154.564	190	0.813		
	Total	161.212	194			
Palatable shrub height, cm	Between Groups	174.220	4	43.555	4.134	**0.003**
	Within Groups	2001.961	190	10.537		
	Total	2176.181	194			
Forb density	Between Groups	13574.218	4	3393.555	14.786	**0.000**
	Within Groups	43607.432	190	229.513		
	Total	57181.650	194			
Forb height, cm	Between Groups	55.359	4	13.84	3.367	**0.011**
	Within Groups	781.047	190	4.111		
	Total	836.406	194			
Species richness	Between Groups	255.426	4	63.857	6.015	**0.000**
	Within Groups	2017.035	190	10.616		
	Total	2272.462	194			

APPENDIX D

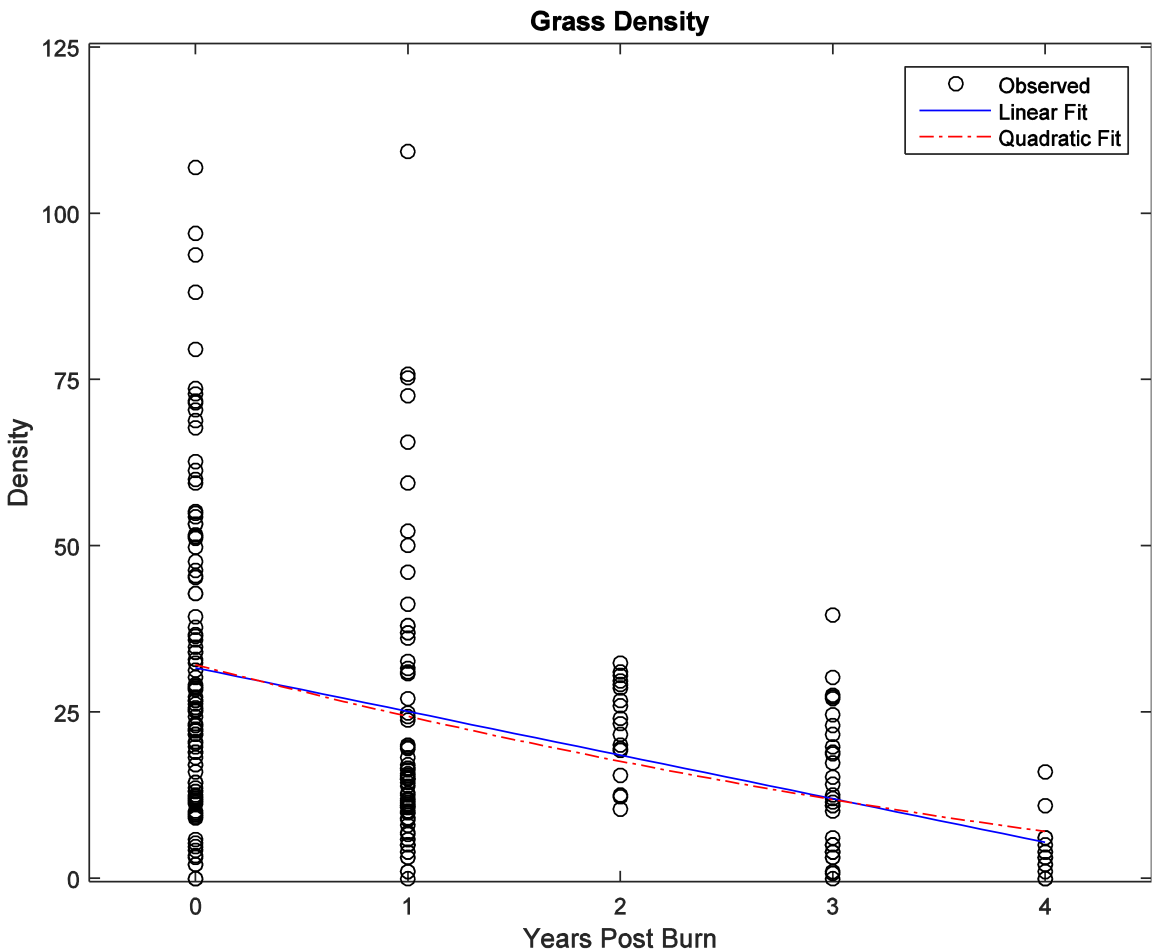
PILE BURN JUNIPER REGRESSION MODELS OF STATISTICALLY SIGNIFICANT VARIABLES AND PERCENT COVER CLASSES WITH YEARS POST-BURN



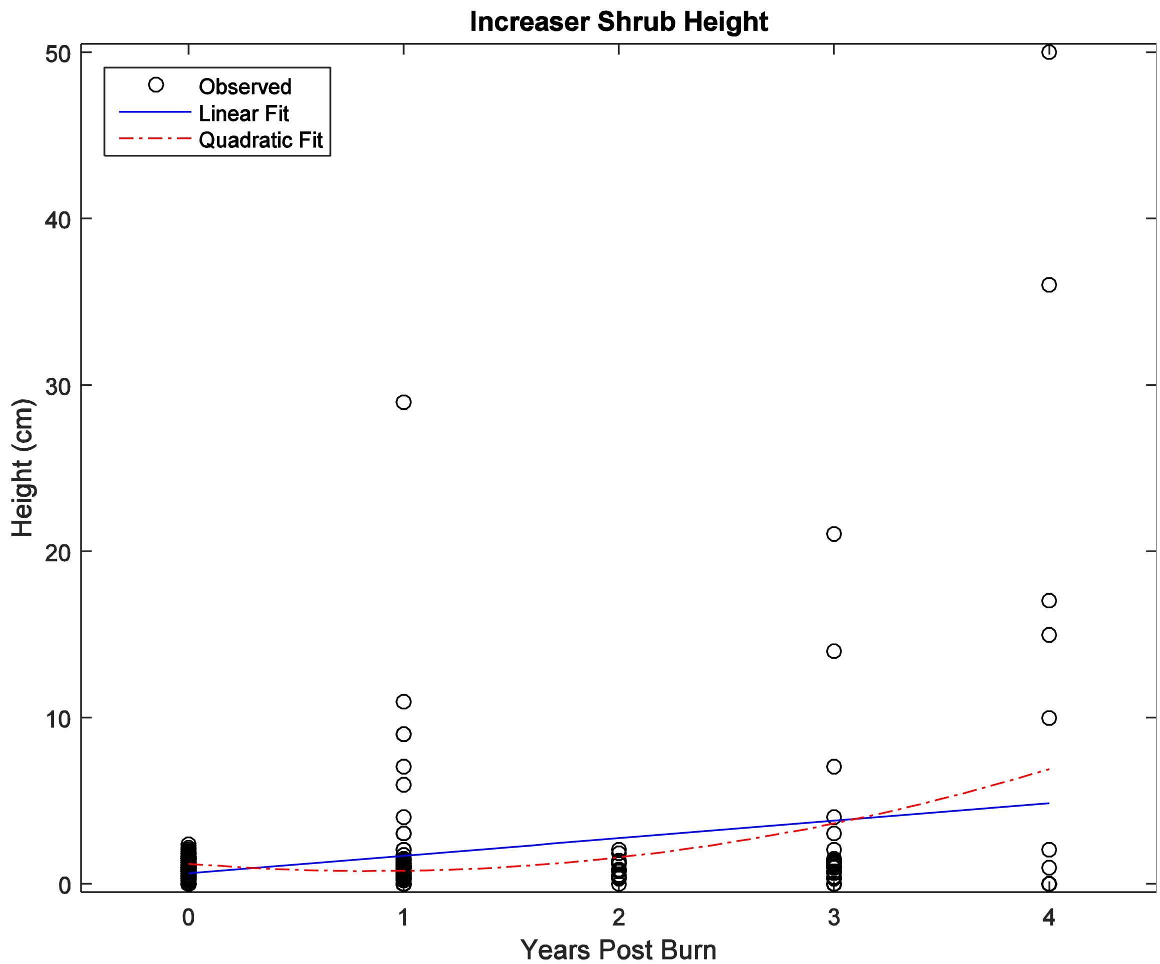
Appendix D-1. Pile burn juniper treatment regression model showing linear and quadratic curves of grass height against years post-burn.



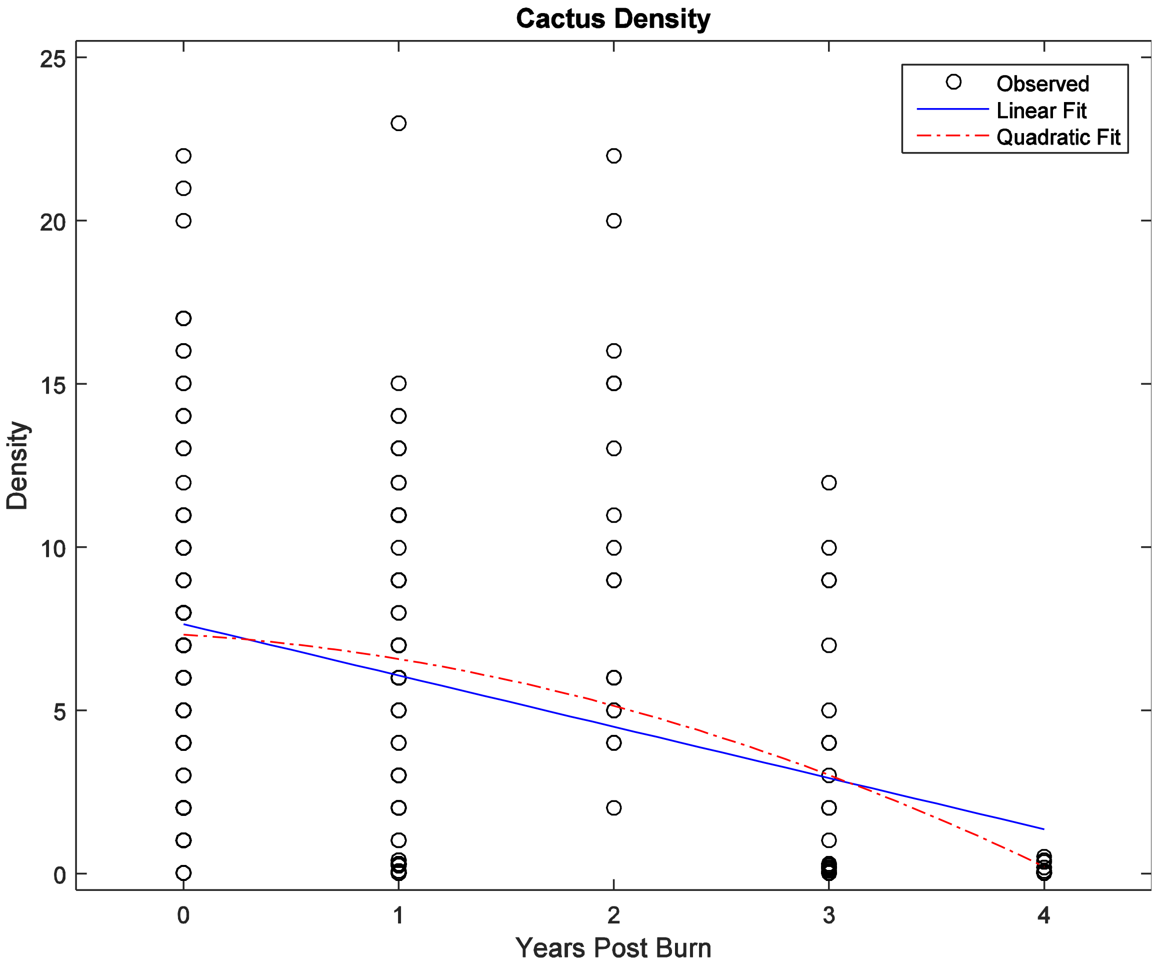
Appendix D-2. Pile burn juniper treatment regression model showing linear and quadratic curves of shrub density against years post-burn.



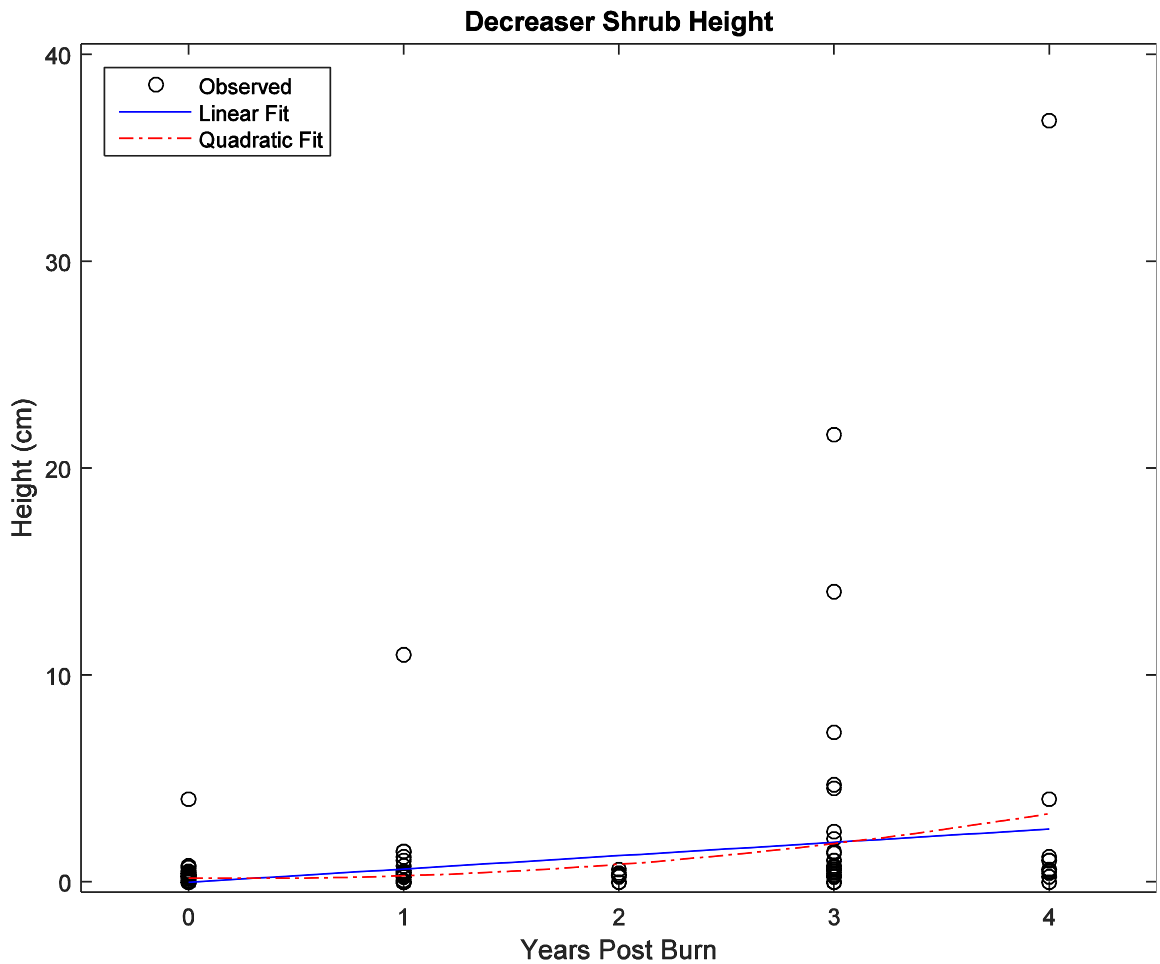
Appendix D-3. Pile burn juniper treatment regression model showing linear and quadratic curves of grass density against years post-burn.



