Semi-arid Grasslands Vegetative Community Response to Prescribed Broadcast Burns and Juniper Thinning and Pile Burning in Central Arizona

by

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ABSTRACT

Grassland habitat restoration activities are occurring within the semi-arid grasslands of the Agua Fria National Monument located 65 km north of Phoenix, AZ. The goal of these restoration activities is to reduce woody species encroachment, remove lignified plant materials and recycle nutrients within the ecosystem thus improving range conditions for both wildlife species and livestock. Broadcast burning, juniper thinning and slash pile burns are the principle tools used to accomplish resource objectives. Line cover, belt transect, densities, heights and biomass of vegetation data were collected to determine the response of the vegetative community to habitat restoration activities. Principal Component Analysis (PCA) was used to reduce data analysis to the more influential factors.

Regression analysis was conducted for statistically significant response variables. Quadratic regression analysis found low predictive values. In broadcast burn treatment units, all important factors as identified by PCA had low predictive factors but significantly differed ($R^2 <0.01$, $p<0.05$) between unburned and the years post treatment. Regression analysis found significant, albeit weak, relationships between time since treatment and independent variables. In pile burn treatment units, data reduction by PCA was not possible in a biologically meaningful way due to the high variability within treatment units. This suggests the effect of juniper encroachment on grassland vegetation persists long after junipers have been cut and burned.

This study concluded that broadcast burning of the central Arizona grasslands does significantly alter many components of the vegetative community. Fuels treatments generally initially reduced both perennial woody species and grasses in number and height for two year post fire. However, palatable shrubs, in particular shrubby buckwheat, were not significantly different in broadcast burn treatment areas. The vegetative community characteristics of juniper encroached woodlands of central Arizona are unaffected by the removal and burning of junipers aside from the removal of hiding cover for predators for multiple years. It is recommended that habitat restoration activities continue provided the needs of wildlife are considered, especially pronghorn, with the incorporation of state and transition models specific to each of the respective ecological site descriptions and with the consideration of the effects of fire to pronghorn fawning habitat.

KEY WORDS: Antelope, Disturbance Response, Grassland, Fire, Forb, Juniper, Tobosa, Pronghorn, Woody Species, Shrubby Buckwheat

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

INTRODUCTION

The Agua Fria National Monument (AFNM) is located approximately 64 km north of the Phoenix metropolitan area. Designated in January of 2000, the Monument encompasses “rich human history” and “expansive mosaic of semi-desert grassland, cut by ribbons of valuable riparian forest” and is noted as containing “outstanding biological resources” (BLM 2010). The AFNM is home to a wide variety of wildlife species, many of which are game species. Typical game species encountered include white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), javelina (*Pecari tajacu*), mountain lion (*Puma concolor*) and pronghorn antelope (*Antilocapra americana*); a focal species of the AFNM.

Management objectives set forth by land and game managers in the semi-desert grasslands of the AFNM and surrounding central Arizona grasslands are focused on improving habitat for pronghorn which are a grassland obligate species. Over the past decade, pronghorn numbers across the state of Arizona have been below target levels and pronghorn fawn recruitment has been lower than the goal of 30-40 fawns: 100 does (AZGFD 2006). Consequently, many management actions have taken place to improve pronghorn numbers within the area.

Projects specifically intended to improve pronghorn habitat have occurred since the mid-1990s. Actions include animal transplants (Ockenfels et al. 1996), wildlife water installations and vegetation manipulation actions. In the late 1990’s, pronghorn from Utah and Wyoming were released within the area to improve population numbers and increase genetic diversity (Ockenfels et al. 1996). Habitat improvement actions have been accomplished through the selective application of both prescribed burns (and the application of resource benefit wildfire), juniper thinning and subsequent pile burning. Pronghorn are thought to benefit from a reduction in woody species (Courtney 1989; Ockenfels 1996; Barstow et al. 2006; Warnecke 2006). Juniper thinning is thought to reduce hiding cover for predators such as mountain lion which are known to cause high mortality rates in adult pronghorn (Ockenfels 1994) and open movement corridors for pronghorn (AZGFD 2010). Also, the application and use of fire is thought to improve tobosa (*Pleuraphis mutica*) dominated semi-desert grasslands through the removal lignified plant material, reduction in woody species and improvement of important forage resources for pronghorn.

Since 2008, an average of 800 hectares of tobosa dominated grasslands has been burned and 60 hectares of juniper treatments has occurred each year. These treatments have been expected to improve pronghorn habitat, but recent drought and lack of data on the effectiveness of treatments has brought the practice into question. In order to determine the effects of land management actions within the AFNM, it is critical that response of the vegetative community prescribed burning and juniper thinning is understood.

STATEMENT OF THE PROBLEM

Little information exists on how land management actions are affecting the vegetative community which compose important pronghorn habitat within the Agua Fria National Monument. With declining pronghorn populations and lower than desired fawn:doe ratios, it is necessary to examine the impacts of broadcast burning and juniper tinning to the vegetative community upon which pronghorn depend. Without knowledge of the effects of management actions on vegetative community, it is difficult to justify ongoing prescribed burning and juniper thinning actions.

HYPOTHESES

It is hypothesized that both broadcast burns and juniper thinning will have a significant effect on many important habitat values for both wildlife and livestock. Both broadcast burns and juniper thinning/pile burning are expected to exhibit a statistically significant difference when comparing the stratified treatments in time since treatment. Broadcast treatments are stratified as follows, pre burn, one year post treatment, two years post burn, and three years post burn. Juniper thinned and pile burned treatments are stratified into pre burn, immediately post burn, one year post pile burn, and two years post pile burn. Broadcast treated areas are predicted to have a reduction in perennial grasses, shrubs, cactus, and trees immediately following treatment but increase as time progresses. Forbs and annual grasses are expected to increase in biomass in the subsequent year following treatment but decrease in time as other perennial species out compete annuals and occupy habitat. Pile burns are expected to have an immediate and long term reduction in woody species which will not statistically vary between treatment years. This should be an obvious relationship due to the fact that juniper trees are selectively being cut and burned. Annuals, including forbs, are predicted to initially increase in the following years after piles are burnt, but decrease overtime as perennial grasses and shrubs occupy burn scars.

REVIEW OF LITERATURE

It is well documented and understood that grassland ecosystems have been maintained through frequent disturbances such as periodic wildfire and grazing by large ungulates (Yoakum 1979; Roberts and Tiller 1985; Courtney 1989; Cook et al. 1994; Erichsen-Arychuk et al. 2002; Valone et al. 2002; Hassler 2006). However, many grassland ecological dynamics have been altered by livestock. Over utilization caused a reduction in fire frequency as a result of inadequate fine fuels to carry fire and fire suppression activities.

The increase in grazing pressure coupled with a reduction of wildfire resulted in much of the former grasslands to become invaded by woody plants and species that are less palatable and less preferred by both wildlife and livestock. Over utilization often results in woody species and non-palatable shrub encroachment. Once established, woody species and shrubs cause an overall reduction in production (Peters et al. 2006), carrying capacity, and altered ecological function (Bates et al. 2007; Davies et al. 2010; Notaro et al. 2012), and often a switch to an altered state as identified by state and transition models (Hassler 2006).

Woody species and increaser shrubs, shrubs that are less palatable, increase in numbers as palatable shrubs, perennial grasses and forbs are removed by grazing or as fire is removed from the landscape (Brown and Archer 1999; Peters et al. 2006; Notaro et al. 2012). The continued use of preferred herbaceous species by livestock compound the problem by: eliminating these species and palatable shrubs through over utilization, increasing interstitial spaces between grass patches which opens up unoccupied area for pioneer and increaser species to establish (Brown and Archer 1999); and the alteration of ecosystem processes which perpetuate the altered state (Hassler 2006).

Woody species such as creosote (*Larrea tridentata*), Mesquite species (*Prosopis sp*.), juniper species (*Juniperus* sp.), and snakeweed (*Gutierrezia sarothrae*) commonly invade over utilized range lands (Brown and Archer 1999; Peters et al. 2006). Peters et al. (2006) found that snakeweed abundance increases in blue grama (*Bouteloua gracilis*) grasslands following the over utilization of the dominate grass. This was attributed to an increase in bare patches and a reduction in soil moisture as a result of the removal of blue grama ground cover. This result contradicts the conclusion of Brown and Archer (1999) that found little relationship between creosote expansion and perennial grass cover. Loeser et al. (2004) found that defoliation due to clipping or grazing increased above ground production in some perennial grasses.

Wildfire is an integral part of the grassland ecosystem and has been reduced if not eliminated in many portions of the landscape. Fire is essential to maintaining the balance between the different vegetative communities (Smith-Thomas 2006; Hassler 2006; Bates et al. 2007; Ravi and D'Odorico 2009; Davies et al. 2010), but when the frequency is greater than the natural variability, fire can cause native perennial grassland degradation (Armas and Pugnaire 2005).

Fires frequently burns in a heterogeneous pattern resulting in complex biotic communities at a landscape scale. Areas affected by fire are often very different when compared to adjacent to unburned areas (Pyke et al. 2010). Ecosystem succession states can be totally different in contiguous habitats as a result of the mosaic pattern of wildfire.

The ecosystem response is dependent upon not only initial conditions such as fuel loading but also fire behavior. Differences in the effects of fire create a diverse range of abiotic factors such as light, water, nutrient availability, pH, as well as soil temperature profile; all of which can be drastically altered by the removal of vegetation by fire (Ahlgren and Ahlgren 1960). Fire intensities can range from low to extreme. Low intensity fires often have little effect on woody species that are fire adapted species (Valone et al. 2002) or the available seed bank (Gonzalez and Ghermandi 2008). Microclimatic factors in low intensity fires can be similar to unburned areas with similar light and moisture retention levels but with an influx of soil nutrients. Conversely, intense fires often denude an area of vegetation, remove the seed bank and sterilize the ground. Extreme fire causes an increased solar radiation levels, moisture loss, water/wind erosion and temperature extremes in comparison to less severely burned or unburned areas (Fielder et al. 2007). This results in biotic and abiotic dissimilarities in comparison to unburned areas. Thus, differential successional pathways can be expressed (Cattelino et al. 1979; McAuliffe and King 2010). A spectrum of fire intensity can occur across a landscape which results in a varied fire effect (Erichsen-Arychuk et al. 2002; Pyke et al. 2010).

The response of wildlife to fire is varied. Large animals such as mule deer (*Odocoileus hemionus*) and bighorn sheep (*Ovis canadensis*) as well as bird species simply vacate an area before fire moves through (Petersen and Best 1987, Holl et al. 2004; Thatcher et al. 2006). Small vertebrates such as small mammals and herpetofauna do not have the mobility to escape a fire and are more susceptible to mortality losses, (Crowner and Barrett 1979; Russell et al. 1999; Esque et al. 2003). However, many species were noted to have adaptive strategies such as burrowing and habitat selection which reduce losses. Amphibians, with their wet habitat preference, simply wait out the fire under water (Russell et al. 1999). Burrowing animals such as rodents, snakes and desert tortoises *Gopherus agassizii* (Esque et al. 2003) avoid the direct effects of fire hiding below ground or in rocky areas that do not burn.