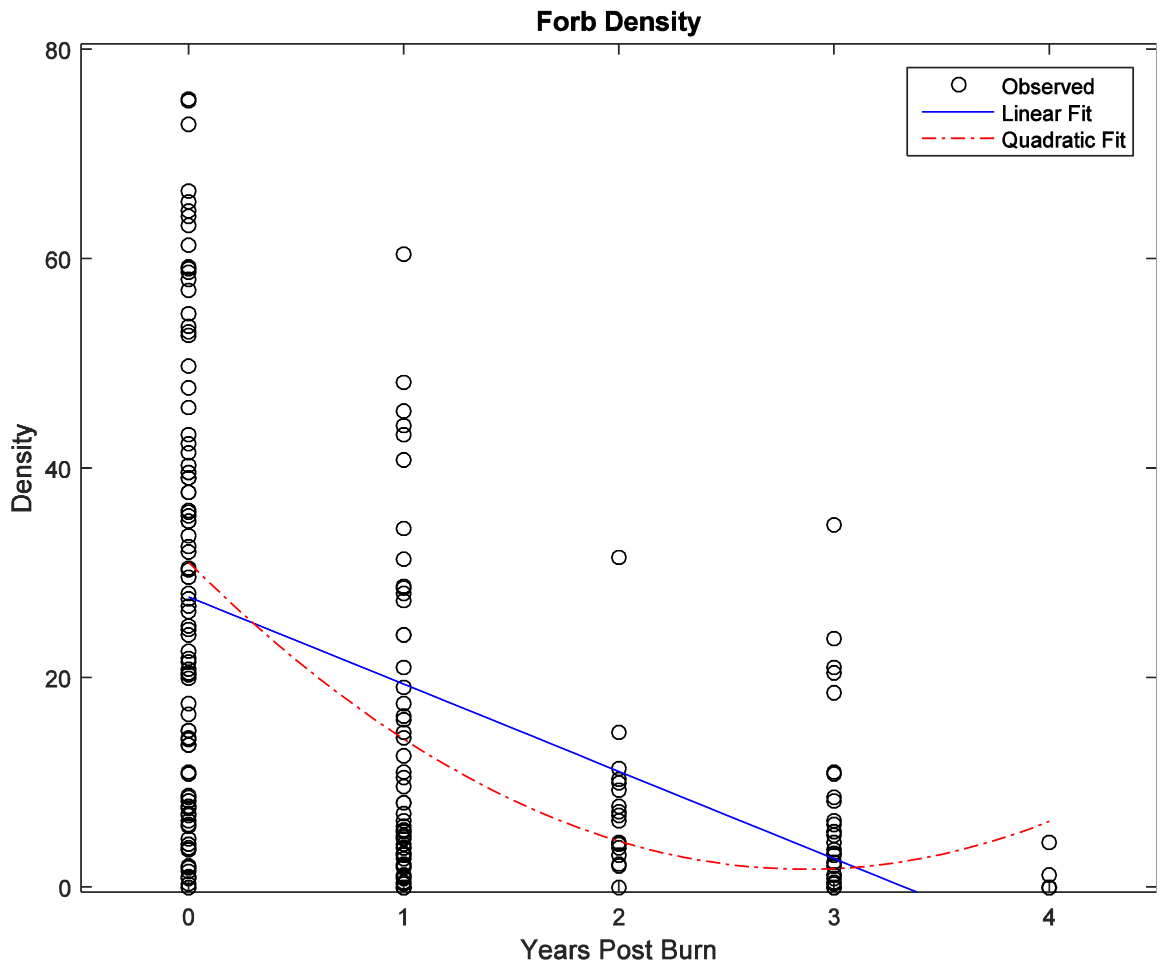
Appendix D-4. Pile burn juniper treatment regression model showing linear and quadratic curves of increaser shrub height against years post-burn.



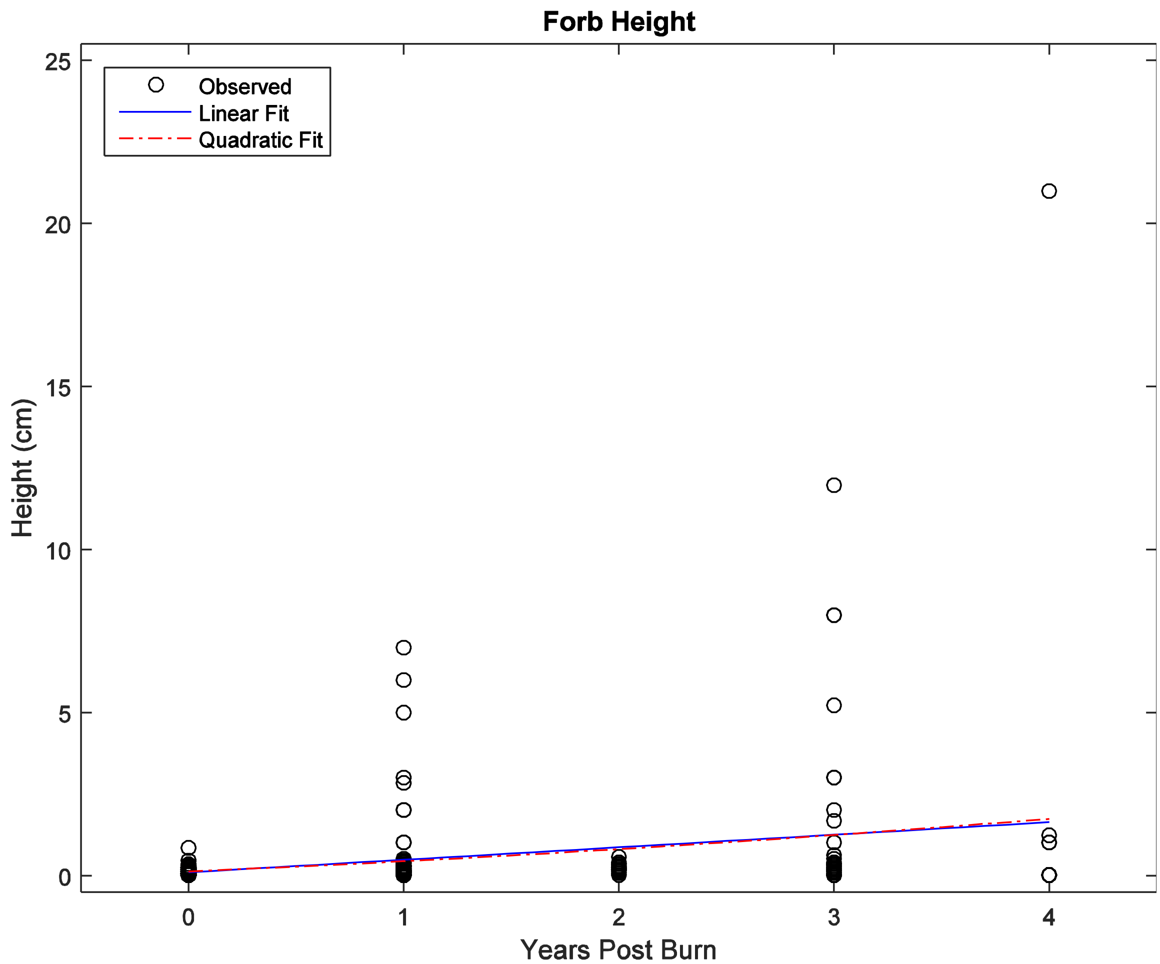
Appendix D-5. Pile burn juniper treatment regression model showing linear and quadratic curves of cactus density against years post-burn.



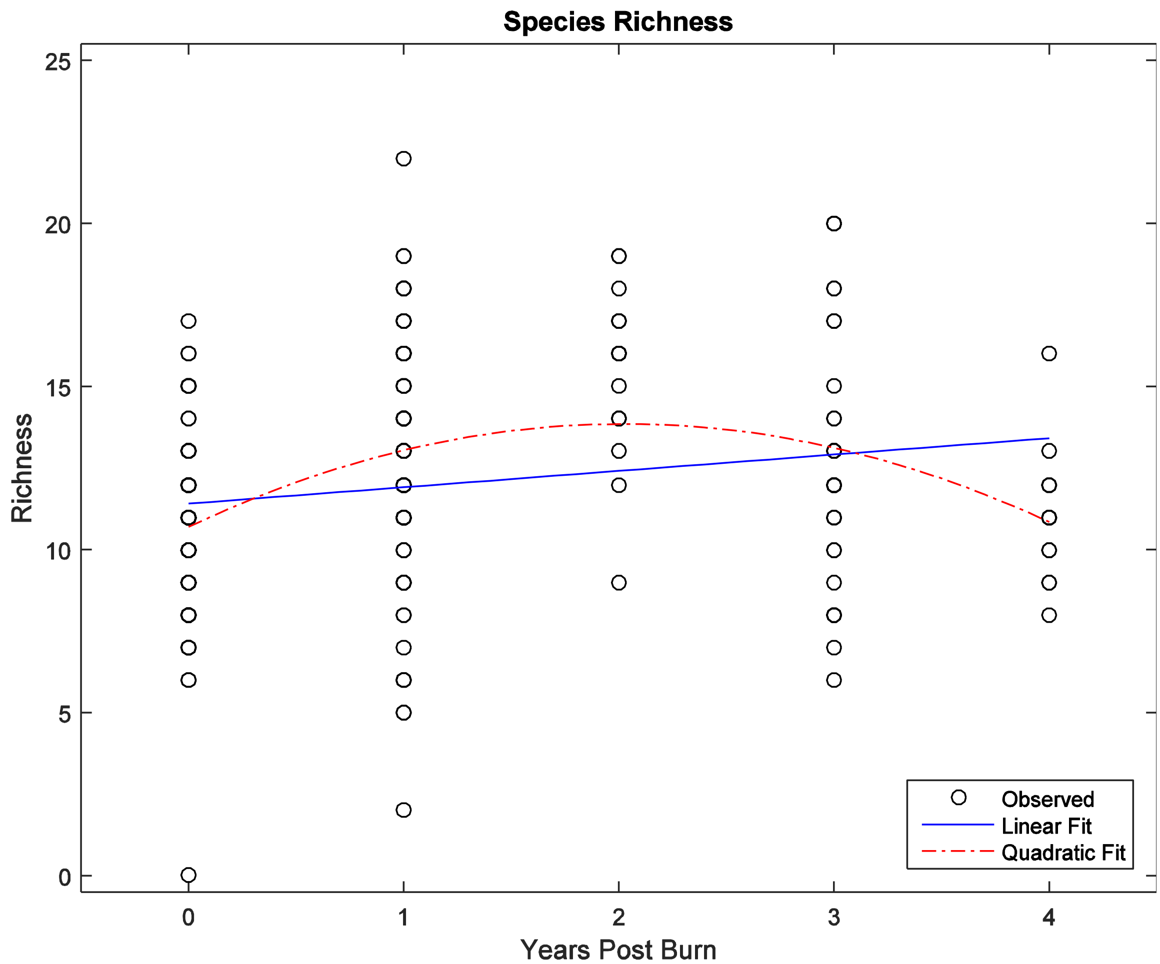
Appendix D-6. Pile burn juniper treatment regression model showing linear and quadratic curves of decreaser shrub height against years post-burn.



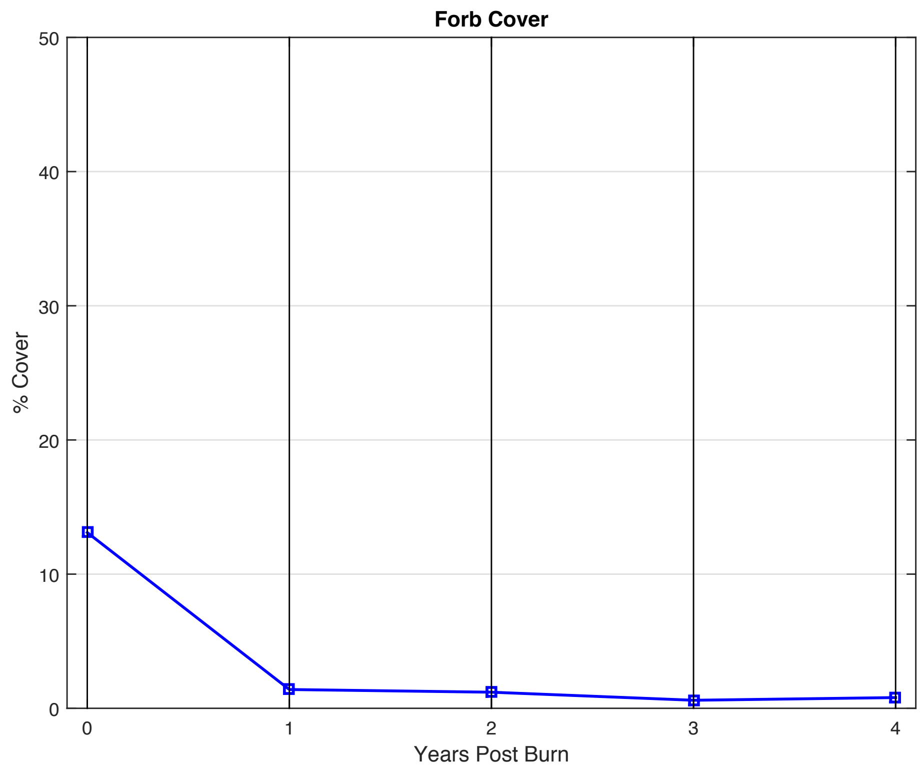
Appendix D-7. Pile burn juniper treatment regression model showing linear and quadratic curves of forb density against years post-burn.



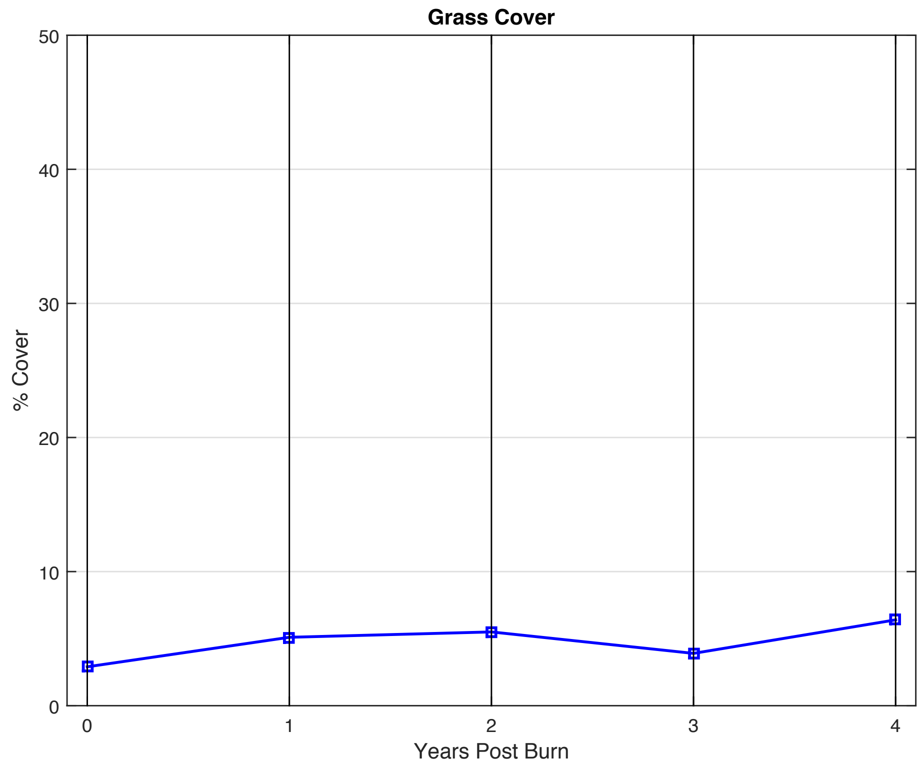
Appendix D-8. Pile burn juniper treatment regression model showing linear and quadratic curves of forb height against years post-burn.



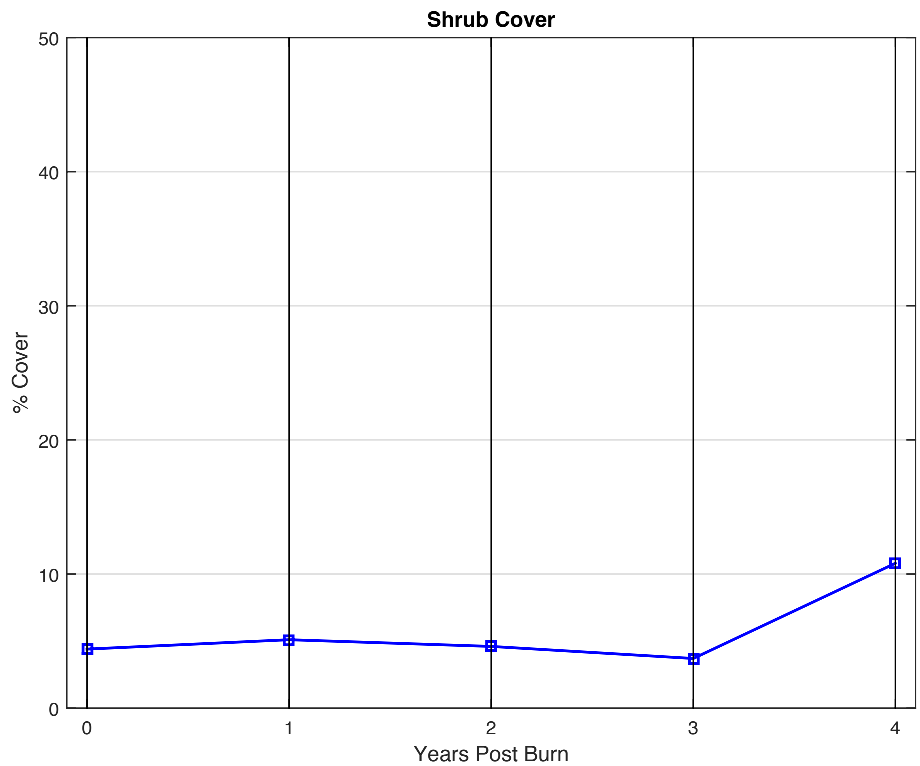
Appendix D-9. Pile burn juniper treatment regression model showing linear and quadratic curves of species richness against years post-burn.



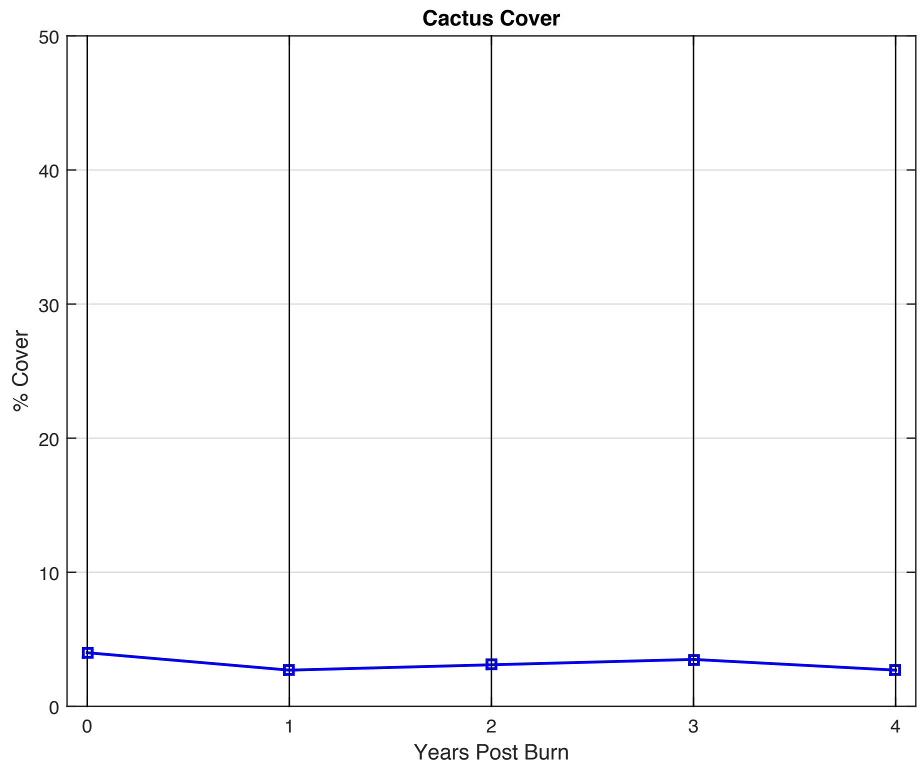
Appendix D-10. Pile burn juniper treatment percent forb cover against years post-burn.



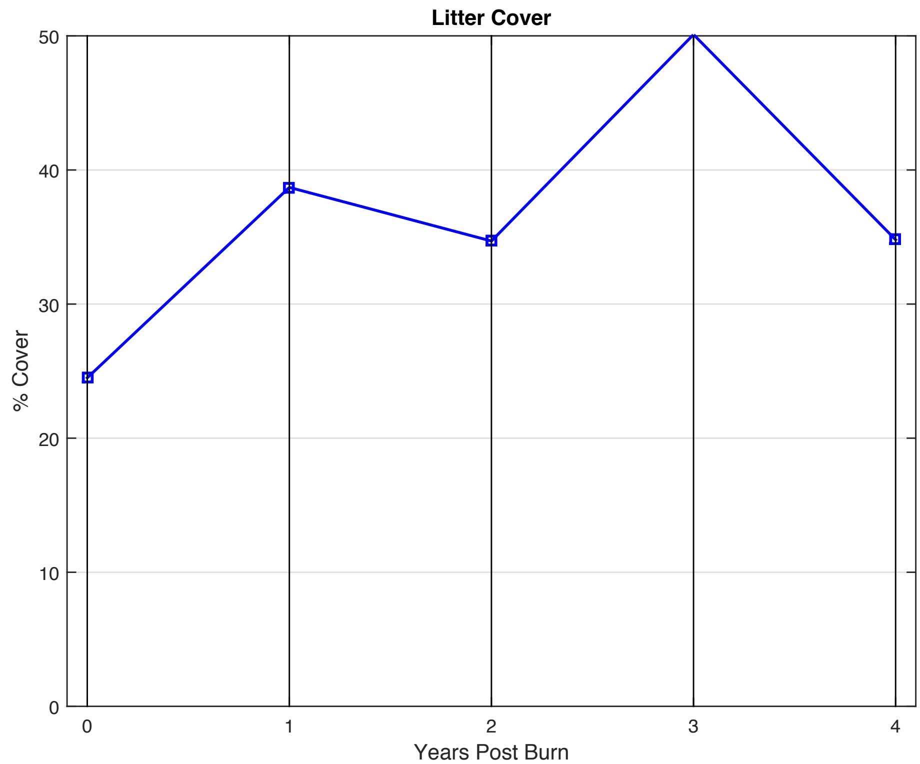
Appendix D-11. Pile burn juniper treatment percent grass cover against years post-burn.



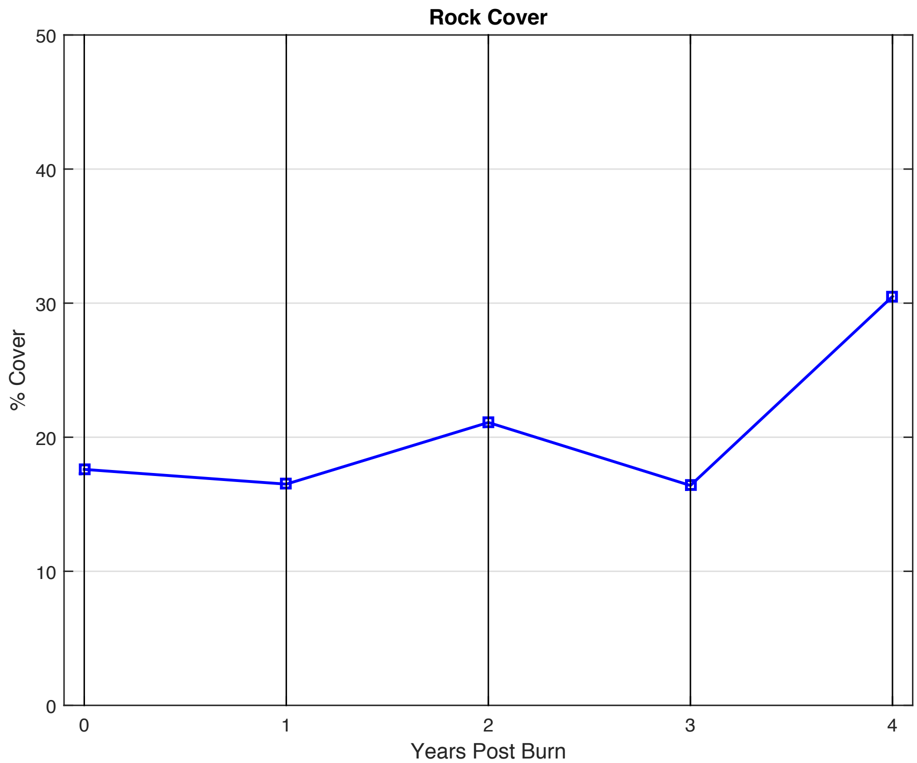
Appendix D-12. Pile burn juniper treatment percent shrub cover against years post-burn.



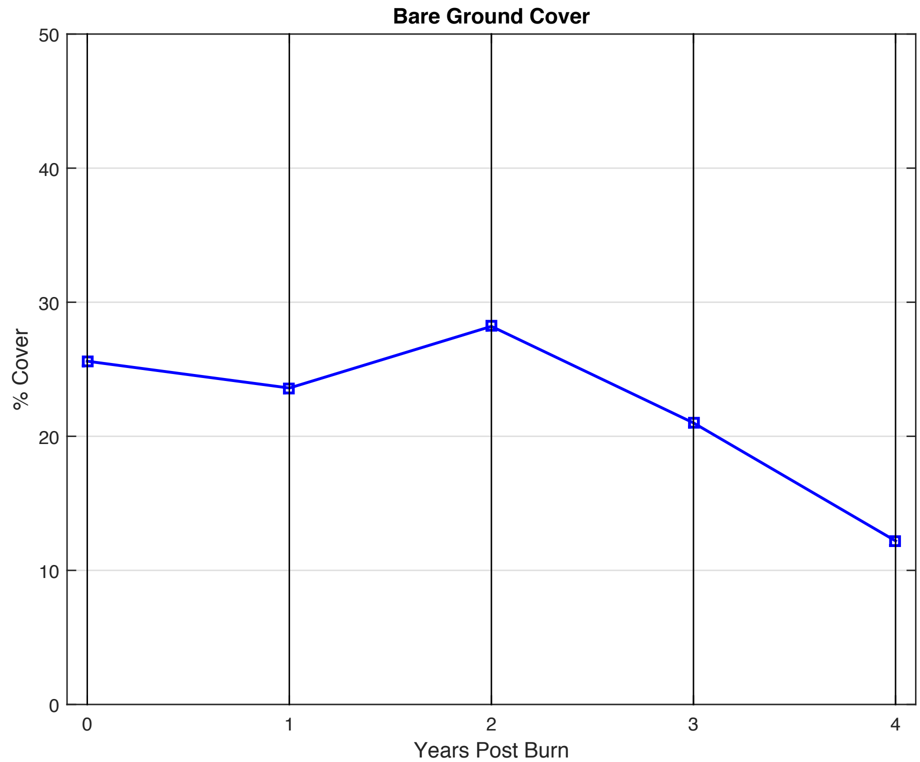
Appendix D-13. Pile burn juniper treatment percent cactus cover against years post-burn.



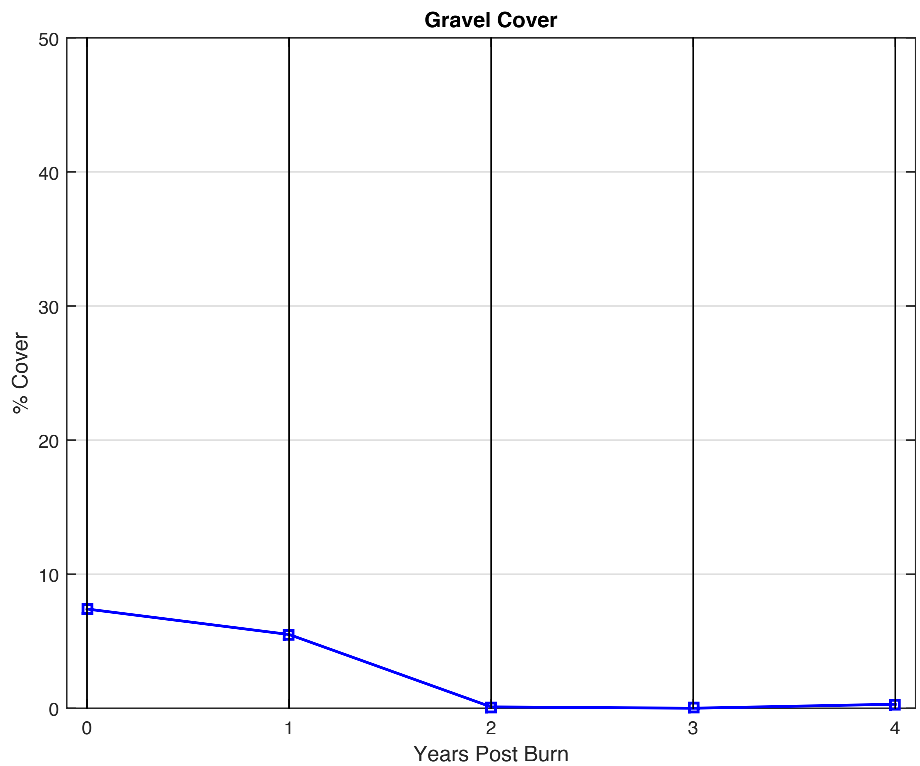
Appendix D-14. Pile burn juniper treatment percent litter cover against years post-burn.



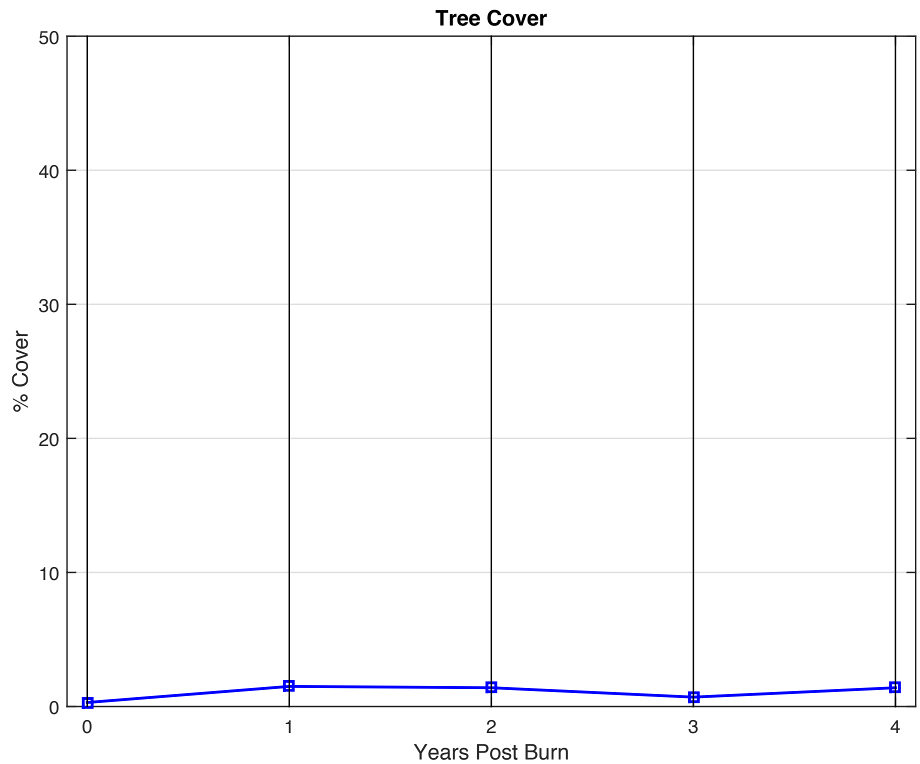
Appendix D-15. Pile burn juniper treatment percent rock cover against years post-burn.



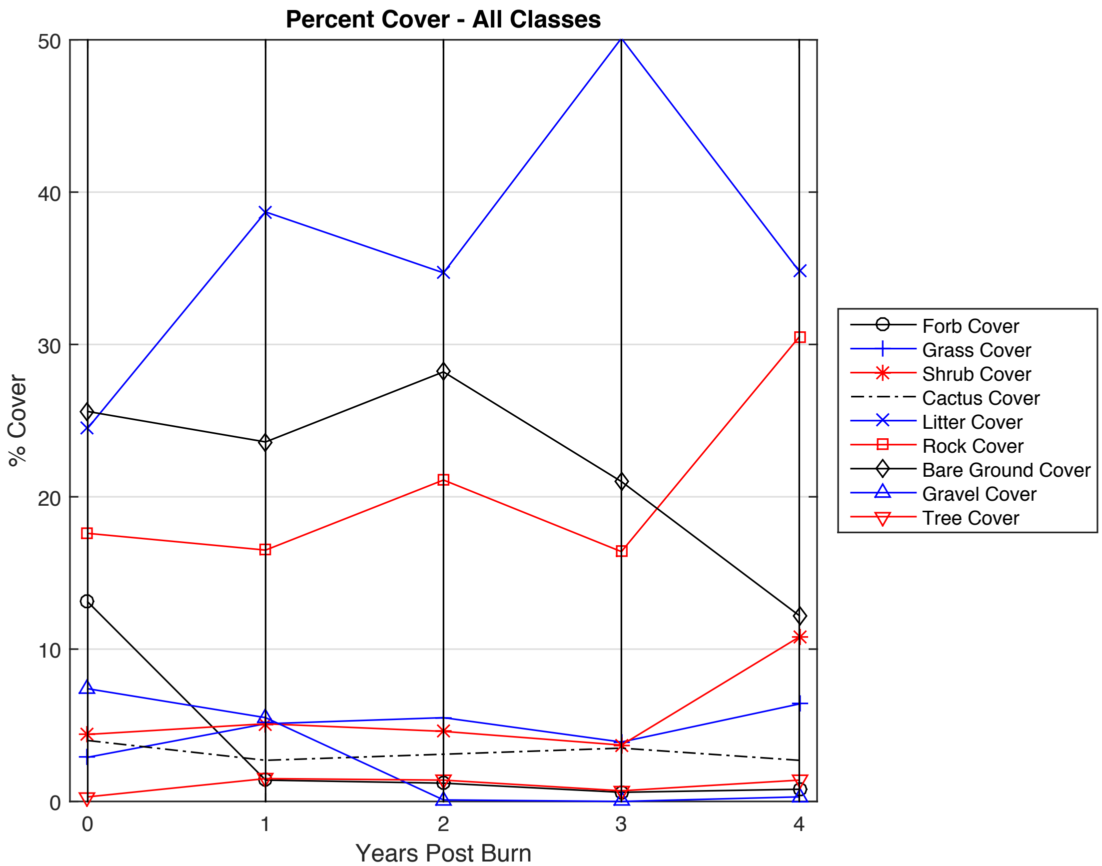
Appendix D-16. Pile burn juniper treatment percent bare ground cover against years post-burn.