Following the initial impacts to wildlife and the habitat upon which they depend, the varied effect of fire on the landscape results in a mosaic of habitats (Valone et al. 2002; Suding et al. 2004; Pyke et al. 2010). Wildfire alters important wildlife needs such as hiding/foraging cover, thermal cover, and forage availability; all of which may vary both temporally and spatially.

These different patches may be preferentially selected, avoided or neutral to wildlife. Wildlife use is dissimilar between the extremes, both of which are drastically different than in unburned areas. One explanation of this phenomenon is the adaptation of plant and animal species to fill different habitat niches. Some species are considered pioneers which exploit a newly created habitat. Other species require a mid-seral stage with the establishment of higher plants and a developed soil configuration (D'Antonio and Chambers 2006). Still other species are late seral obligates and are dependent upon plant and animal species to be at a climax in structure with dominant tree species as the major overstory. Since fire frequently acts in a mosaic pattern, all stages of succession can be present in a relatively small area (Ravi and D'Odorico 2009).

Fire has been applied to the landscape for resource benefit in the semi-desert grasslands of central Arizona. Both large scale broadcast burns, juniper thins and subsequent pile burns have occurred since the mid 2000s. The goal of these projects is to restore grassland communities and improve habitat for pronghorn. Fire has been selected as the preferred restoration tool because of the relative low cost, high benefit and ability to treat large areas. Broadcast burns are implemented on grasslands with a low tree component whereas juniper thins/pile burns occur in areas were juniper trees have encroached. Broadcast burns maintain grasslands by preventing woody species encroachment and releasing nutrients for grasses and forbs which are typically sequestered in lignified plant tissue (Cook 1994; Valone et al. 2002; O'Brien et al. 2006). Juniper thins and subsequent pile burns are used to convert woodlands back into grasslands. Pile burns are used to kill the root crown of junipers that would otherwise be unaffected by fire.

Management goals have focused on the improvement of rangelands through a reduction of woody species and in increase of native herbaceous species. Many of these goals have been developed and implemented to benefit pronghorn which are characteristic of the grasslands. Although not an ecosystem driving species, pronghorn are indicative of healthy grasslands, and may be reflective of the quality of the habitat.

METHODS

STUDY AREA

This study is focused within the Agua Fria National Monument (AFNM). The 28,000 ha AFNM is located 64 km north of Phoenix, AZ located between Black Canyon City to the south and Cordes Lakes to the north (Map 1). The AFMN was designated in 2000 because of the rich cultural and biological resources (BLM 2010). Important landscape features found within the Monument are Perry Mesa, Joe's Hill, Sycamore Mesa, and the Agua Fria River and its tributaries. Mesa tops are dominated by tobosa grasses.

The study area falls within both the Sonoran Desert Major Land Resource Area (MLRA 40) and the Mogollon Transition Zone (MLRA 38) (Natural Resource Conservation Service accessed 2011). The southern portion and canyon walls of the area comprise the upland desert scrub habitat type (MLRA 40). The focus of this study falls within MLRA 38 which is dominated by semi-desert grasslands, savanna desert scrub, juniper woodlands. Soils are mixed but typically Barkerville series in granitic hills and Cabezon-Springerville associations in basalt clay uplands which overlay Precambiran granitics.

Precipitation ranges from 25.4 cm–33.2 cm annually (Figure C-1). The distribution of rain is bimodal with summer monsoons that occur between July and August and winter storms which are most frequent between November and February (Yavapai County Flood Control District accessed Nov. 2012). Rain gauge data was collected from in Cordes Lakes, AZ which is directly north of the AFNM. Below average precipitation for multiple years occurred prior to data collection (Figure C-1). Elevation of the AFNM ranges between 660 m to 1400 m. and study plots were located within higher portions of the AFNM. Average temperature range between 20 and 21.5 centigrade (Figure C-2).

Understory vegetation frequently consists of tobosa grass (*Pleuraphis mutica*), threeawns (*Aristida* sp.), grama grasses (*Bouteloua* sp.), and an abundance of forbs interspersed with woody shrubs such as shrubby buckwheat (*Eriognonum wrightii*), globe mallow (*Sphaeralcea ambigua*), snakeweed (*Gutierrezia sarothrae*), and many prickly pear cactus species (*Opuntia* sp.) and cholla (*Cylindropunita* sp.). Cat-claw acacia (*Acacia greggii*), velvet mesquite (*Prosopis velutina*) and one-seed juniper (*Juniperus monosperma*) dominate hill slopes and can be found interspersed within the grasslands. Many non-native plants have established and now dominate portions of the study area. These species include wild oat (*Avena fatua*), filaree (*Erodium cicutarium*), and red brome (*Bromus rubens*). Riparian gallery forests dominated by Gooding's willow (*Salix gooddingii*), Fremont's cottonwood *(Populus fremontii*) and other riparian obligate species occupy canyon bottoms.

The AFNM is home to a wide variety of wildlife species. Nearly 200 bird species have been recorded on the monument. Many native fish thrive in the canyons of the AFNM as well as an abundance of herpetofauna. Typical game species that can be encountered include white-tailed deer mule deer, javelin, mountain lion and pronghorn antelope which are one of the focal species of the AFNM and surrounding central Arizona grasslands.

The AFNM contains slightly over 6800 ha of land designated as pronghorn fawning habitat. This area is located in the central part of the AFNM and extends to lands managed by the Tonto National Forest. Fawning grounds are typified by flat to gentle slopes which are dominated by tobosa grass and generally devoid of woody species.

The AFNM also encompasses over 3600 ha that have been identified and designated as pronghorn movement corridors. These areas are generally rolling hills and moderately steep canyon sides where it is expected that pronghorn use to travel to more desirable habitat juniper trees dominate the landscape and contribute to almost all of the over story canopy.

STUDY DESIGN

Study plot locations were stratified by habitat type. The two main habitat types which were subjected to two different types of habitat restoration efforts. First, the mesa tops are characterized by tobosa grasslands. In an effort to prevent woody species encroachment, 1200 ha broadcast burns have been applied prior to the summer monsoon season. Secondly, the granitic and basalt hills in the northern portion of the area are dominated by juniper trees. In an effort to reduce juniper densities and improve habitat permeability for pronghorn, juniper cuts and subsequent slash pile burns have been implemented. Areas treated for juniper approximate to 121.5 ha and are typically burned in the winter months.

FIELD DATA COLLECTION

Geographic Information Systems (GIS) software was used to randomly select 0.01 ha plots at a density of one plot every 15 ha. Sample plots within each treated area further stratified by year since treatment (broadcast burn plots n= 556 and pile burn plots n = 107). The broadcast burn treatment units sampled included an unburned area (n=50), one year post burn (n=219), two years post burn (n=136), and three years post burn (n=151). Juniper treated areas were sampled at pre-burn (n=18), immediately post burn (n=49), one year post treatment (n=20), and two years post treatment (n=20). Vegetation data was collected between March and August of 2012

At each random sample location, a randomly placed a 0.01 ha (25 m x 4 m) macro plot, was established to collect vegetation data. Along the midline of the macro plot data on ground cover by plant species was collected using a 25 m line intercept method. Data on woody species density by species were collected within the 0.01 ha plot. Herbaceous species density by species was determined using four 0.5 m^2 circular micro plots placed at five meter intervals along midline of the macro plot. Biomass production by species was estimated in each micro plot using a double sampling method with the vegetation of all four micro plots being collected from every fifth macro plot. These samples were collected by species within each micro plot, stored in paper bags, weighted and transported to the laboratory where they were dried at 50° C for 48 hr and reweighed to adjust field biomass estimates. See Table C-1 for list of plant species encountered.

STATISTICAL ANALYSIS

Statistical analysis was conducted with SPSS 19 and SPSS 22 by SPSS Inc.. Principal Component Analysis (PCA) was used to determine the primary contributing factors in the dataset. Factors with an absolute component score matrix of >0.3 were considered important. Once important factors were identified by PCA, further combination of similar factors were combined were data were insufficient to calculate statistics. Analysis of Variance (ANOVA) was conducted in broadcast burn grasslands and juniper treated areas because no covariate was identified as important which included both precipitation and mean growing season temperature. Significant factors were then regressed with quadratic regression analysis.

Data were also combined when information for biologically similar attributes was needed to answer important landscape and habitat management questions. Data on tree densities, tree heights, palatable shrub densities, increaser shrub heights, total shrub densities, cacti densities, forb densities, forb biomass, annual grass biomass, annual grass height, annual grass densities, perennial grass biomass, perennial grass height, and perennial grass densities were summed at each plot to determine the effects of treatments on biologically important habitat and wildlife values.

RESULTS

Results of principal component analysis (PCA) of both broadcast treated areas and pile burn treated areas varied between treatment stratifications (Figures A-1 and B-1). In the broadcast burn treatment areas, seven components explained over 96 % of the variability in the dataset (Table A-1). Data had to be aggregated in juniper pile burn treatment units by vegetation classification/form to determine important component factors. Once aggregated, six components explained 71 % of the variability of the juniper pile burn treatment units (Table B-1). A component score matrix with an absolute individual component score coefficient values of ≥ 0.3 were used to identify important habitat variables.

Both precipitation and mean growing season temperature were thought to possibly be covariate's to the independent variable and included in the PCA. In the broadcast burn unit, PCA did not identify precipitation or temperature as an important factor. Consequently, precipitation and temperature were removed and covariates for further analysis in both broadcast burn treatment areas and juniper thinned areas.

BROADCAST BURN RESULTS

Of the total of 97 habitat variables measured, twelve variables were identified as important in the seven important components identified by PCA in broadcast burn treatment which explained 96% of the variability in the data set (component score coefficient value of ≥ 0.3) (Table A-2). These habitat variables were cat-claw acacia density, tree density, total shrub densities, shrubby buckwheat density, palatable shrub density, snakeweed density, increaser shrub density, cacti density, Toumey's agave density, perennial grass height, annual grass density, and annual grass height (Table A-2 and Figure A-1). Further statistical analyses were concentrated on these twelve habitat variables identified by PCA. Analysis of variance (ANOVA) and regression analysis was used to test the predictive ability using quadratic regression analysis of variables that were significantly different between the treatment units.

Of the twelve habitat variables identified in the PCA, all except palatable shrub density and shrubby buckwheat density were significantly different ($\alpha = 0.05$, $p<0.05$) (Table A-2). All significant factors had predictive values (R^2) < 0.1 (Table A-3). Cat-claw acacia densities (Figure A-2), tree densities (Figure A-3), cacti densities (Figure A-8), perennial grass height (Figure A-9) and annual grass densities (Figure A-11) decreased in years 1 and 2 post fire and increased in year 3 post fire. Snakeweed (Figure A-4), increaser shrubs (Figure A-5), and total shrubs densities (Figure A-6) slightly decreased in the 1 year and 2 year post fire followed by a slight increase at year 3 year post treatment. However, outliers in year three make conclusions about increaser shrub densities difficult.

Quadratic regression analysis results of Toumey's agave density were significant but weakly predictive ($R^2 = 0.017$, $p < 0.002$) Toumey's agave densities were greatest in the year 3 post treatment (Table A-3, Figure A-7). However, Toumey's agave was only found in the 3 post burn treatment area and is not likely a predictive response variable.

Annual grass height was the only significant response variable to increase for the first two years post fire followed by an overall decrease by the third year (Table A-3, Figure A-10).

JUNIPER PILE BURN RESULTS

In juniper pile burn treatment areas, many shrubs, perennial grasses, cacti, and trees species seen in the grasslands were rarely encountered. Because many species were rarely encountered, sample size was not adequate to calculate statistical values.

PCA results determined that it took 27 components to explain 85 % of the variability in the data with an absolute component score threshold of ≥ 0.3 (Table B-1). The first component comprised of 15 response variables which only explained 7 % of the variability (Table B-2). Additionally, the second component which comprised 11 response variables at the absolute value of ≥ 0.3 only explained an additional 6% of the variability of the data (Table B-1).

Data reduction by PCA was not possible in a biologically meaningful way. Even when the absolute value component score used to identify important variables was increased to ≥ 0.7, it took over seven components and five response variables to explain only 35% of the variability in the data set (Table B-1, Table B-2). Since the variability of response variables in juniper pile burn treatment areas were so great, further statistical analysis was not conducted.

DISCUSSION AND SUMMARY

The vegetative community response to habitat treatments varied between both treatment types and in time since treatment in reference to pretreatment condition. The two stratified treatments did not have similar statistic results. Independent variables in broadcast burn areas were often statically different whereas those in juniper pile burn treated areas were not. Consequently, the effects of fuels treatments are not similar across the two treatment stratifications and conclusions about the effects of broadcast burning on grasslands cannot be carried over to juniper treatments event though many of the vegetative species are similar.

Principal Component Analysis (PCA) of broadcast burn treatment areas found that much of the variability in the data can be explained by specific species like shrubby buckwheat, cat-claw acacia densities but aggregated data were often much more important (Table A-2, Table B-2). Factors were considered important if their respective absolute component value were >0.3. Prior winter's precipitation was not identified as an important factor by PCA in broadcast burn treatment area and was removed as a factor in juniper and pile burn treatment areas due to the close spatial proximity to the broadcast burn areas. Consequently, precipitation was removed as a covariate and analysis of variance (ANOVA) was conducted for important factors in broadcast burn treatment units.

Post hoc pairwise comparisons of the broadcast burn treatment yielded statistically different and biologically important results. Post hoc analysis in juniper pile burn treatment areas supported the lack of statistical difference. Consequently, regression analysis was possible for the broadcast burn treatment stratification and not possible for the juniper and pile burn treated areas.

The effects of broadcast fuels treatments on grasslands had many biologically important and statistically significant results. Densities and heights for many of the vegetation classes significantly differed ($\alpha=0.05$, $p<0.05$). Cat-claw acacia densities, total tree densities, snakeweed densities, increaser shrub densities, Toumey's agave, cacti densities, perennial grass height, annual grass height, and annual grass densities significantly differed between treatment units of broadcast burned areas. Regression analysis yielded insight on how these variables change through time.

Tree densities and cat-claw acacia densities were found to respond to broadcast fuels treatments. It was found that both were significantly reduced the first two years post treatment (Figure A-2, Figure A-3) but by year 3 post treatment. This study concludes that woody species initially respond to broadcast burn fuels treatments for two years following fire. Both densities and heights are reduced which is one of the primary resource management goals for grassland restoration in the grasslands of the AFNM. Many woody species that are found within the grasslands of the AFNM are fire adapted species, particularly cat-claw acacia and velvet mesquite. Because of this adaptation, it may be necessary to treat woody species encroachment on semi-desert grasslands with an alternative restoration method for longer term results.

Interestingly, shrubby buckwheat, a key forage species for pronghorn did not significantly differ within the broadcast burn treatment areas (Table A-3). Even when aggregated with all palatable shrubs which included are key forage species wildlife such as mule deer and pronghorn, results were not significant with ANOVA in broadcast burn treatment units. Due to the lack of significant difference between treatment years and pre burn status, no regression analysis was conducted. Biomass on key browse species was not conducted, it is expected that there was a reduction in palatable shrub biomass following initial burning but recovered through time. These results indicate that many of the palatable shrub species are fire adapted.

Unlike palatable shrubs, increaser shrub densities and snakeweed significantly differed between treatment years and pre-burn status (Table A-2). The densities were significantly reduced the first two years following treatment (Table A-3). By the third year post treatment, increaser shrub density was not significantly different that the pre-burn status (Figure A-4, Figure A-6).

Total shrub densities were statistically different differed in broadcast burn treatment areas (Table A-2). Quadratic regression analysis indicates shrub numbers, both increaser and palatable, take two years to recover in number (Table A-6). However, it is likely that increaser shrubs are dominant in the data and cause the ANOVA results of total shrub densities to be significantly different.

Cacti densities were found to differ significantly (Table A-3). Quadratic regression analysis shows a significant reduction in cacti densities the first two years following fire (Table A-2). By the third year post fire, cacti densities were higher than initial pre-burn conditions (Figure A-8). This result may be an artifact of the soils within 3 years post burn unit which had a higher calcium content and expected higher cacti density. Additionally, in the 3 year post fire treatment block, a large number of Toumey's agave were encountered. These agave did significantly differ between the treatment areas. However, it is likely that their inclusion in the total cacti densities artificially drove up densities through time. It is possible that the removal of these agave from the aggregated cacti group would either change cacti from an important factor to an unimportant on or have a significant and persistent decrease in cacti densities through time. Courtney (1989) that found fire did not affect cacti densities which is likely the case with the semi-desert grasslands of central Arizona.

Perennial grass height was found to be significantly different (Table A-3, Figure A-9). Both the unburned and third year post fire had an approximate perennial grass height of 10 cm. Following fire, the first and second year had an overall reduction in perennial grass height which averaged about 5 cm. It is likely that drought conditions played a role in the lower perennial grass height.

Annual grass height significantly varied between the treatment years (Table A-3). Annual grass was statistically different and greatest in year 1 post treatment. Average height was at a maximum in the one year post burn treatment area and had an average height of nearly 20 cm. This suggests that annual grasses were exploiting the newly exposed habitat resulting from fire. By year 2 of post fire, there was a minor decrease in height which was similar to the un-burned area which averaged about 15 cm. As other vegetation classes recovered from the fire and increased in densities and size, along with intraspecific competition from other annual grasses, heights likely decreased through time.

Also of note, annual grass densities were less in all of the burned treatment areas (Figure A-11). Although not critical for adult pronghorn, hiding cover is necessary for neonates (Warnecke 2006). Pronghorn fawns are very susceptible to coyote predation (Loeser et al. 2004, Jacques et al. 2005) and parturition is known to coincide with the spring green up (Ticer et al. 1996). This is especially true if groundcover requirements are not met. Jacques et al. 2005, in a study in South Dakota, found that vegetation or other hiding objects are an important component for vertical and horizontal fawn concealment. The vegetative component of cover can be reduced for multiple years following fire (Erichsen-Arychuk et al. 2002) and is consistent with this study but not always (Fischer et al. 1996). Increases in annual plants may suffice for hiding cover in the absence of perennial grasses but are often rain dependent. McKinney et al. (2008) found that winter precipitation is a limiting factor for pronghorn fawn recruitment. The combination of both fire and drought likely negatively affect pronghorn fawn recruitment in the central Arizona grasslands.

In pile burn treatment units, Principal Component Analysis found that many response variables contributed to the variability of the data set (Figure B-1). The percent of the variance explained by the each of the components was low. It took 27 components to explain 84 % of the variability of the data with each component explaining between one and seven percent of variability (Table B-1). Data reduction by PCA was not possible in a biologically meaningful way. When the arbitrary absolute values of the component score matrix were at the extremes (|0.7|)(Table B-2), four response variables and ten components were needed explain less than 50 percent of the variability of the data. Absolute values less than 0.7 resulted in the labeling of many response variables as important factors. This suggests that juniper encroached grasslands have similar vegetative characteristics to pile burned areas for multiple years. The effect of juniper encroachment to grassland vegetative characteristics lasts for many years even after they have been cut and burned. This finding is similar to Brown and Archer (1999) that found height, aboveground biomass and seedling recruitment of woody species were comparable across all density, defoliation and watering combinations in a two year study.

These results suggest that the disturbance resulting from pile burning has a similar effect of standing juniper trees that out compete other vegetation classes. The effect of ground sterilization likely takes greater than three years to recover. These results are confounded by an ongoing drought that has likely hindered recovery (Figure 1-C). Horman and Anderson (1999) found that litter from juniper needles significantly reduced grass and shrub seed germination, not an allelopathic chemical factor. Litter was not a factor in burn scar colonization because it was removed by fire.

MANAGEMENT IMPLICATIONS

This study found that management objective for grassland restoration in the Agua Fria National Monument are being met in grassland areas and juniper encroached woodlands. In broadcast burn grasslands, wood species area being reduced by burning. Increaser shrubs are reduced for multiple year post fire but palatable shrubs such as shrubby buckwheat remain as a component of the landscape after fire. In juniper treated areas, the goal is to remove juniper trees to benefit pronghorn. This study concludes that the vegetative community is un-affected by the removal of junipers in juniper encroached woodlands. Also, this study suggests that it may take many years for the vegetative community to respond in these areas due to ground sterilization which is compounded by drought.

Grassland restoration efforts accomplished by the use of fire in grasslands and the use of hand crews of sawyers in juniper encroached woodlands are critical tools to restore and maintain the semi-desert tobosa dominated grasslands. However, careful thought and planning must occur to ensure management objectives are met. The use of these tools will affect the vegetative community, especially in grasslands. The overuse may cause landscape degradation and cause a shift to an alternate ecological state.

The effects of the application of fire and juniper pile burning undoubtedly affect wildlife. When the vegetative community is affected, the wildlife that depends upon that habitat will also be affected. For example, pronghorn antelope prefer open grasslands. In broadcast burn treated grasslands, woody species are reduced thus improving habitat quality. Since juniper thinning only appears to reduce the number of juniper and not the other vegetative characteristics, it is important for resource managers to identify where woodland treatments are being used by pronghorn to benefit that species. This will allow land managers to maximize the benefit to pronghorn and other grassland obligate species such as many grassland birds while minimizing costs.

Repeated measures are needed to gain a better understanding of the vegetative community response to both broadcast and pile burns. Data for this study was collected over one year. The time stratification of the treatment areas were of different areas. However, these areas are in close proximity to one another. These areas are likely very similar but do have different soil characteristics which will undoubtedly affect the vegetative community. Repeated measures of each of the treatment blocks will allow for landscape level habitat level predictions to be determined through the addition of the temporal component to the ecosystem because variables such as soil and other geographic features will be accounted for.

This study, an initial analysis of multiple post treatment, will serve to inform land management of the Agua Fria National Monument and associated central Arizona Grasslands. This study confirms that grassland restoration efforts accomplished by the use of fire are effective in grasslands. Additionally, this study affirms that juniper treatments are effectively removing hiding cover for predators and improving habitat permeability for pronghorn while largely not affecting other vegetative characteristics.

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APPENDIX A

DATA COLLECTED MARCH –AUGUST 2012

APPENDIX A

Table A- 1: Eigenvalues and variation of each component as derived from the principal component analysis of habitat data collected form broadcast burn grassland treatments areas on the Agua Fria National Monument, AZ in 2012.