Appendix D-17. Pile burn juniper treatment percent gravel cover against years post-burn.



Appendix D-18. Pile burn juniper treatment percent tree cover against years post-burn.



Appendix D-19. Pile burn juniper treatment with all classes of percent cover overlaid against years post-burn.

APPENDIX E

BROADCAST BURN TREATMENT RESULTS FROM ANALYSIS OF VARIANCE FOR SIGNIFICANT FACTORS BY YEARS POST-BURN

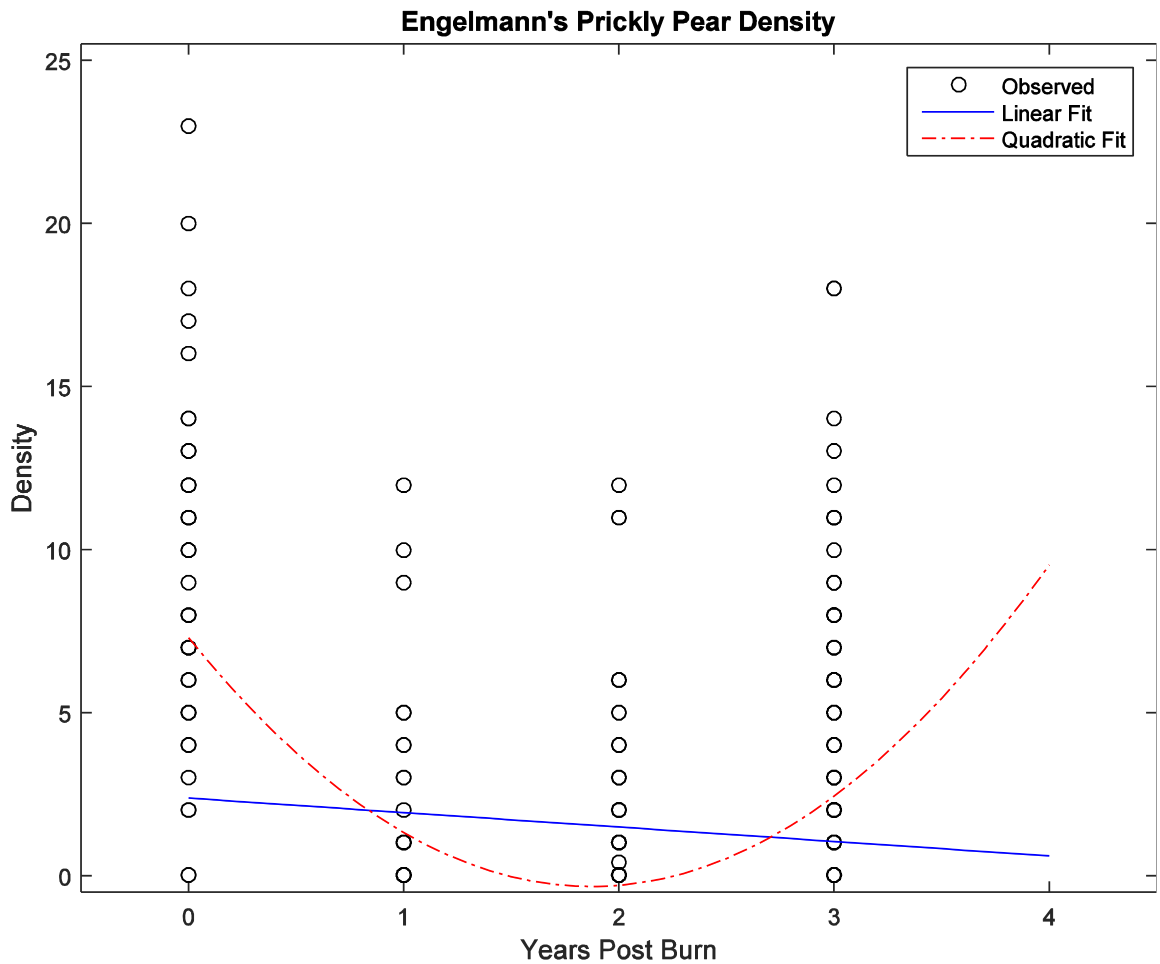
Appendix E. Broadcast burn treatment results from 1-way ANOVA for significant variables by years post-burn. Variables at $p \leq 0.05$ were used to further analyze the predictability of vegetation changes in years post-burn. Wright's buckwheat and forb height did not have significant differences between years post-burn.

Broadcast burn Variable		Sum of Squares	df	Mean Square	F	Sig.
Eng. prickly pear density	Between Groups	3276.34	3	1092.113	166.828	**0.000**
	Within Groups	5145.427	786	6.546		
	Total	8421.767	789			
Eng. prickly pear height, cm	Between Groups	10.843	3	3.614	69.068	**0.000**
	Within Groups	41.13	786	0.052		
	Total	51.973	789			
Eng. prickly pear % cover	Between Groups	1321.28	3	440.427	67.683	**0.000**
	Within Groups	5114.634	786	6.507		
	Total	6435.914	789			
Wright's buckwheat % cover	Between Groups	99.083	3	33.028	4.484	**0.004**
	Within Groups	5789.439	786	7.366		
	Total	5888.522	789			
Wright's buckwheat density	Between Groups	1821.414	3	607.138	2.176	0.089
	Within Groups	219335.433	786	279.053		
	Total	221156.847	789			
Shrub % cover	Between Groups	572.912	3	190.971	8.133	**0.000**
	Within Groups	18456.171	786	23.481		
	Total	19029.083	789			
Broom snakeweed % cover	Between Groups	120.909	3	40.303	7.936	**0.000**
	Within Groups	3991.512	786	5.078		
	Total	4112.421	789			
Broom snakeweed density	Between Groups	11976.492	3	3992.164	11.767	**0.000**
	Within Groups	266664.623	786	339.268		
	Total	278641.115	789			
Tobosa % cover	Between Groups	1514.015	3	504.672	13.533	**0.000**
	Within Groups	29310.617	786	37.291		
	Total	30824.632	789			
Tobosa biomass, g	Between Groups	4295.38	3	1431.793	21.254	**0.017**
	Within Groups	52949.414	786	67.366		
	Total	57244.794	789			
Perennial grass density	Between Groups	24.86	3	8.287	3.409	**0.000**
	Within Groups	1910.442	786	2.431		
	Total	1935.301	789			
Perennial grass height, cm	Between Groups	1744.173	3	581.391	20.32	**0.000**
	Within Groups	22489.24	786	28.612		
	Total	24233.414	789			

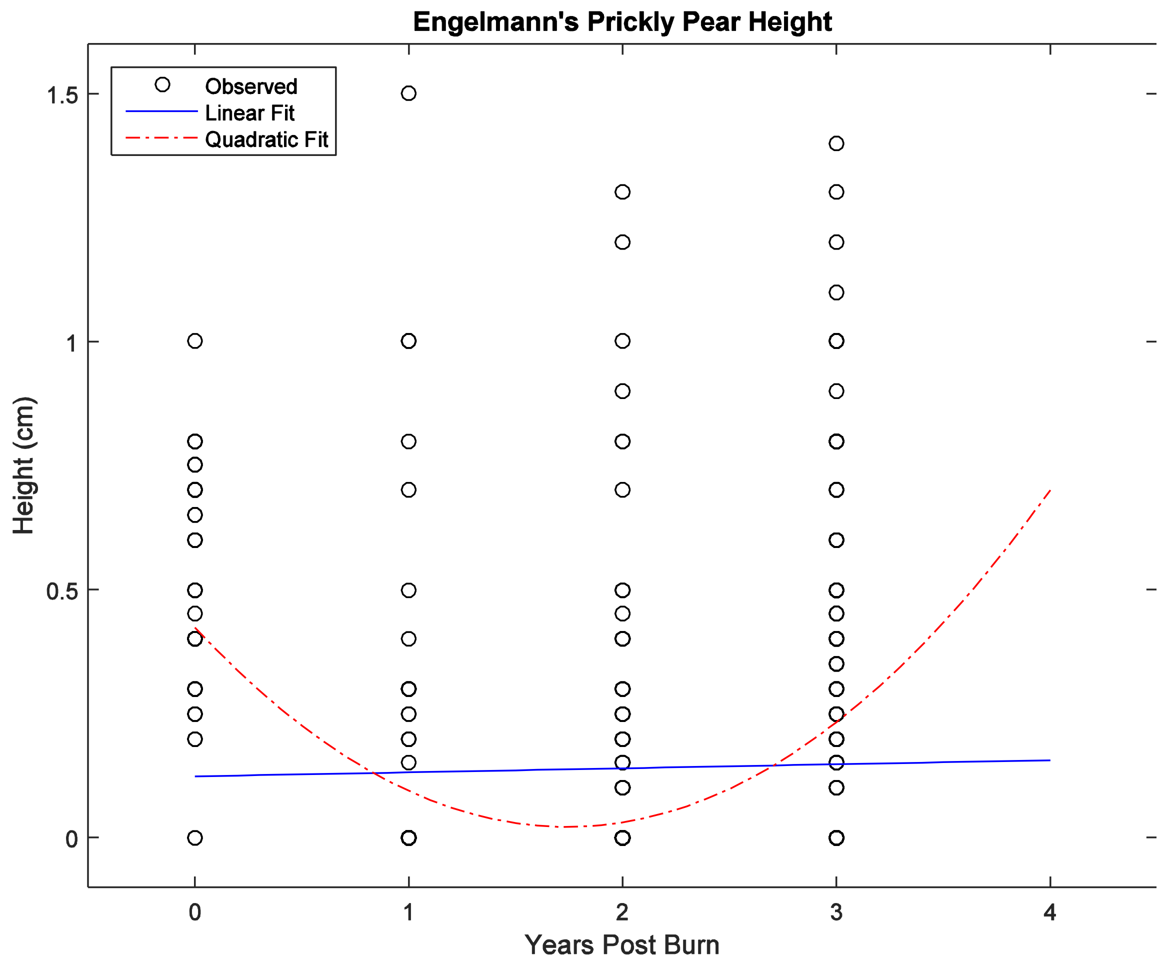
Broadcast burn Variable		Sum of Squares	df	Mean Square	F	Sig.
Annual grass height, cm	Between Groups	42782.23	3	14260.743	109.352	**0.000**
	Within Groups	102503.366	786	130.411		
	Total	145285.596	789			
Velvet mesquite height, cm	Between Groups	12.973	3	4.324	18.63	**0.000**
	Within Groups	182.441	786	0.232		
	Total	195.414	789			
Velvet mesquite density	Between Groups	6.938	3	2.313	5.256	**0.001**
	Within Groups	345.852	786	0.44		
	Total	352.79	789			
Forb density	Between Groups	8354.419	3	2784.806	8.525	**0.000**
	Within Groups	256757.268	786	326.663		
	Total	265111.688	789			
Forb height, cm	Between Groups	435.215	3	145.072	0.682	0.563
	Within Groups	166876.394	785	212.581		
	Total	167311.61	788			
Species richness	Between Groups	1699.778	3	566.593	58.354	**0.000**
	Within Groups	7631.793	786	9.71		
	Total	9331.571	789			

APPENDIX F

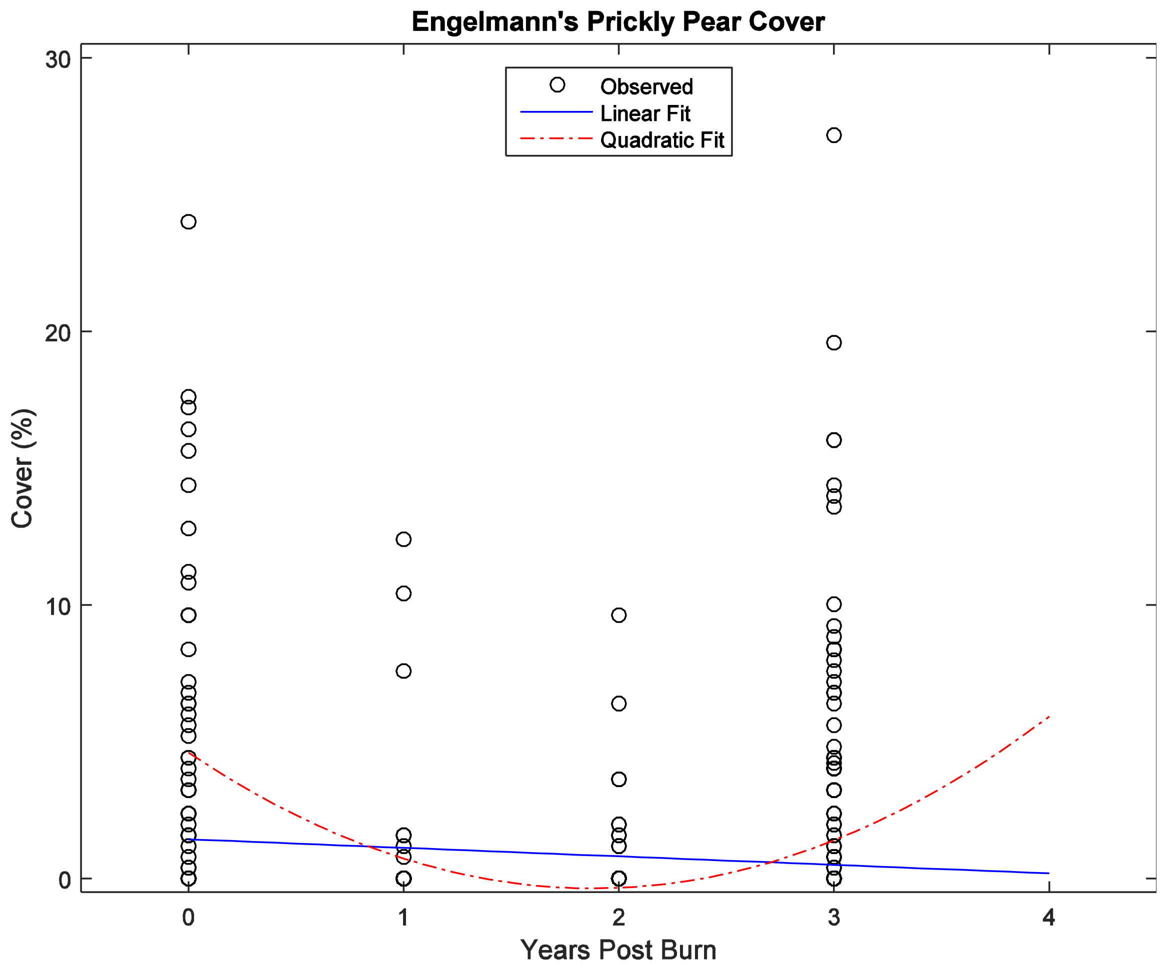
GRASSLAND TREATMENT REGRESSION MODELS OF STATISTICALLY SIGNIFICANT VARIABLES AND PERCENT COVER CLASSES WITH YEARS POST-BURN