	Initial Eigenvalues[a]			Extraction Sums of Squared Loadings		
Component	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	1429.913	41.474	41.474	1429.913	41.474	41.474
2	996.507	28.903	70.378	996.507	28.903	70.378
3	418.285	12.132	82.510	418.285	12.132	82.510
4	338.446	9.817	92.326	338.446	9.817	92.326
5	69.359	2.012	94.338	69.359	2.012	94.338
6	46.890	1.360	95.698	46.890	1.360	95.698
7	38.963	1.130	96.828	38.963	1.130	96.828

Table A- 2: Component score coefficients of the significant broadcast burn habitat variables identified by principal component analysis for the Agua Fria National Monument, Arizona to the period 2009 to 2012.

	Component						
Habitat Variable	1	2	3	4	5	6	7
Cat-Claw Acacia Density	.000	.001	.007	-.006	-.030	-.101	.331
Shrubby Buckwheat Density	.103	-.129	-.008	-.443	.063	-.059	.003
Broom Snakeweed Density	.186	-.101	-.010	.671	-.206	-.134	.121
Total Shrub Density	.474	-.372	-.003	.208	-.032	-.034	.048
Palatable Shrub Density	.109	-.123	-.011	-.442	.120	.016	-.096
Increaser Shrub Density	.150	.278	.004	-.113	-.363	-.916	.982
Tree Density	.000	.001	.009	-.006	-.024	-.097	.353
Cacti Density	.210	.333	.005	-.022	.542	1.335	-.433
Toumey's Agave Density	.148	.270	-.033	-.084	-.225	-.416	-.615
Annual Grass Density	.011	.002	.980	.002	.160	-.212	-.260
Perennial Grass Height	.001	.000	.015	-.006	.059	.564	.470
Annual Grass Height	-.001	-.005	.035	-.039	-.920	.397	-.102

Figure A- 1: Principal Component Analysis Component Plot of vegetation and weather data within broadcast burn treatment units of grassland areas of the Agua Fria National Monument, AZ 2012.

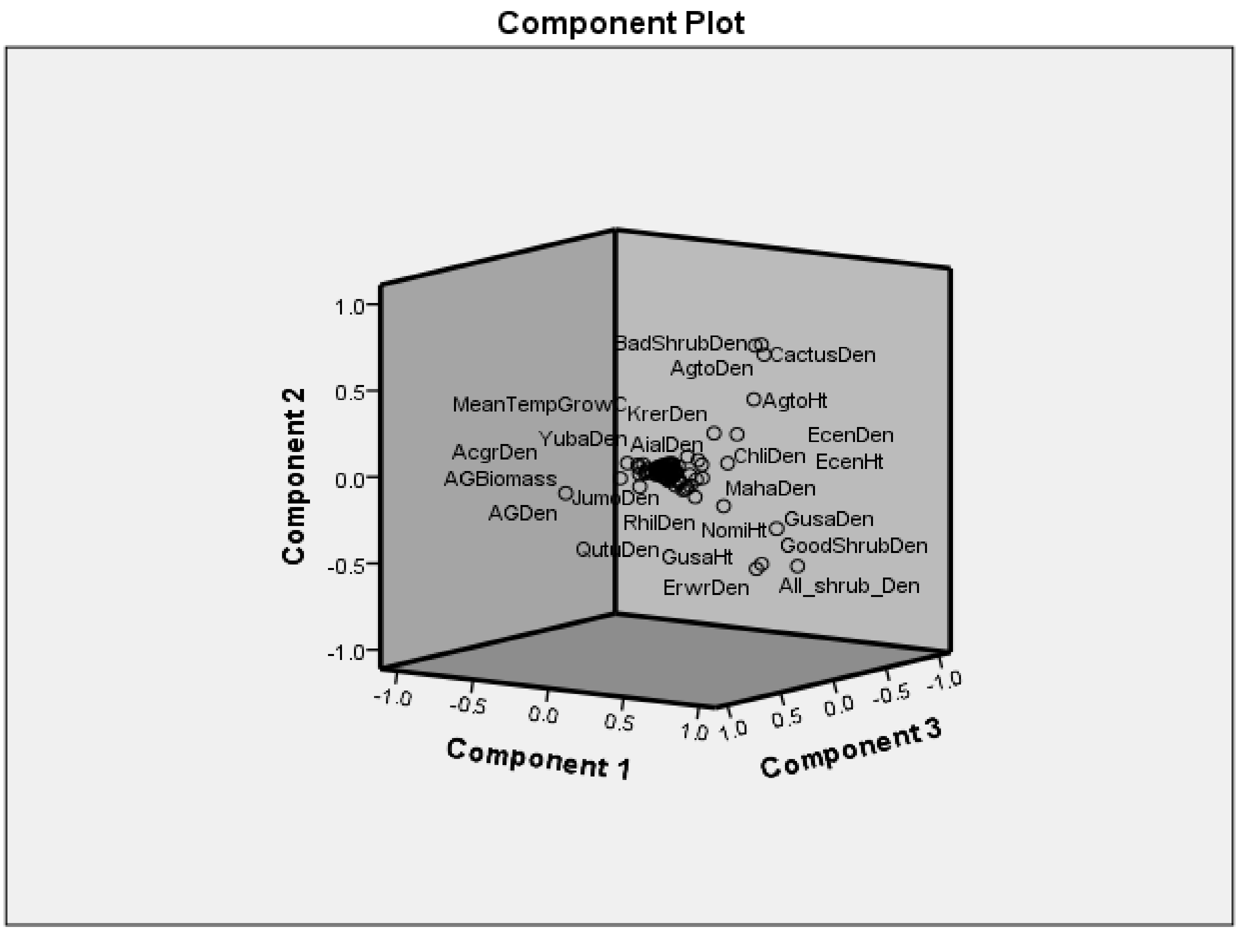


Table A- 3: Results of quadratic regression analysis (where x is time (years) post fire) by significant habitat variables in response to broadcast burning of grasslands within the Agua Fria National Monument, AZ, from 2009 to 2012.

Habitat Variable Regression Equation	$P <$	R^2	SE
Cat-Claw Acacia Density			
$Y = 6.089 -3.063(X) + 0.690(X^2)$	0.000	0.027	3.885
Tree Density			
$Y = 6.805 – 3.762(X) + 0.913(X^2)$	0.000	0.057	3.939
Broom Snakeweed Density			
$Y = 2.866 – 0.922(X) + 1.257(X^2)$	0.000	0.029	18.819
Increaser Shrub Density			
$Y = 7.201- 6.467(X) + 2.408(X^2)$	0.003	0.017	18.727
Total Shrub Density			
$Y = 9.961 + 3.738(X) + 0.122(X^2)$	0.003	0.017	27.624
Toumey's Agave Density			
$Y = 0.951 – 3.252(X) + 1.651(X^2)$	0.003	0.014	18.500
Cacti Density			
$Y = 10.428 – 15.662(X) + 5.698(X^2)$	0.000	0.081	20.455
Perennial Grass Height			
$Y = 9.702 – 5.628(X) + 1.718(X^2)$	0.000	0.054	6.164
Annual Grass Height			
$Y = 15.245 + 2.260(X) – 1.509(X^2)$	0.000	0.195	7.789
Annual Grass Density			
$Y = 42.956 – 28.681(X)+ 7.400(X^2)$	0.000	0.135	7.789

Table A- 4: Table of Analysis of Variance (ANOVA) results for important factors determined with Principal Component Analysis of vegetation response to broadcast burns of grasslands within the Agua Fria National Monument, AZ 2012.

Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Cat-claw Acacia Density	455.657	3	151.886	10.278	0.000
Tree Density	554.459	3	184.82	11.889	0.000
Shrub Density	9466.823	3	3155.608	4.133	0.007
Shrubby Buckwheat Density	1570.634	3	523.545	2.115	0.097
Palatable Shrub Density	1570.874	3	523.625	2.095	0.100
Increaser Shrub Density	4478.552	3	1492.851	4.258	0.005
Snakeweed Density	6819.541	3	2273.18	6.413	0.000
Tourmey’s Agave Density	4455.024	3	1485.008	4.356	0.005
Cacti Density	21382.092	3	7127.364	17.005	0.000
Perennial Grass Height	1336.236	3	445.412	11.738	0.000
Annual Grass Height	7754.109	3	2584.703	45.785	0.000
Annual Grass Density	28560.218	3	9520.073	26.463	0.000

Figure A- 2: Linear and Quadratic Regression Analysis graph of cat-claw acacia responses in broadcast burn treatment areas in the Agua Fria National Monument, AZ of data collected in 2012.

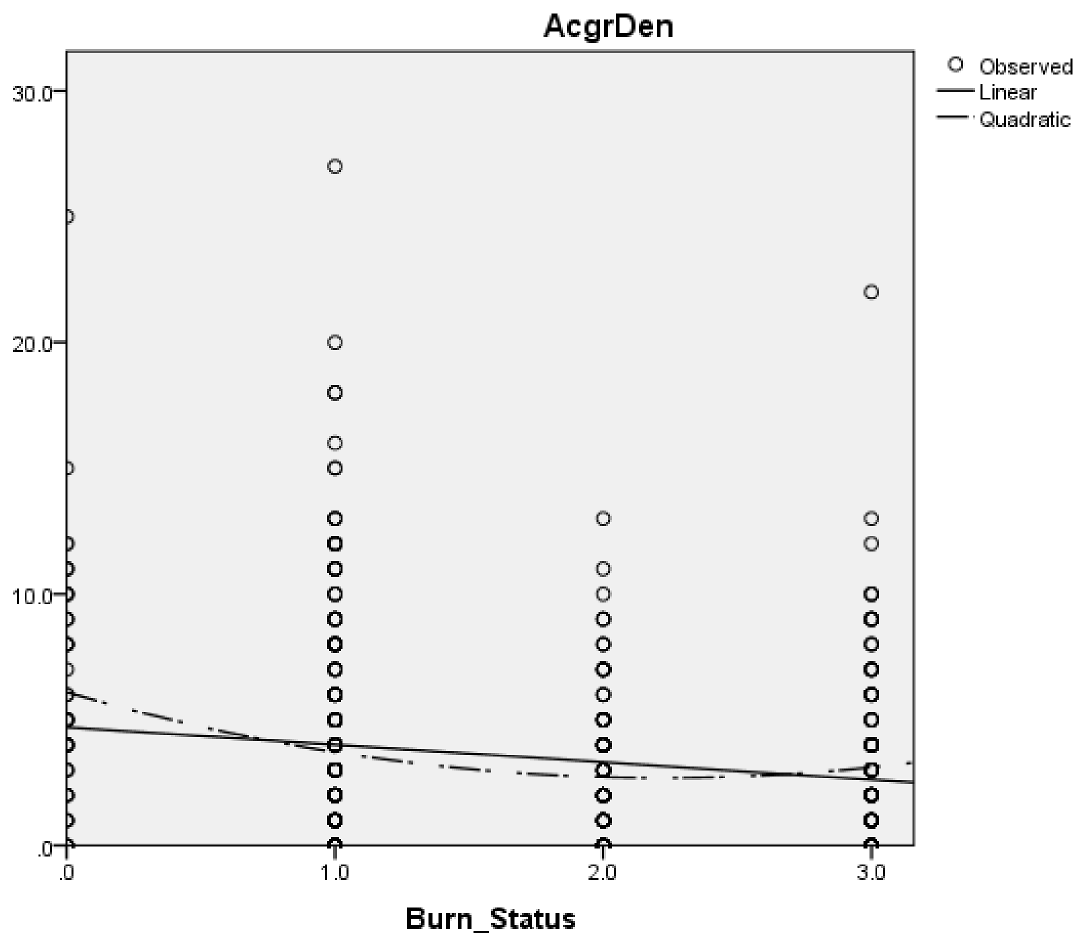


Figure A- 3: Linear and Quadratic Regression Analysis graph of tree responses in broadcast burn treatment areas in the Agua Fria National Monument, AZ of data collected in 2012.

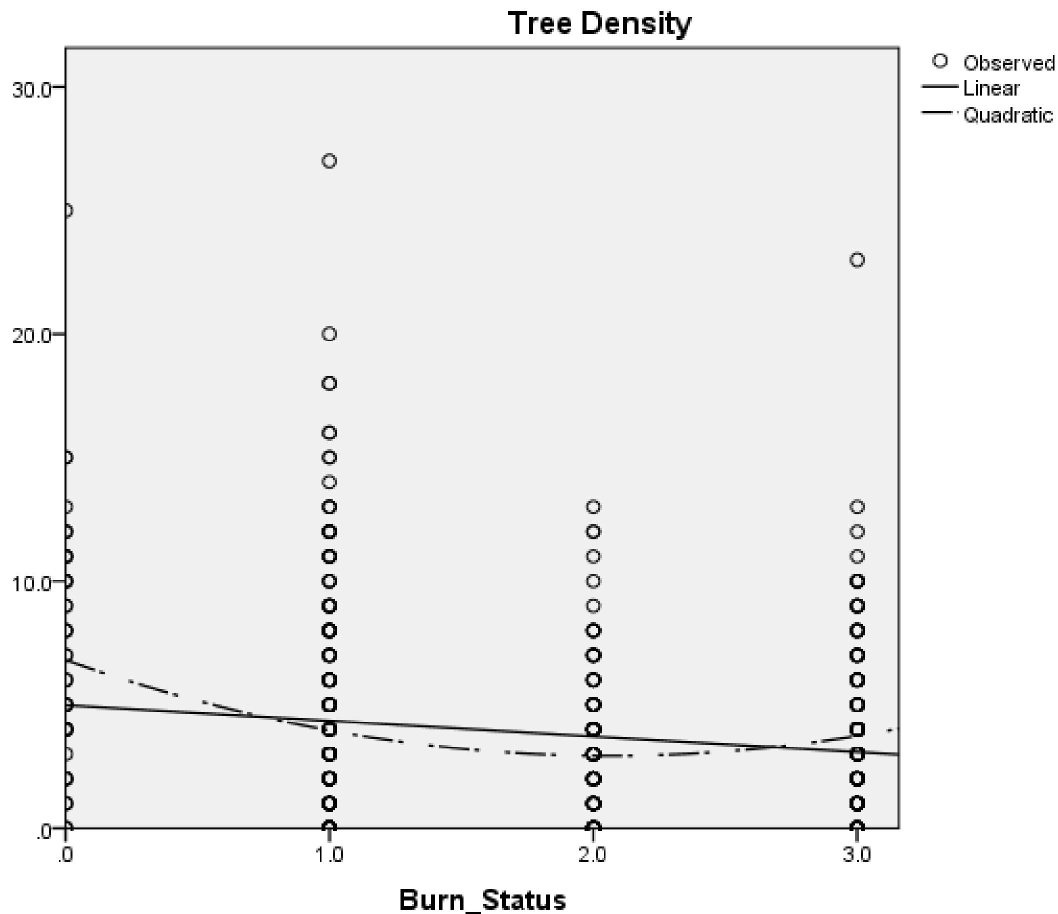


Figure A- 4: Linear and Quadratic Regression Analysis graph snakeweed responses in broadcast burn treatment areas in the Agua Fria National Monument, AZ of data collected in 2012.

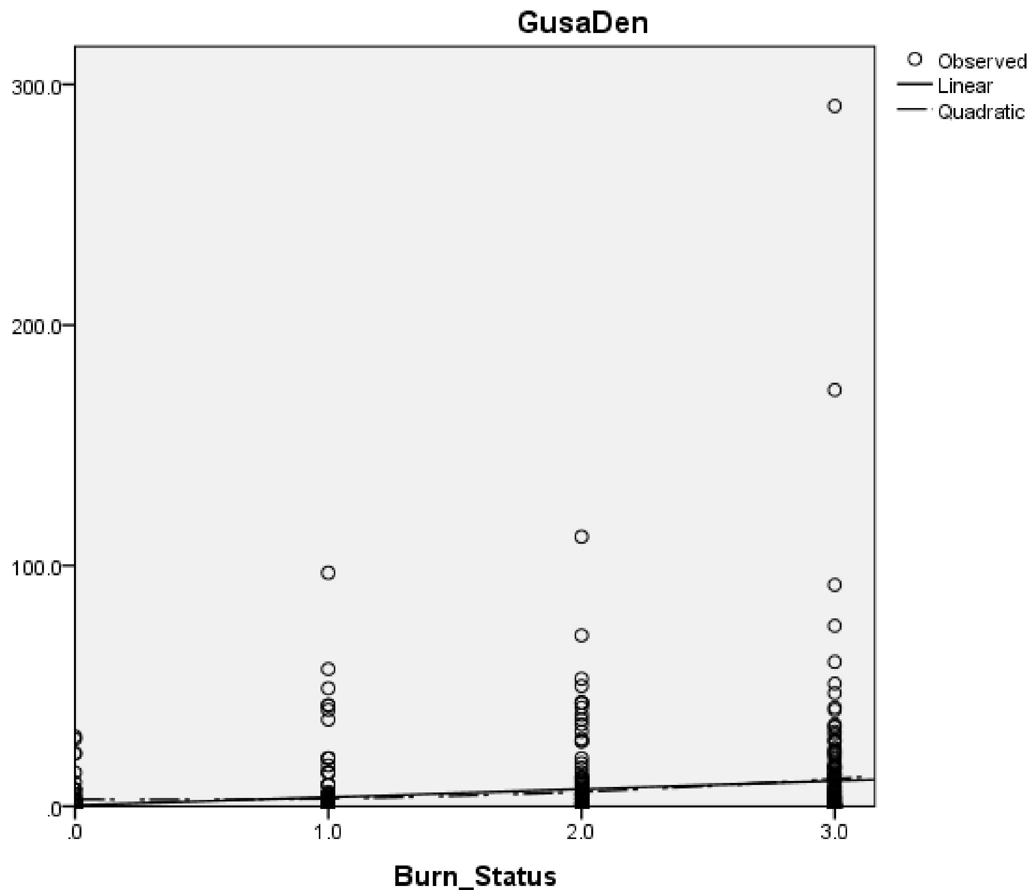


Figure A- 5 Linear and Quadratic Regression Analysis graph of increaser shrub responses in broadcast burn treatment areas in the Agua Fria National Monument, AZ of data collected in 2012.

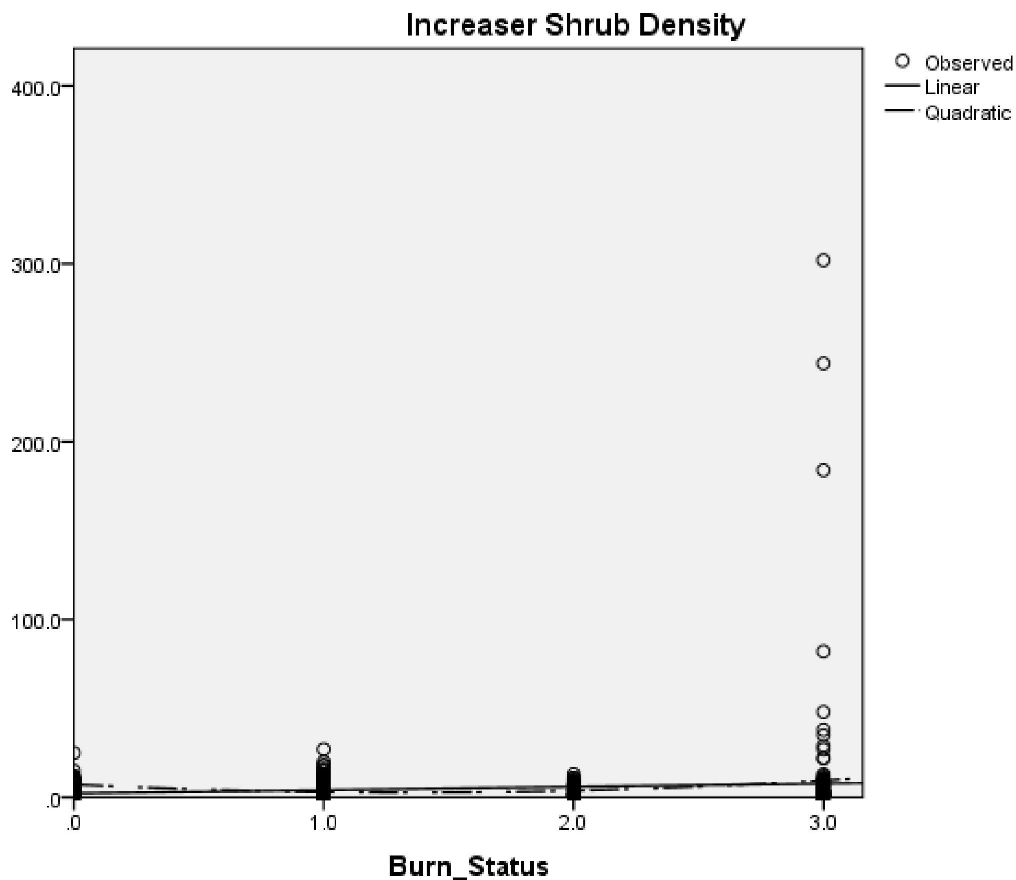


Figure A- 6 Linear and Quadratic Regression Analysis graph of total shrub density responses in broadcast burn treatment areas in the Agua Fria National Monument, AZ of data collected in 2012.