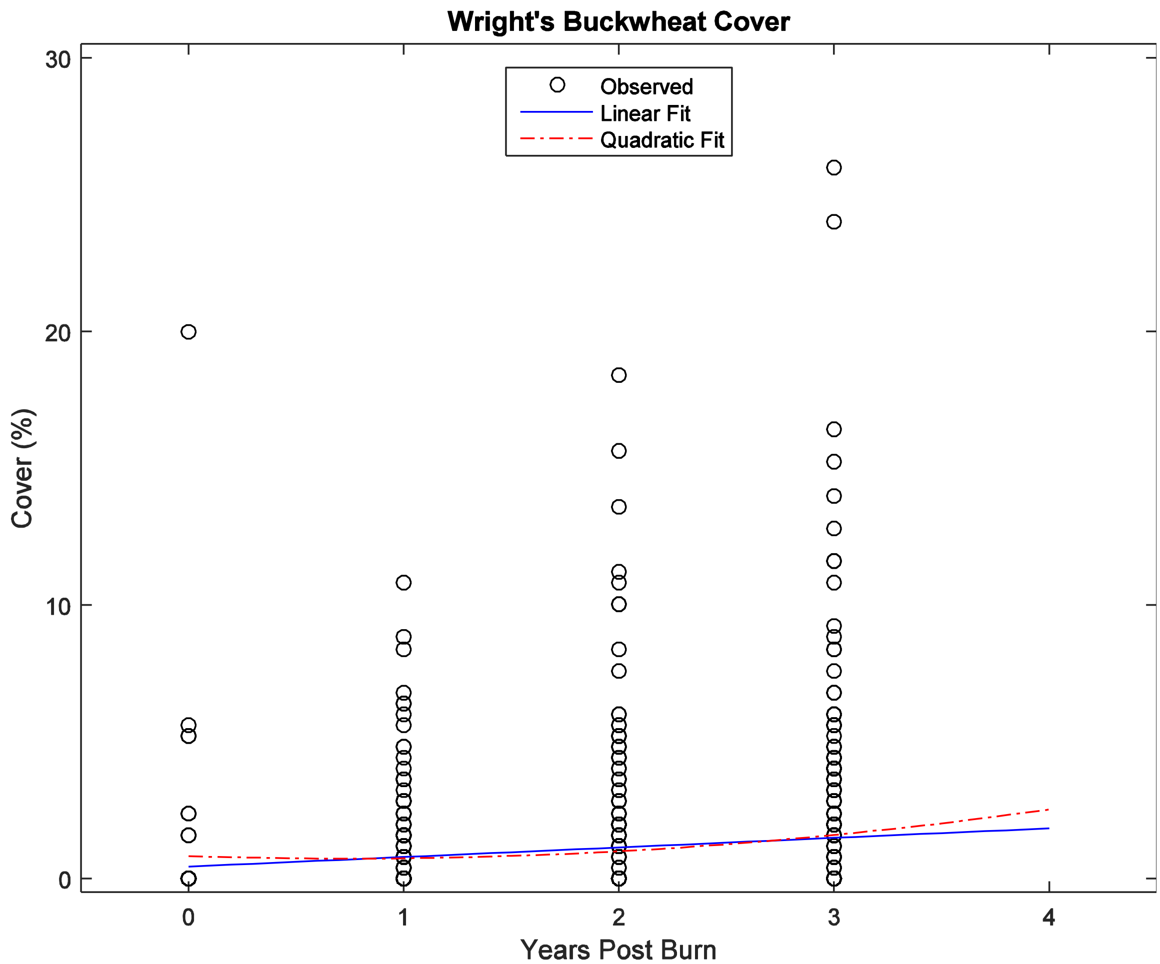
Appendix F-1. Broadcast burn treatment regression model showing linear and quadratic curves of Engelmann's prickly pear density against years post-burn.



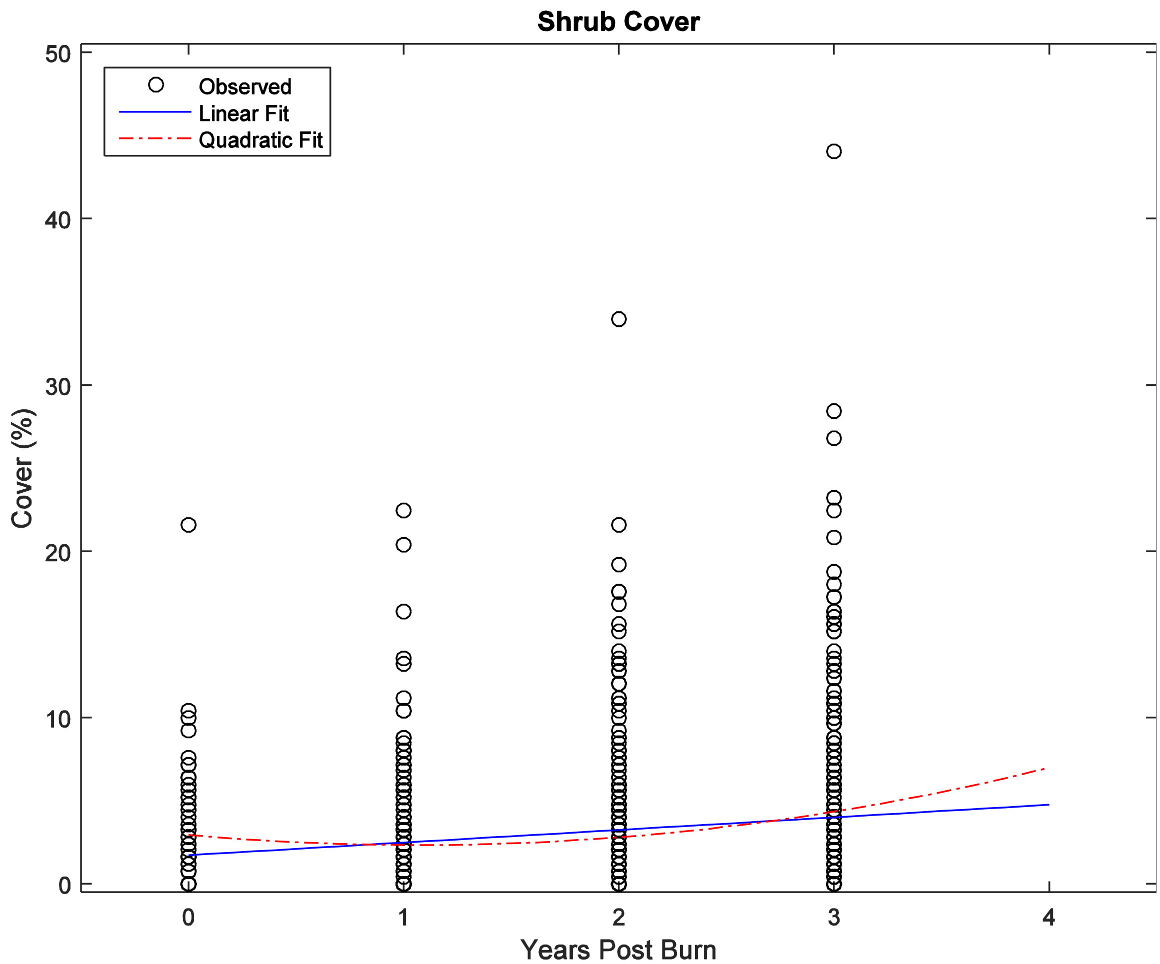
Appendix F-2. Broadcast burn treatment regression model showing linear and quadratic curves of Engelmann's prickly pear height against years post-burn.



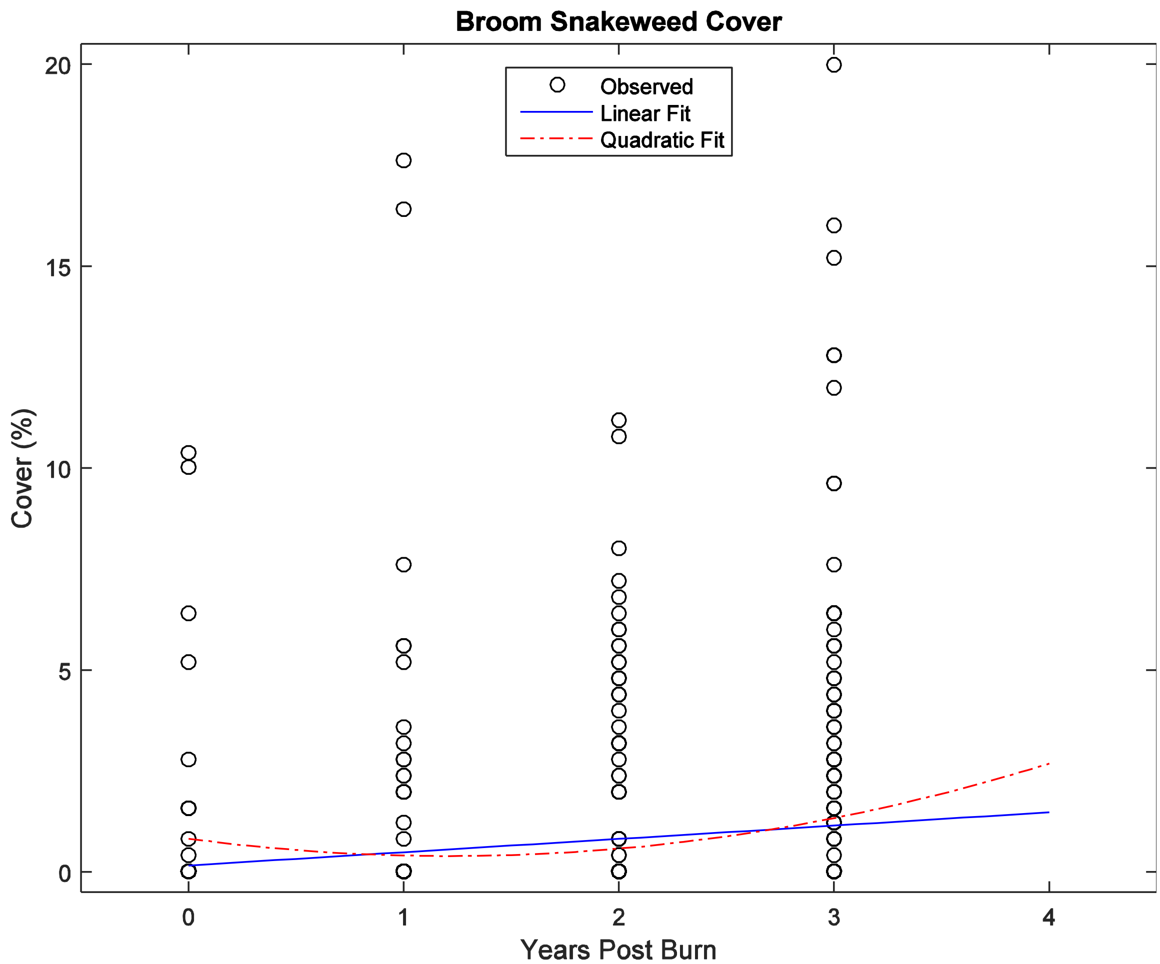
Appendix F-3. Broadcast burn treatment regression model showing linear and quadratic curves of Engelmann's prickly pear cover against years post-burn.



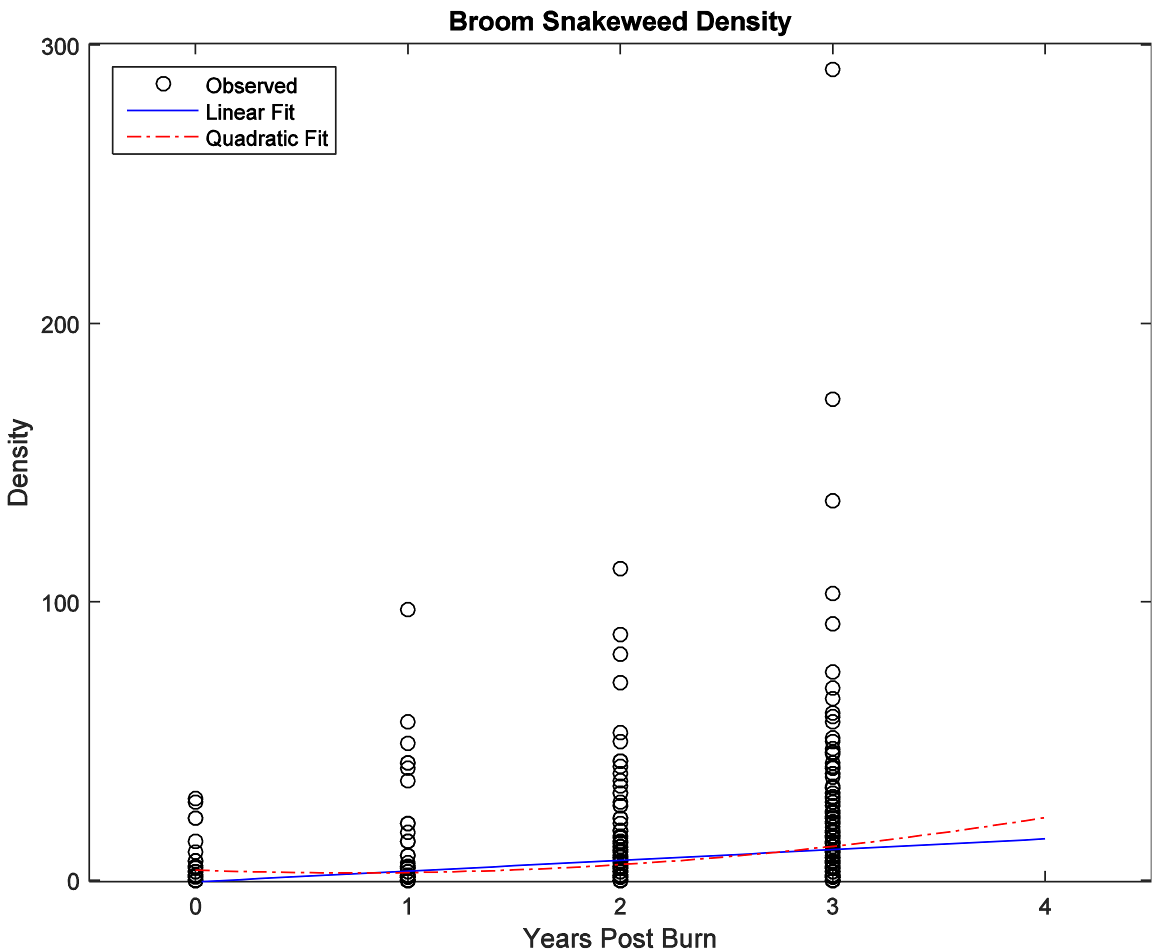
Appendix F-4. Broadcast burn treatment regression model showing linear and quadratic curves of Wright's buckwheat cover against years post-burn.



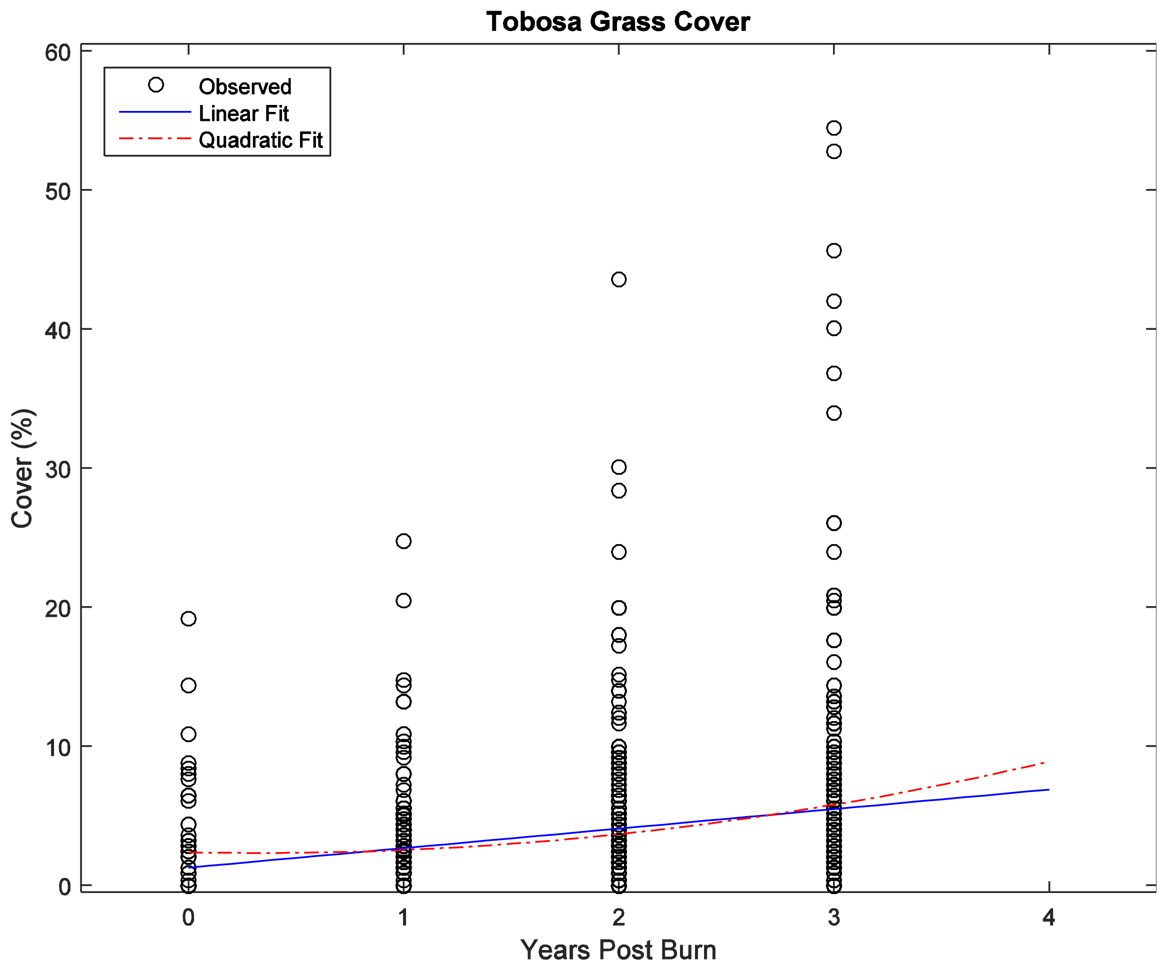
Appendix F-5 Broadcast burn treatment regression model showing linear and quadratic curves of shrub cover against years post-burn.