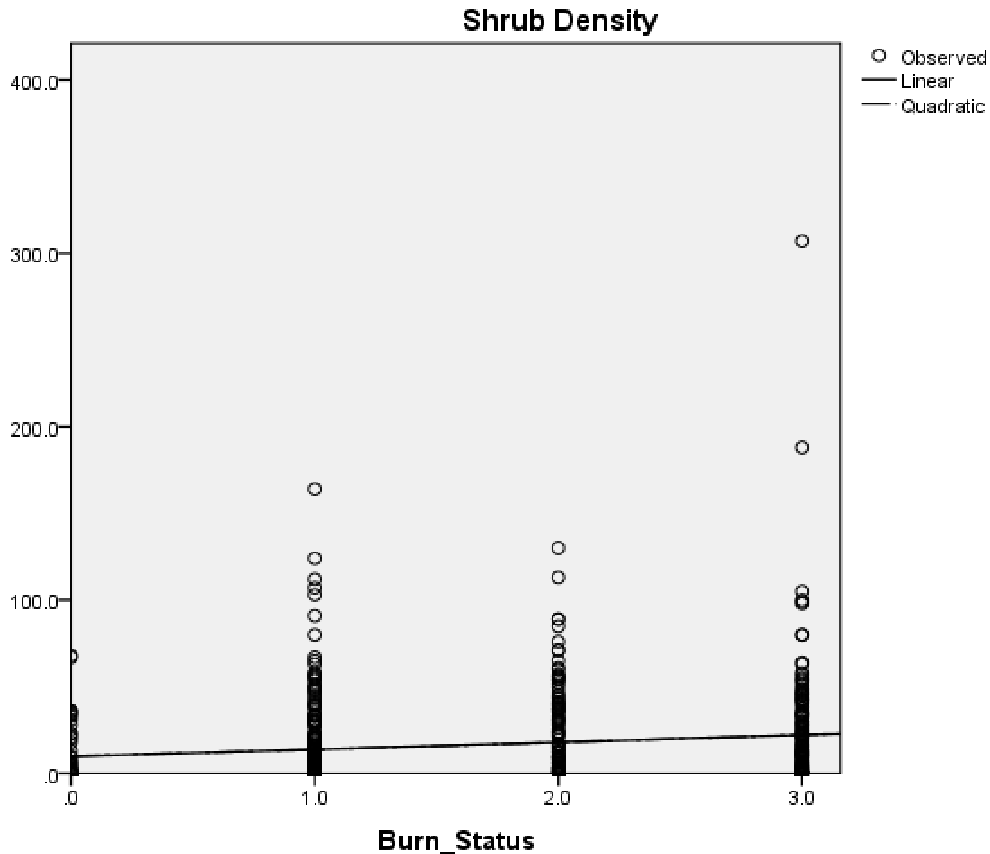


Figure A- 7 Linear and Quadratic Regression Analysis graph of agave toumeyana density responses in broadcast burn treatment areas in the Agua Fria National Monument, AZ of data collected in 2012.

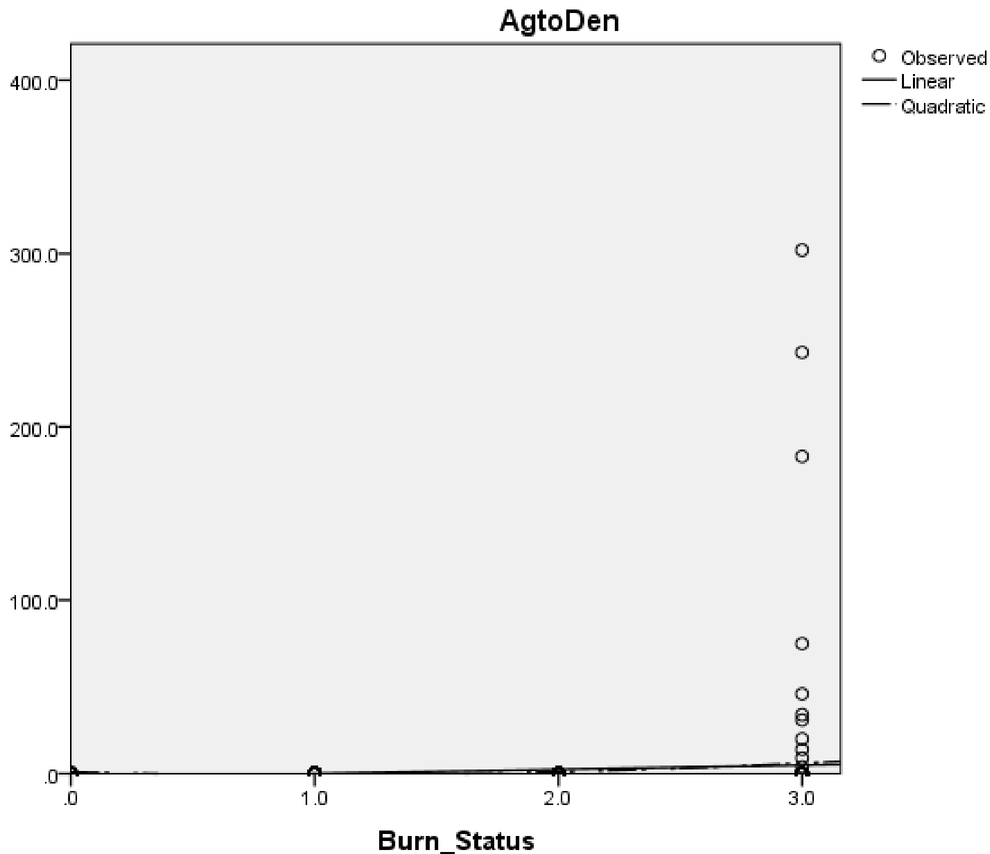


Figure A- 8: Linear and Quadratic Regression Analysis graph of cacti density responses in broadcast burn treatment areas in the Agua Fria National Monument, AZ of data collected in 2012.

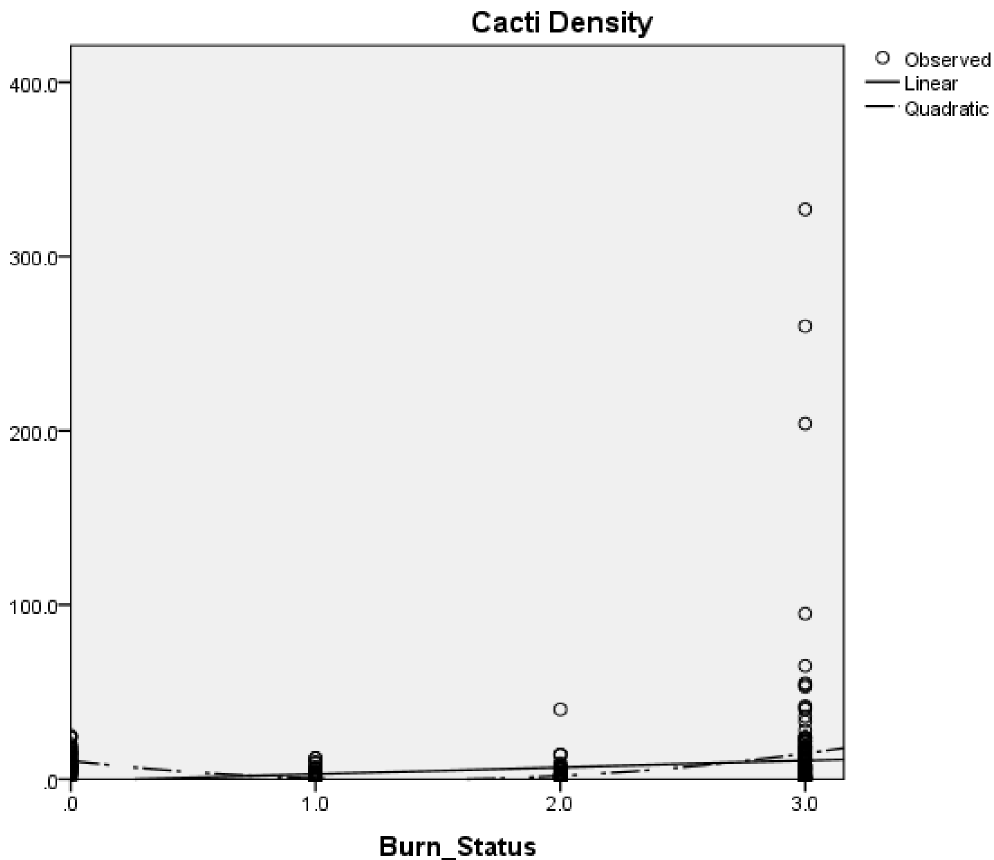


Figure A- 9 Linear and Quadratic Regression Analysis graph of perennial grass height (cm) responses in broadcast burn treatment areas in the Agua Fria National Monument, AZ of data collected in 2012.

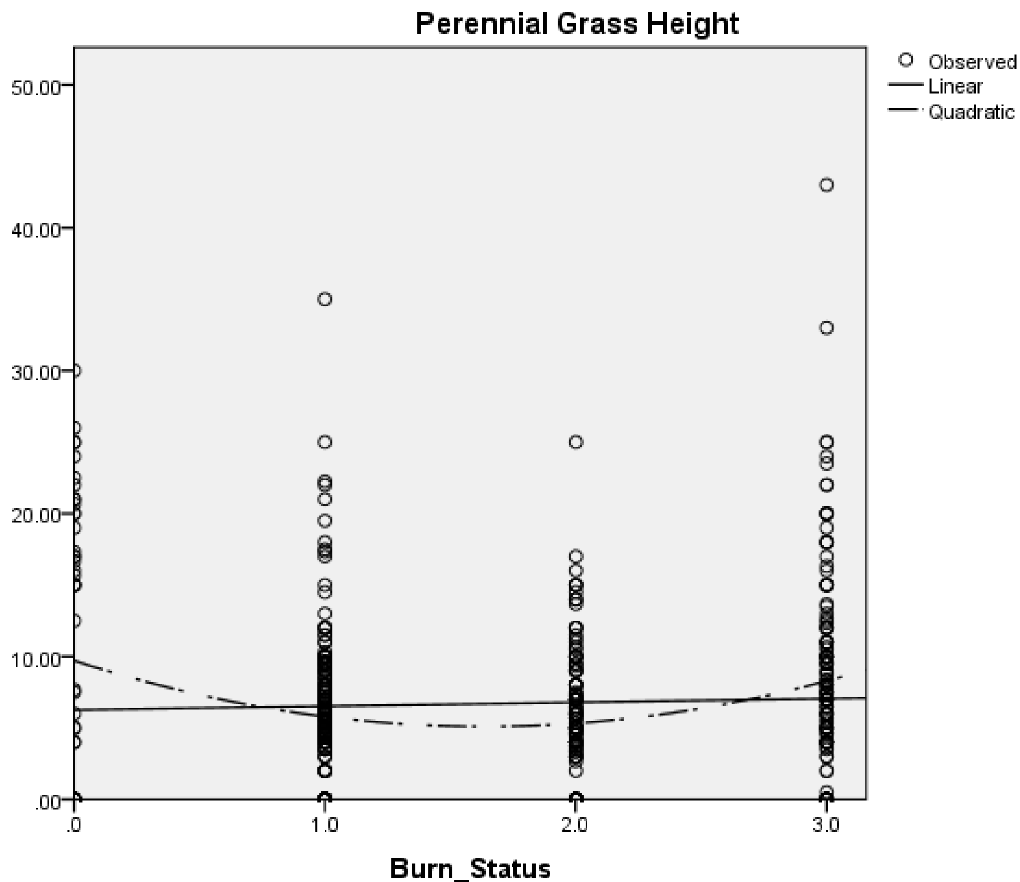


Figure A- 10: Linear and Quadratic Regression Analysis graph of annual grass height (cm) responses in broadcast burn treatment areas in the Agua Fria National Monument, AZ of data collected in 2012.

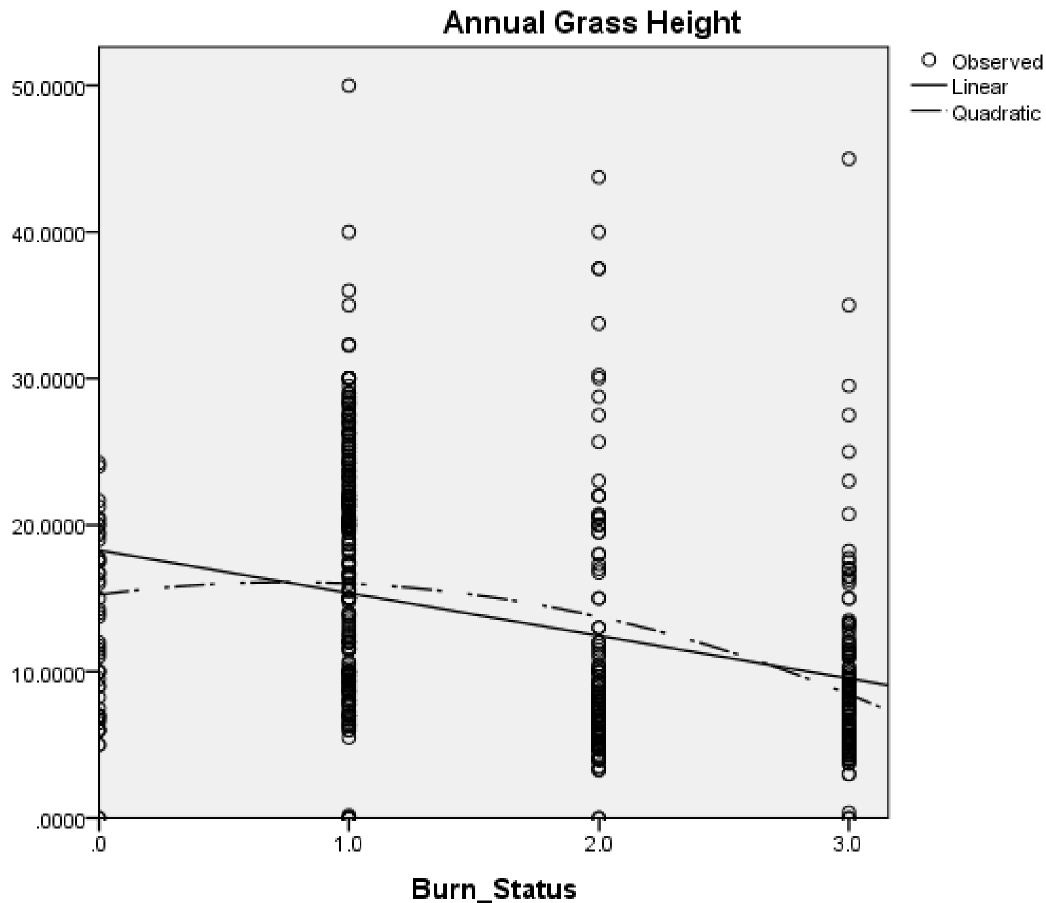
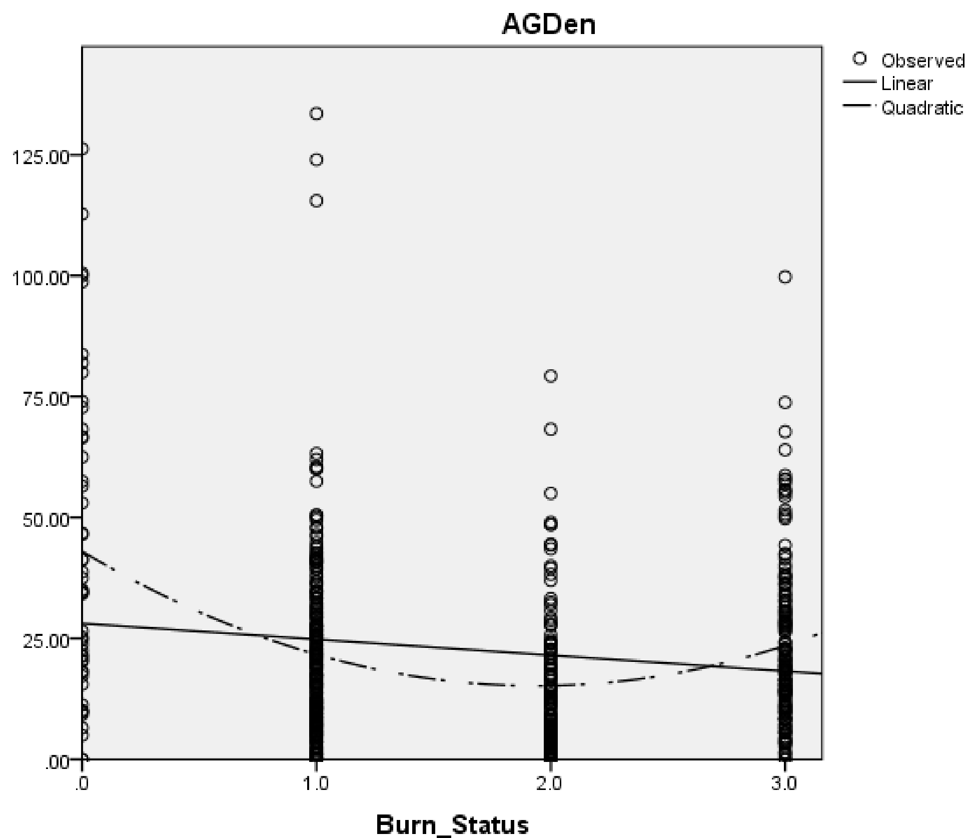


Figure A- 11. Linear and Quadratic Regression Analysis graph of annual grass density responses in broadcast burn treatment areas in the Agua Fria National Monument, AZ of data collected in 2012



APPENDIX B

DATA COLLECTED MARCH –AUGUST 2012

APPENDIX B

Table B- 1: Eigenvalues and variation of each component as derived from the principal component analysis of habitat data collected form juniper thinned and pile burned treatments areas on the Agua Fria National Monument, AZ in 2012.

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.408	7.116	7.116	5.408	7.116	7.116
2	4.829	6.354	13.470	4.829	6.354	13.470
3	3.971	5.225	18.695	3.971	5.225	18.695
4	3.638	4.787	23.482	3.638	4.787	23.482
5	3.396	4.469	27.950	3.396	4.469	27.950
6	3.062	4.030	31.980	3.062	4.030	31.980
7	3.000	3.947	35.927	3.000	3.947	35.927
8	2.963	3.898	39.826	2.963	3.898	39.826
9	2.564	3.374	43.200	2.564	3.374	43.200
10	2.533	3.333	46.533	2.533	3.333	46.533
11	2.387	3.141	49.674	2.387	3.141	49.674
12	2.272	2.989	52.663	2.272	2.989	52.663
13	2.244	2.953	55.615	2.244	2.953	55.615
14	2.096	2.757	58.373	2.096	2.757	58.373
15	2.012	2.648	61.021	2.012	2.648	61.021
16	1.938	2.550	63.570	1.938	2.550	63.570
17	1.891	2.488	66.058	1.891	2.488	66.058
18	1.761	2.317	68.376	1.761	2.317	68.376
19	1.679	2.209	70.584	1.679	2.209	70.584
20	1.590	2.092	72.676	1.590	2.092	72.676
21	1.568	2.063	74.739	1.568	2.063	74.739
22	1.469	1.933	76.672	1.469	1.933	76.672
23	1.369	1.802	78.474	1.369	1.802	78.474
24	1.269	1.670	80.144	1.269	1.670	80.144
25	1.149	1.512	81.656	1.149	1.512	81.656
26	1.114	1.466	83.122	1.114	1.466	83.122
27	1.004	1.321	84.443	1.004	1.321	84.443

Table B- 2: Component score coefficients of the important juniper thinned and pile burn treatment habitat variables identified by principal component analysis for the Agua Fria National Monument, Arizona to the period 2009 to 2012.

Habitat Variable	Component						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Tree Height	0.771	-0.099	0.131	0.014	-0.071	-0.212	0.037
Tree Density	0.733	0.079	-0.081	0.296	0.116	-0.291	-0.042
Juniper Height	0.666	-0.066	0.145	-0.051	-0.114	-0.203	-0.061
Cat-claw Acacia Density	0.59	0.109	-0.114	0.284	0.073	-0.359	-0.034
Curley Mesquite Height	0.526	-0.054	-0.184	0.17	-0.112	0.28	-0.031
Juniper Density	0.518	0.057	0.013	-0.122	-0.078	-0.159	-0.108
Mesquite Density	0.516	-0.031	-0.205	0.266	-0.075	0.251	-0.053
Annual Grass Density	0.505	0.037	-0.056	-0.026	0.26	0.291	0.138
Cat-claw Acacia Height	0.496	0.057	-0.106	0.19	-0.086	-0.19	0.115
Banana Yucca Height	0.494	-0.252	0.363	-0.068	-0.054	-0.084	0.04
Banana Yucca Density	0.437	-0.217	0.391	-0.074	0.13	-0.261	0.095
Annual Grass Biomass	0.396	0.198	0.062	0.138	0.238	0.304	0.074
Shrub Density	0.221	0.724	-0.168	-0.358	0.266	0.003	0.203
Range Ratany Height	0.01	0.591	0.394	-0.014	-0.163	0.093	-0.162
Palatable Shrub Density	0.022	0.586	0.252	0.011	-0.034	0.064	-0.28
Increaser Shrub Density	0.252	0.56	-0.362	-0.404	0.237	-0.043	0.307
Range Ratany Density	0.029	0.557	0.286	0.046	-0.045	0.125	-0.289
Rubber Rabbitbrush Density	-0.03	0.546	-0.123	0.237	0.16	0.127	0.084
Hedgehog Cactus Density	-0.186	0.385	0.33	-0.219	-0.295	0.031	-0.259
Wolfberry Density	-0.001	-0.147	0.531	-0.008	0.523	0.082	0.14
Cacti Density	0.216	0.182	0.469	-0.187	-0.245	0.02	-0.064

Cat-claw Tree Density	0.247	-0.148	0.44	-0.12	0.4	-0.124	0.217
Cat-claw Height	0.232	-0.155	0.431	-0.089	0.366	-0.156	0.196
Snakeweed Density	0.307	0.3	-0.309	-0.553	0.154	-0.099	0.261
Rubber Rabbitbrush Height	-0.143	0.359	-0.062	0.544	0.093	0.09	0.191
Snakeweed Height	0.329	0.178	0.075	-0.462	-0.191	0.121	0.12
Forb Biomass	-0.178	0.195	0.249	0.321	-0.157	0.032	-0.053
Wolfberry Height	-0.033	-0.176	0.515	0.06	0.611	0.177	0.132
Mesquite Density	-0.077	-0.159	0.318	0.128	0.495	0.241	0.067
Wait-a-minute Bush Height	-0.14	0.006	0.284	0.096	0.416	0.305	0.008
Greythorn Density	0.358	-0.278	-0.098	0.088	-0.235	0.624	0.077
Greythorn Height	0.353	-0.276	-0.098	0.087	-0.233	0.62	0.077
Sticky Tansyaster Density	0.289	-0.287	-0.062	0.041	-0.282	0.489	0.021
Sticky Tansyaster Height	0.232	-0.269	-0.053	0.026	-0.27	0.425	0.007
Field Brome Height	-0.135	0.12	0.256	0.201	-0.439	-0.109	0.743
Field Brome Density	-0.135	0.12	0.256	0.201	-0.439	-0.109	0.743
Desert Ceanothus Height	-0.135	0.12	0.256	0.201	-0.439	-0.109	0.743
Flat-top Buckwheat Height	-0.089	0.086	-0.049	0.316	0.047	0.062	0.109
Flat-top Buckwheat Density	-0.089	0.086	-0.049	0.316	0.047	0.062	0.109
Buckhorn Cholla Height	0.144	0.31	0.021	0.263	0.045	0.287	0.023
Turbinella Oak Height	-0.077	0.023	-0.376	-0.202	0.168	-0.013	0.201
Brittlebush Density	0.121	0.492	-0.068	0.117	0.092	0.139	0.008
Brittlebush Height	0.15	0.465	-0.089	0.128	0.099	0.158	0.014
Perennial Grass Biomass	0.074	-0.021	-0.309	-0.248	0.111	0.262	0.151
Turbinella Oak Density	-0.07	0.01	-0.306	-0.271	0.141	-0.073	0.167

Figure B- 1: Principal Component Analysis Component Plot of vegetation and weather data within pile burn treatment units of juniper treatment areas of the Agua Fria National Monument, AZ 2012.