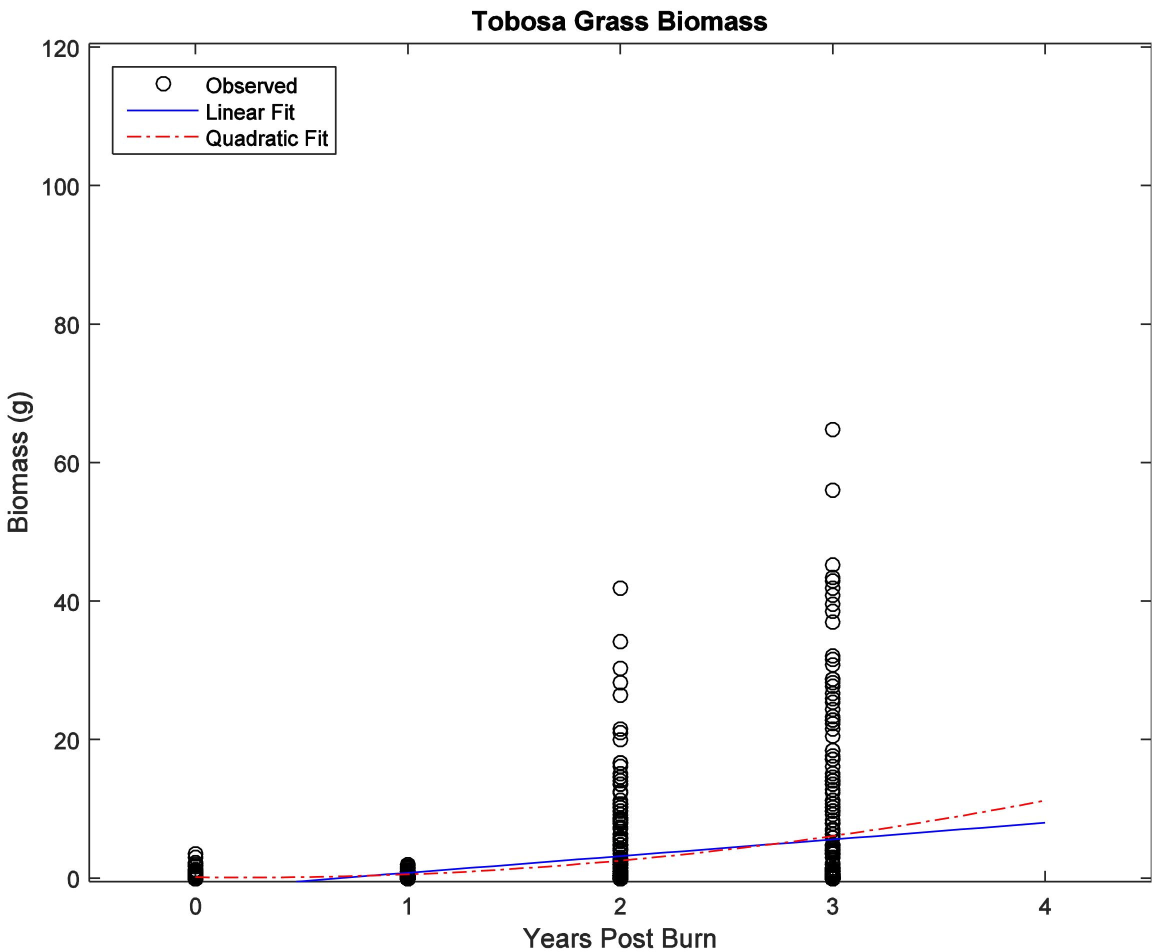
Appendix F-6. Broadcast burn treatment regression model showing linear and quadratic curves of broom snakeweed cover against years post-burn.



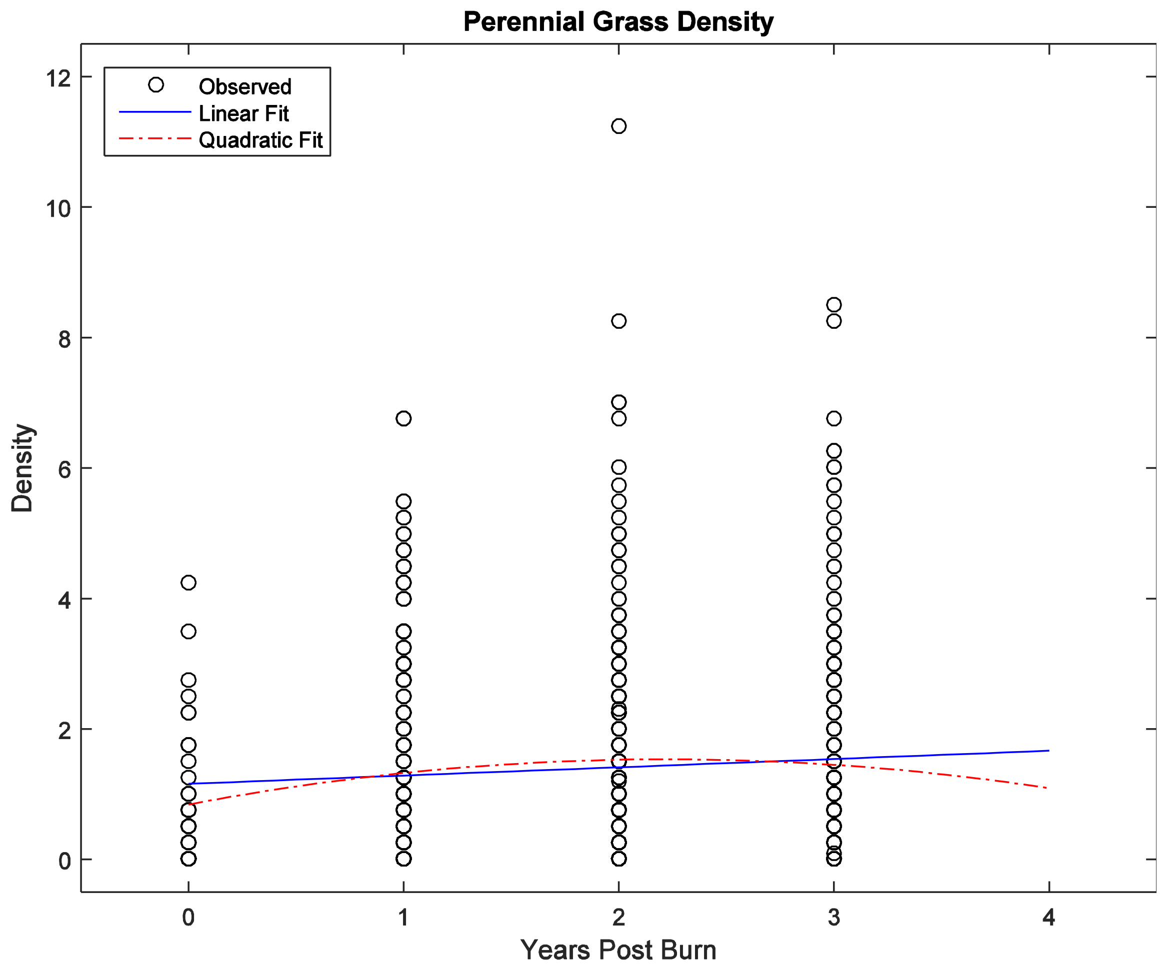
Appendix F-7. Broadcast burn treatment regression model showing linear and quadratic curves of broom snakeweed density against years post-burn.



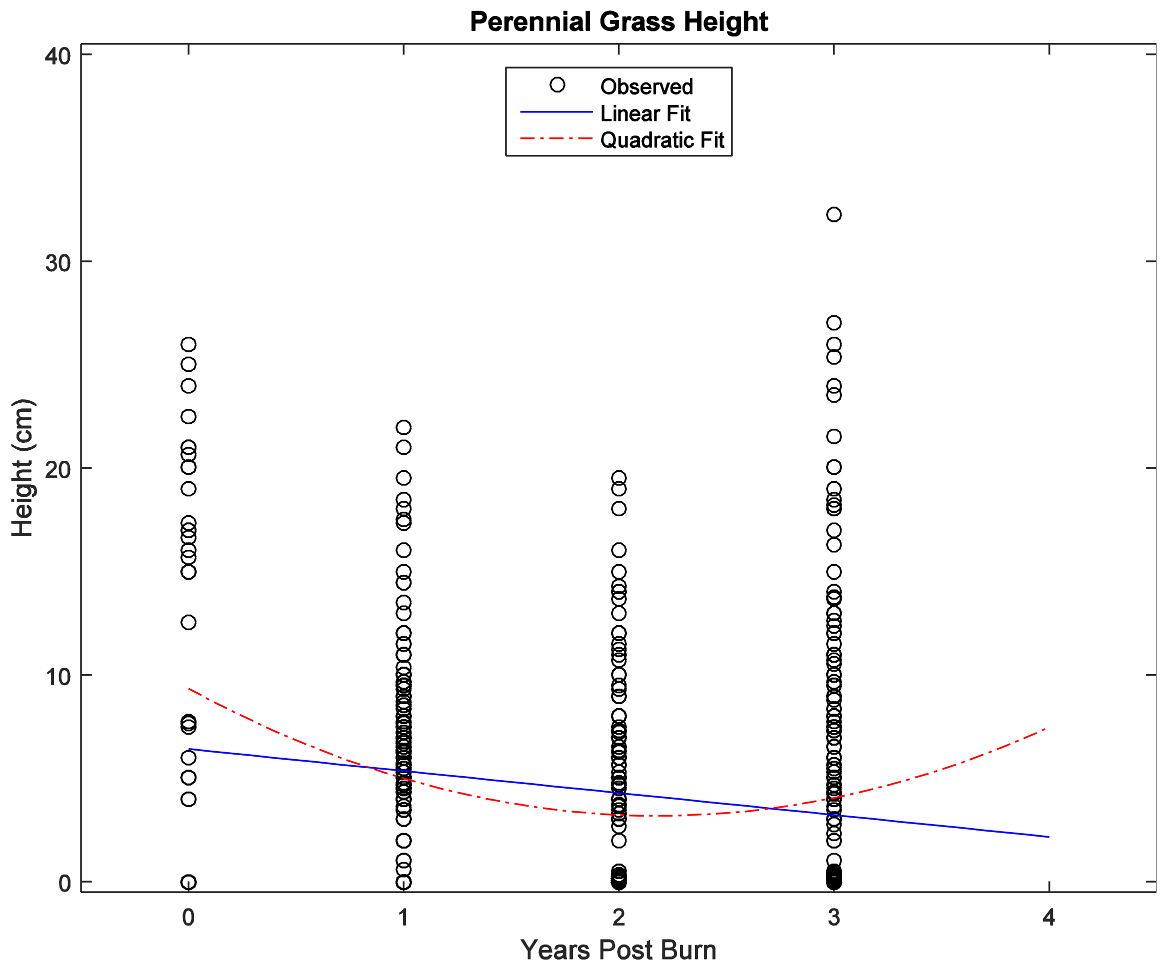
Appendix F-8. Broadcast burn treatment regression model showing linear and quadratic curves of tobosa grass cover against years post-burn.



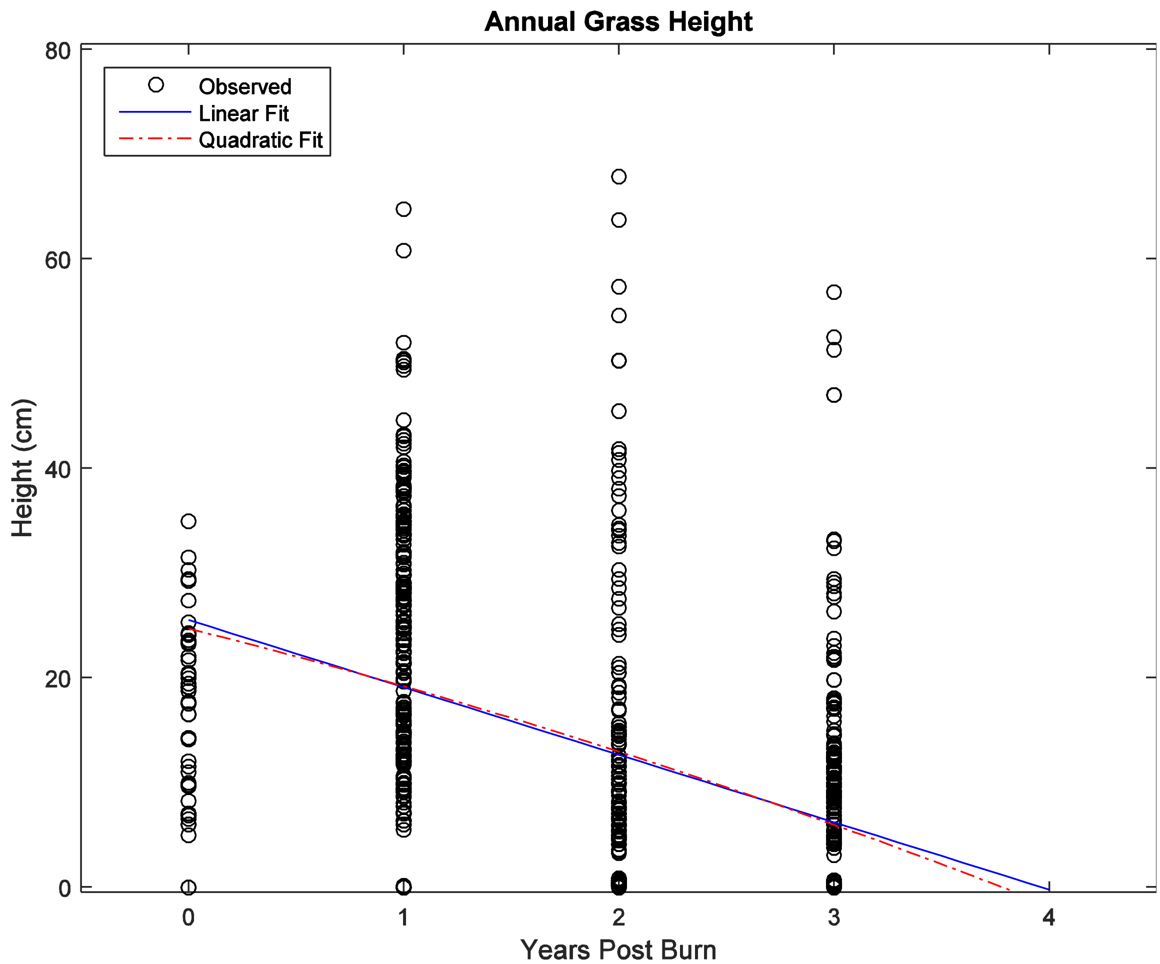
Appendix F-9. Broadcast burn treatment regression model showing linear and quadratic curves of tobosa grass biomass against years post-burn.



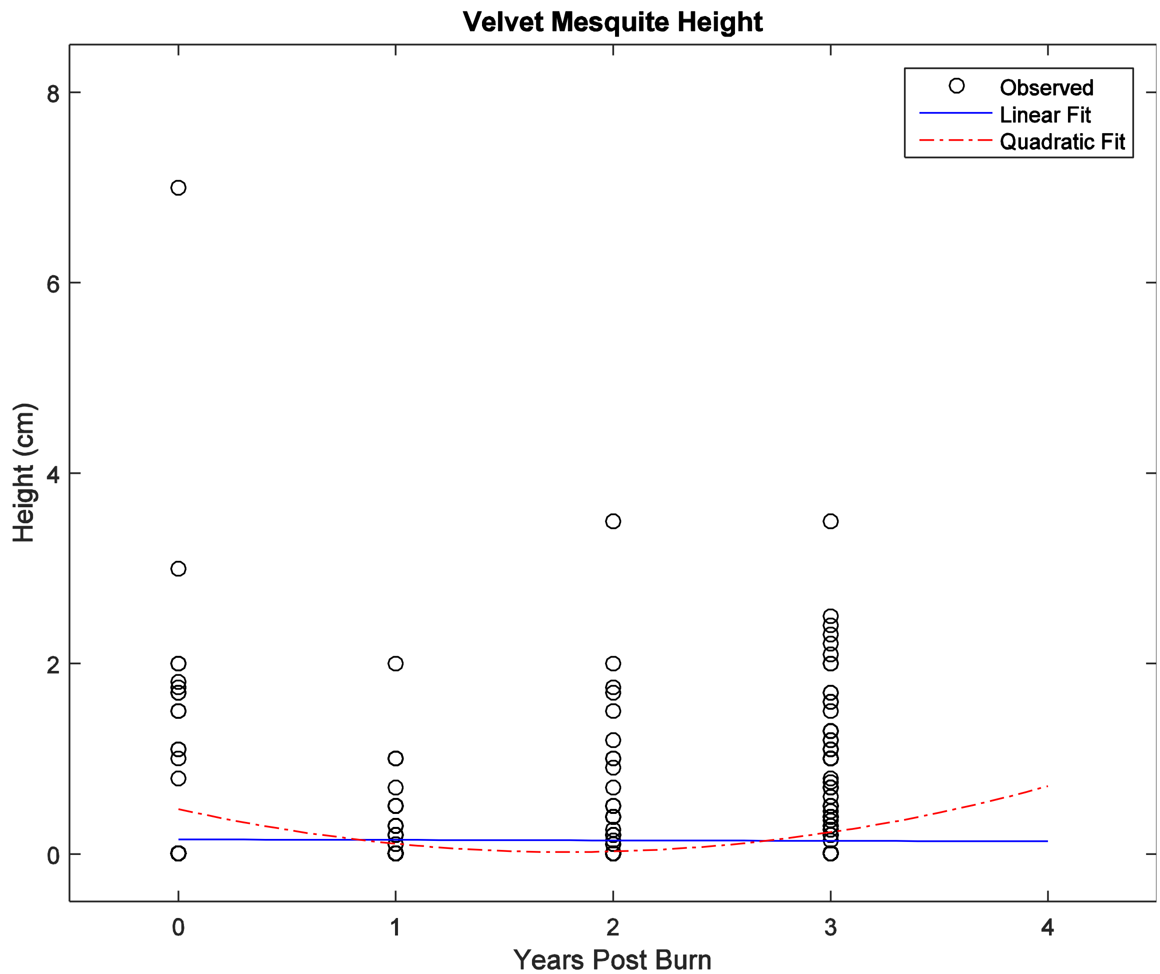
Appendix F-10. Broadcast burn treatment regression model showing linear and quadratic curves of perennial grass density against years post-burn.



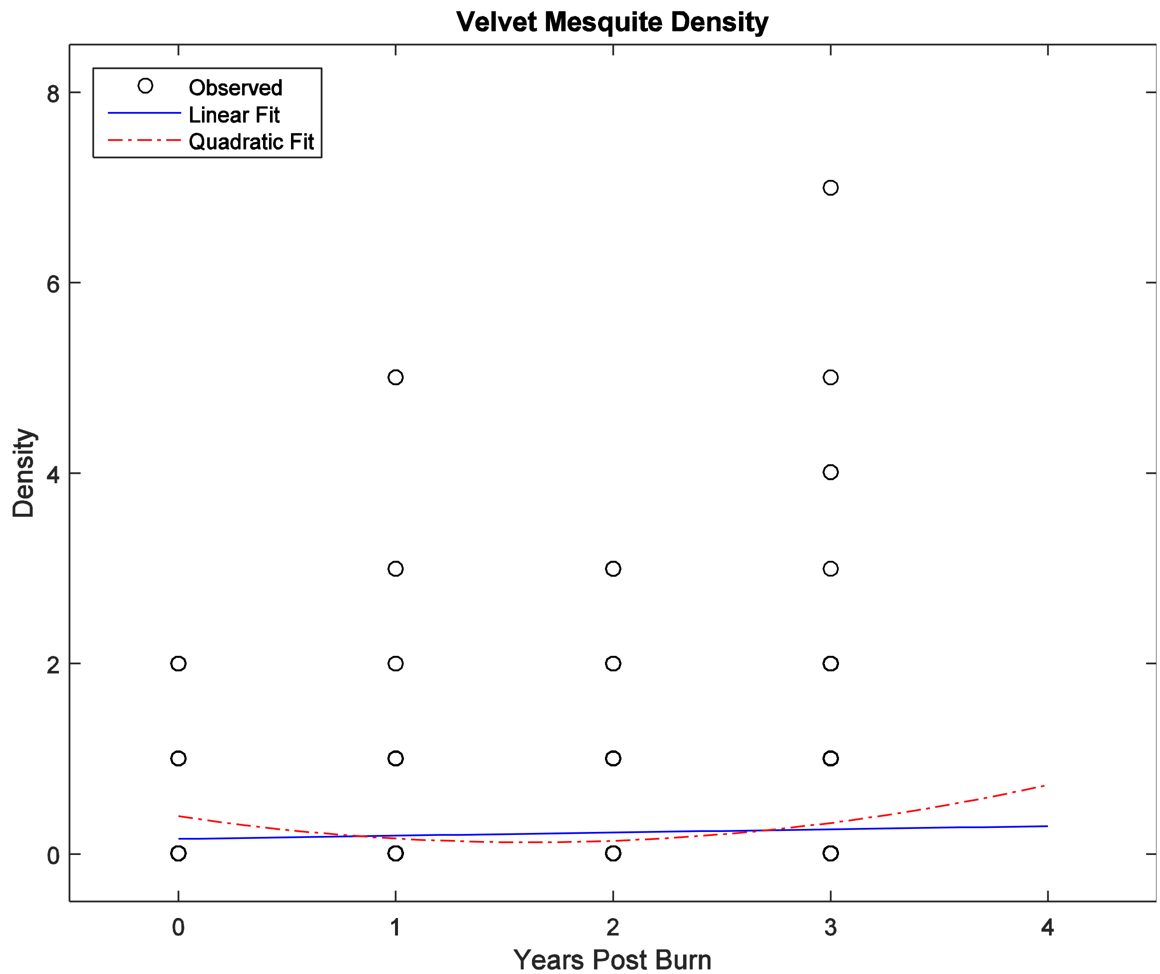
Appendix F-11. Broadcast burn treatment regression model showing linear and quadratic curves of perennial grass height against years post-burn.



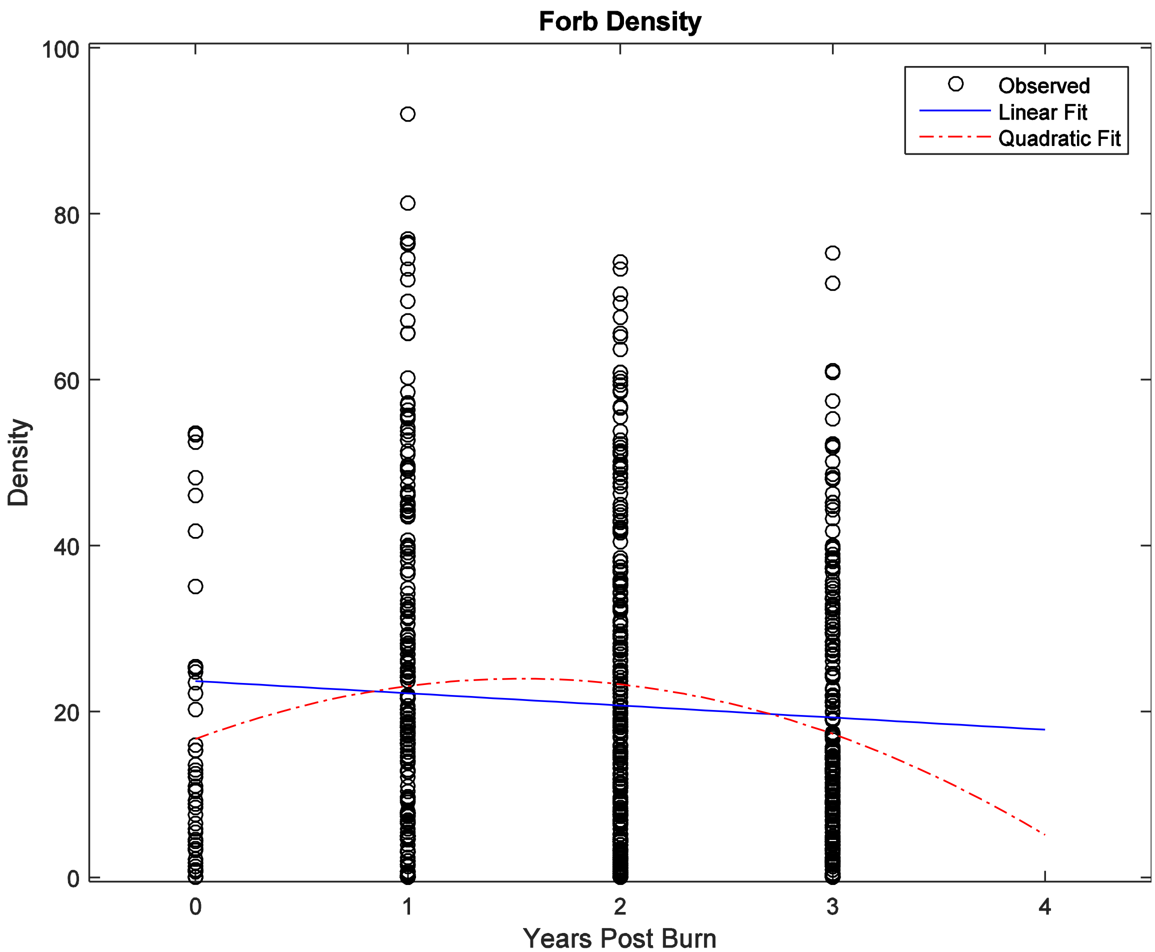
Appendix F-12. Broadcast burn treatment regression model showing linear and quadratic curves of annual grass height against years post-burn.



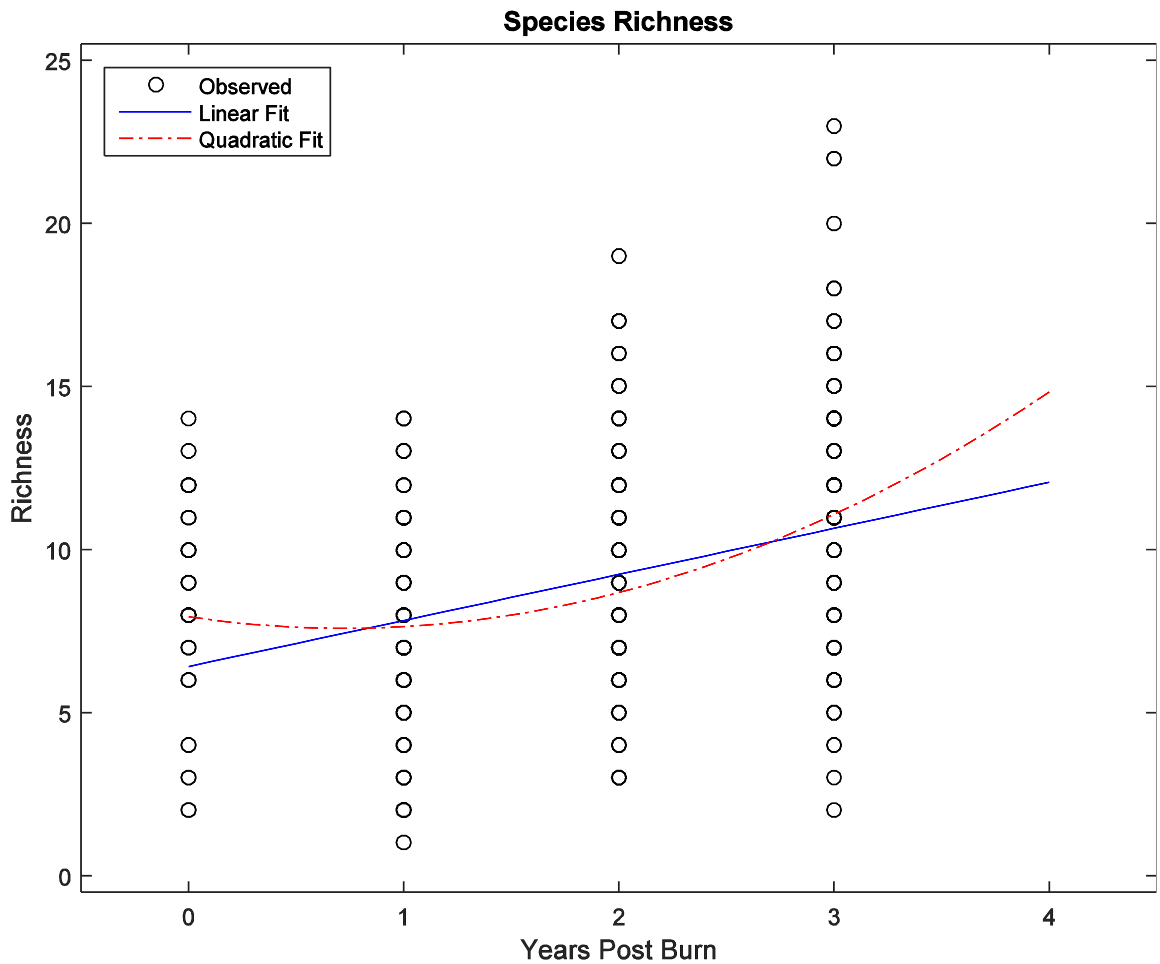
Appendix F-13. Broadcast burn treatment regression model showing linear and quadratic curves of velvet mesquite height against years post-burn.



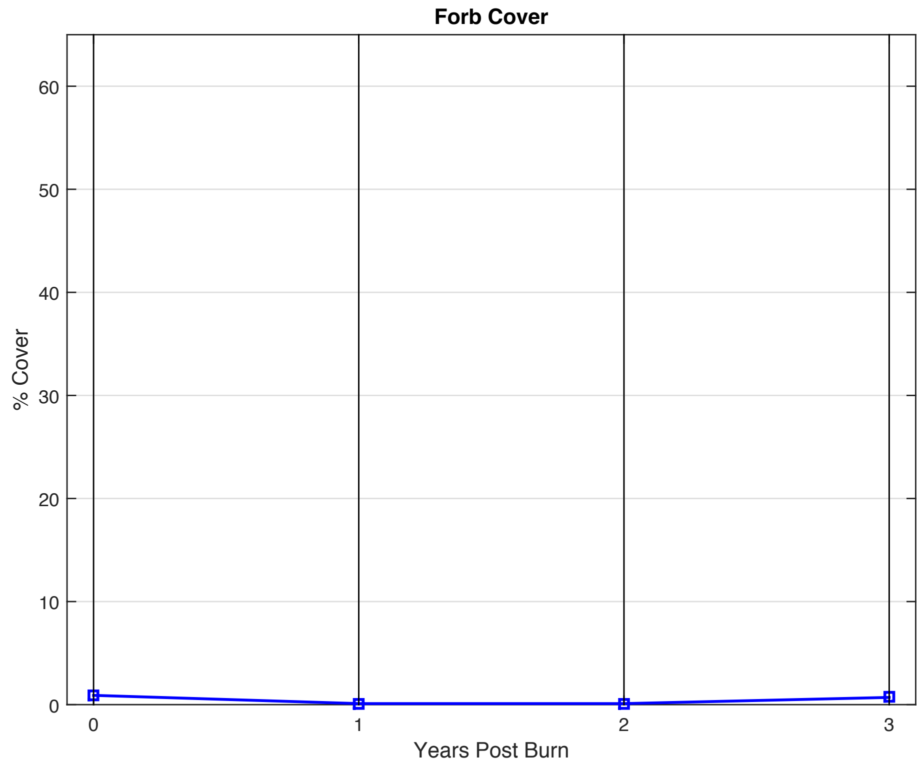
Appendix F-14. Broadcast burn treatment regression model showing linear and quadratic curves of velvet mesquite density against years post-burn.



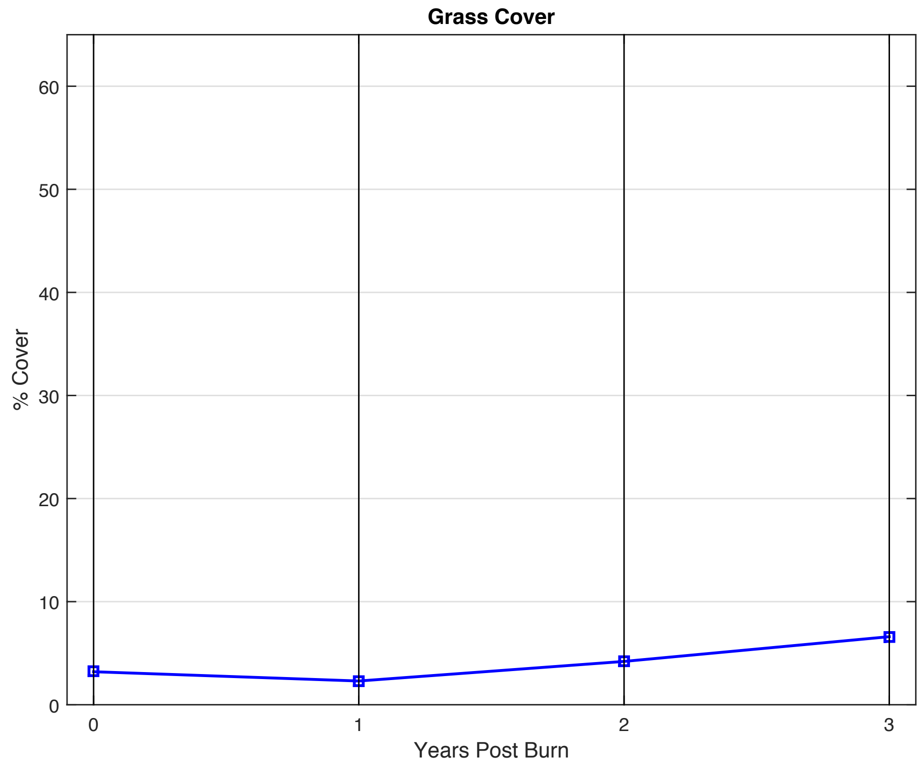
Appendix F-15. Broadcast burn treatment regression model showing linear and quadratic curves of forb density against years post-burn.



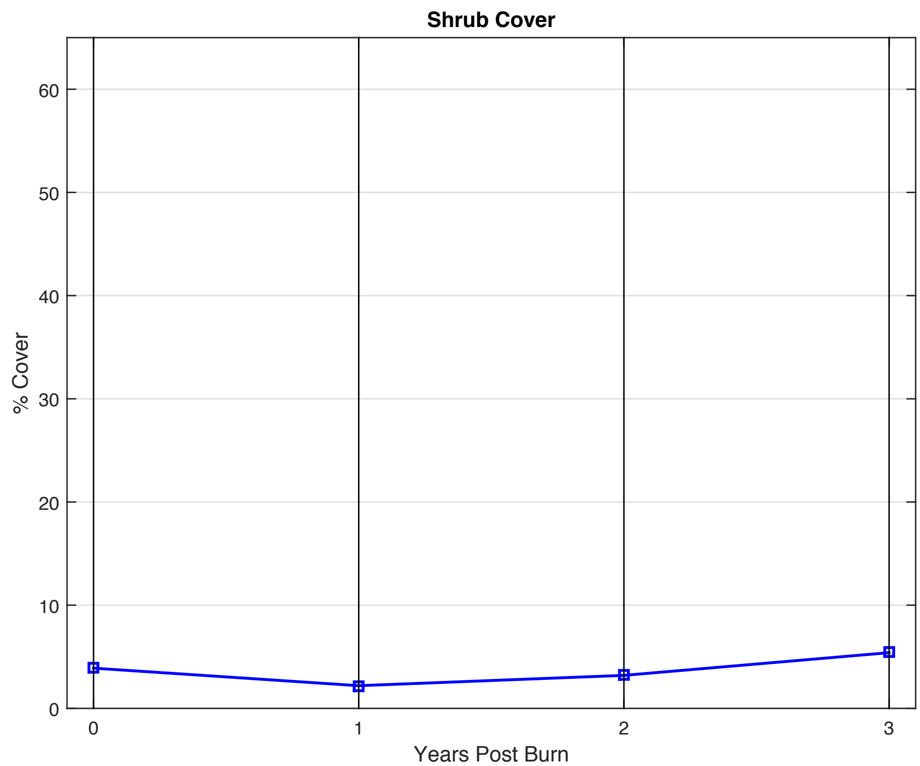
Appendix F-16. Broadcast burn treatment regression model showing linear and quadratic curves of species richness against years post-burn.



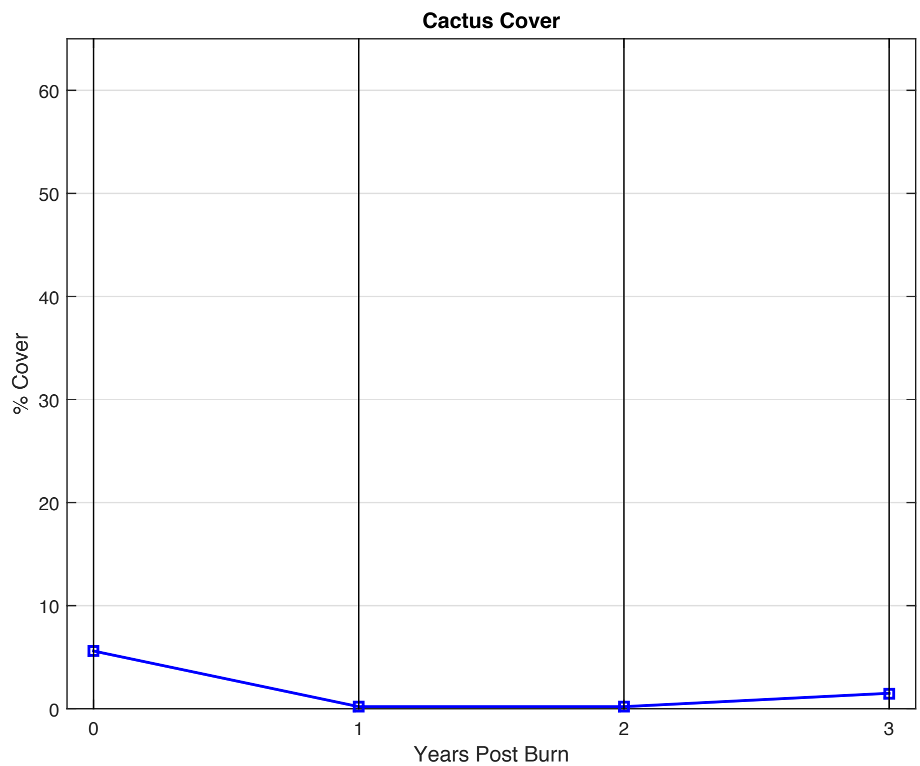
Appendix F-17. Broadcast burn treatment percent forb cover against years post-burn.



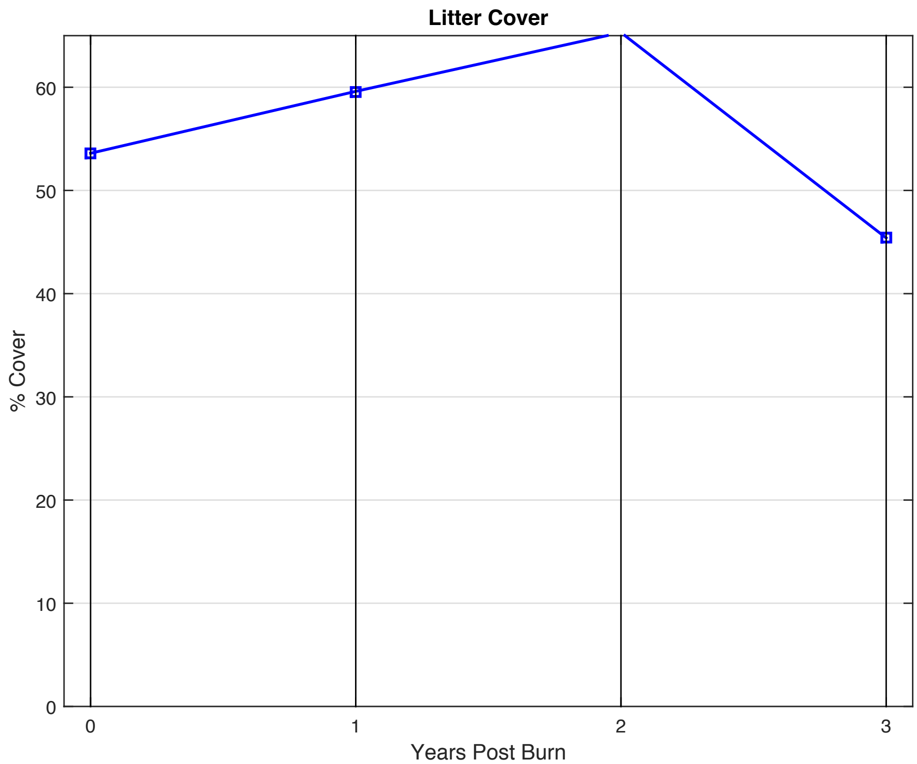
Appendix F-18. Broadcast burn treatment percent grass cover against years post-burn.



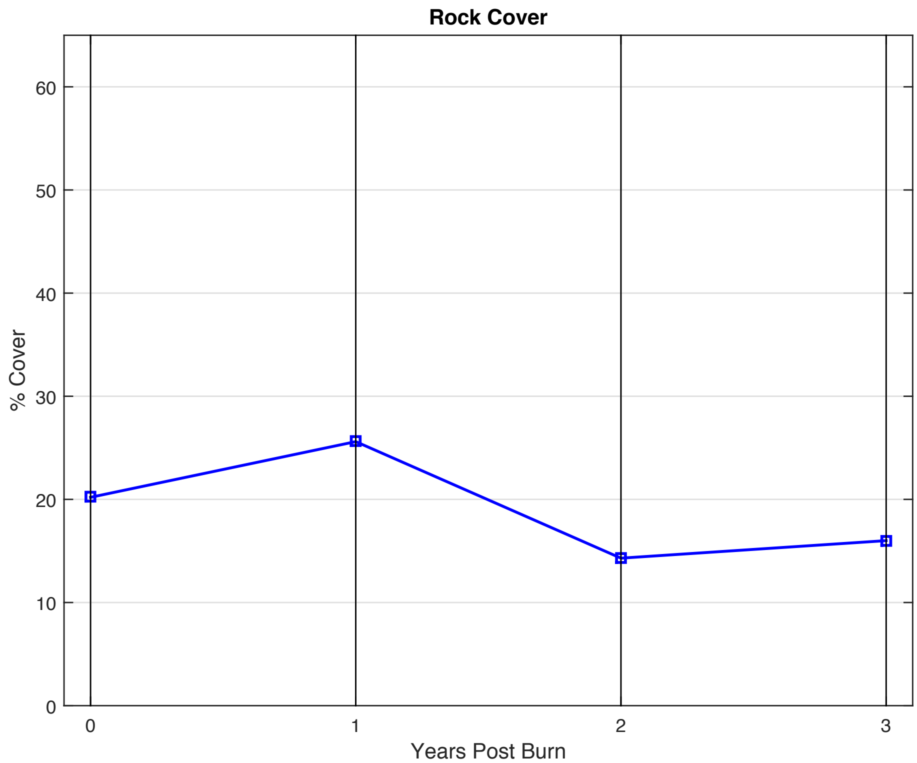
Appendix F-19. Broadcast burn treatment percent shrub cover against years post-burn.



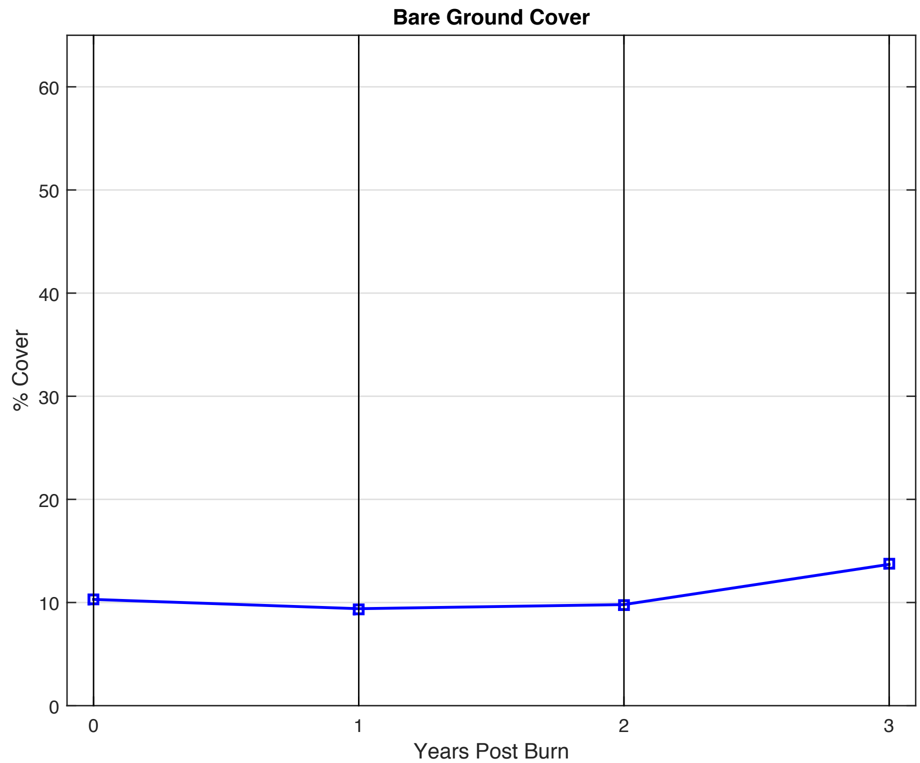
Appendix F-20. Broadcast burn treatment percent cactus cover against years post-burn.



Appendix F-21. Broadcast burn treatment percent litter cover against years post-burn.

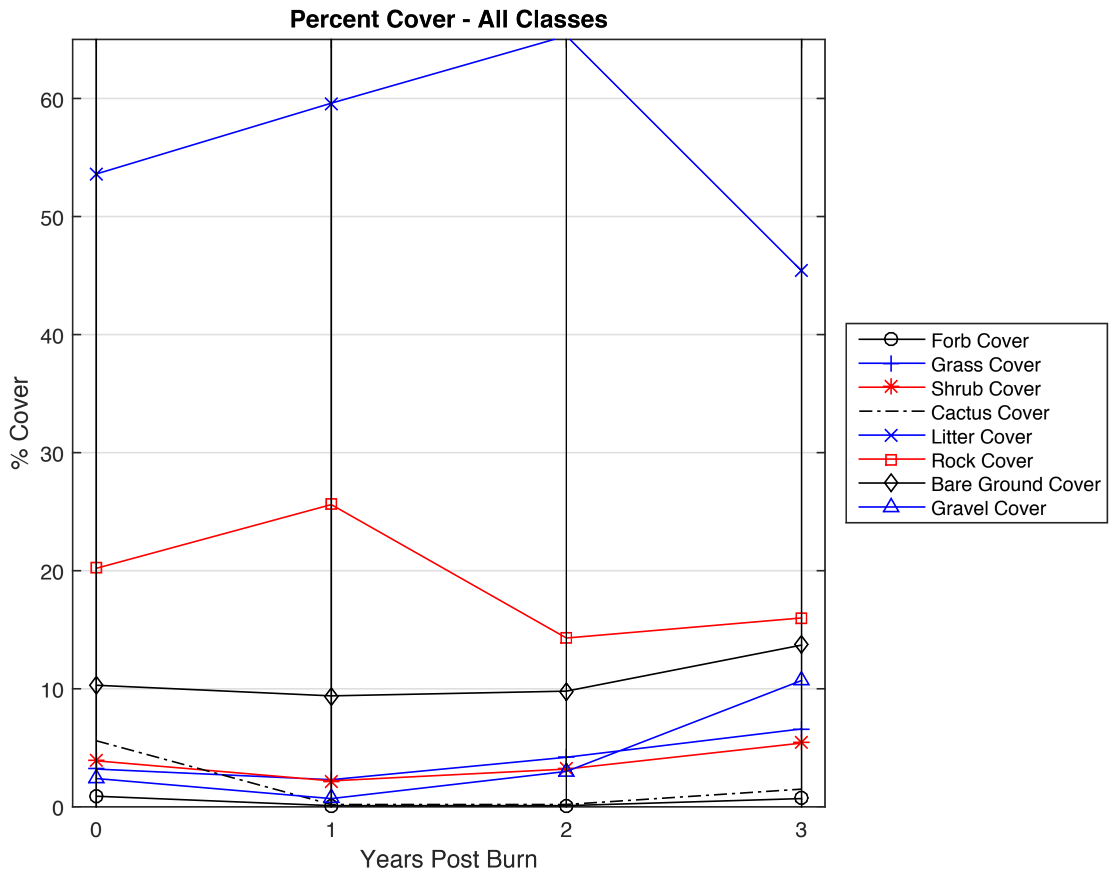


Appendix F-22. Broadcast burn treatment percent rock cover against years post-burn.



Appendix F-23. Broadcast burn treatment percent bare ground cover against years post-burn.

Appendix F-24. Broadcast burn treatment percent gravel cover against years post-burn.



Appendix F-25. Broadcast burn treatment with all classes of percent cover overlaid against years post-burn.