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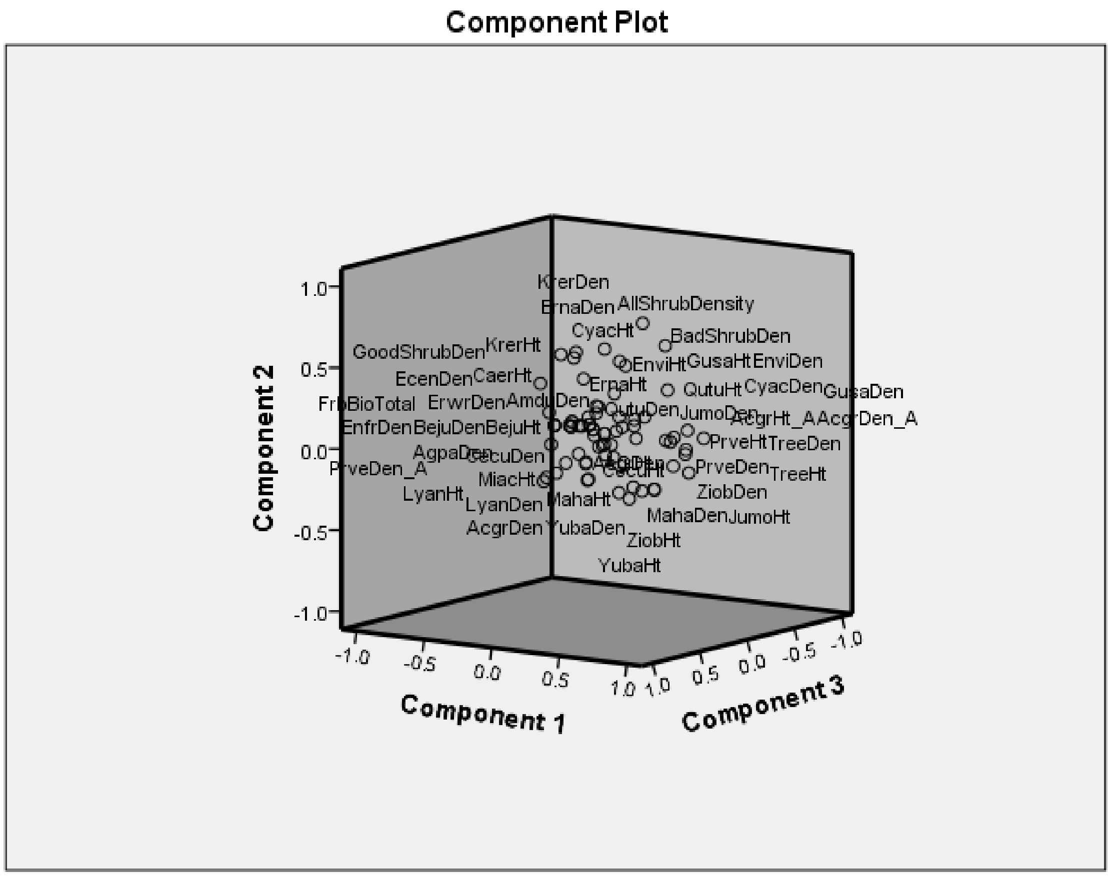


APPENDIX C

DATA COLLECTED FROM 2007-2012

APPENDIX C

Figure C-1: Annual precipitation (cm) between the years 2007 and 2012 for the Agua Fria National Monument.

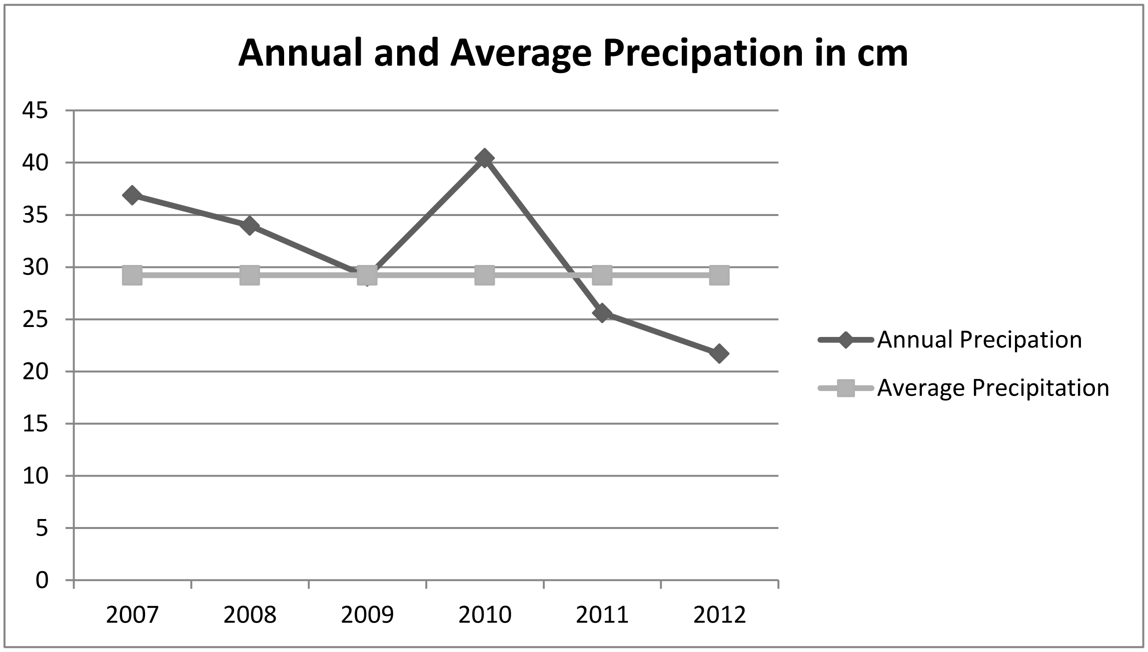


Figure C-2: Annual temperature in Celsius between the years 2007 and 2012 for the Agua Fria National Monument.

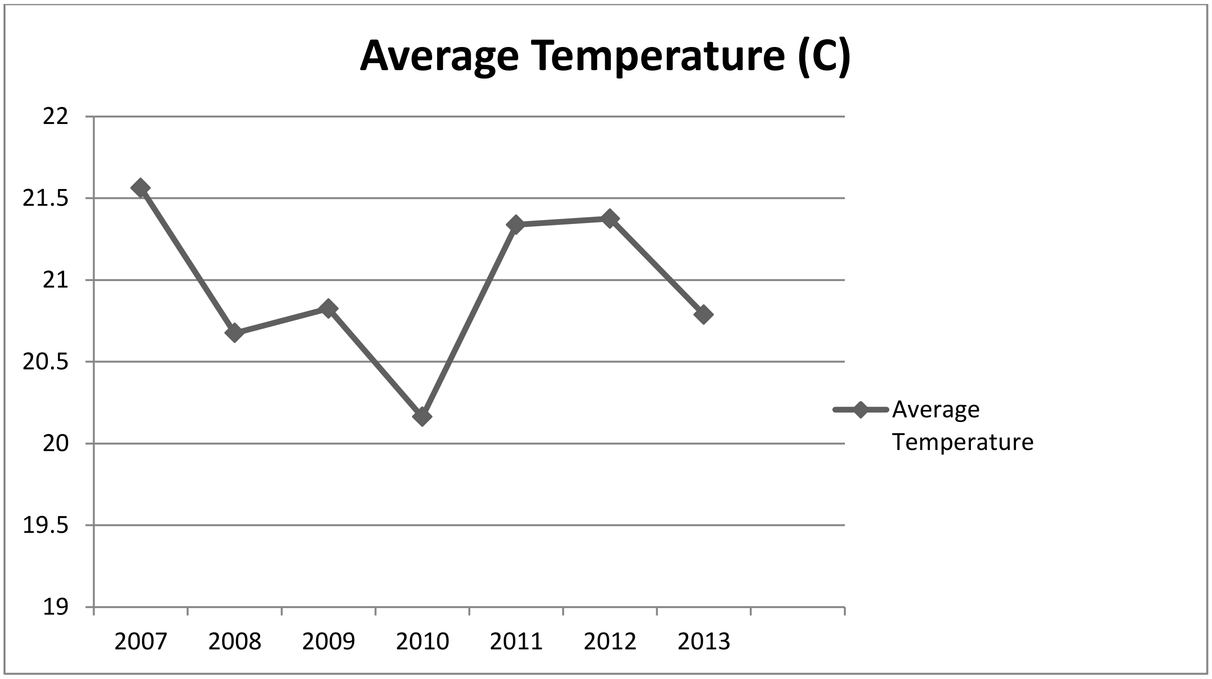


Table C- 1: List of common and scientific name of plant species encountered during the 2012 field season on the Agua Fria National Monument.

Common Name	Scientific Name
TREES	
Cat-claw acacia	*Acacia greggii* (>2m)
One seed juniper	*Juniperus monosperma*
Yellow paloverde	*Parkinsonia microphylla*
Velvet mesquite	*Prosopis velutina*
SHRUBS	
Cat-claw acacia	*Acacia greggii (<2m)*
Wooly bursage	*Ambrosia eriocentra*
White bursage	*Ambrosia dumosa*
Yerba de pasmo	*Baccharis pteronioides*
Desertbroom	*Baccharis sarathoides*
Desert hacberry	*Celtis pallida*
Rabbitbrush	*Chrysothamnus viscidiflorus*
Brittlebush	*Encelia frutescens*
Virgin River bottlebrush	*Encelia virginensis*
Rubber rabbitbrush	*Ericameria nauseosa*
Flat-top buckwheat	*Eriognonum fasciculatum*
Shrubby buckwheat	*Eriogonum wrightii*
Snakeweed	*Gutierrezia sarathrae*
Range ratany	*Krmerica erecta*
Anderson wolfberry	*Lycium andersonii*
Wait-a-minute bush	*Mimosa aculeaticarpa var. biuncifera*
Red barberry	*Mahonia haematocarpa*
Arrowweed	*Pluchea sericea*
Turbinella oak	*Quercus turbinella*
Skunkbush sumac	*Rhus aromatica var. triobata*
Hollyleaf redberry	*Rhamnus ilicifolia*
Banana yucca	*Yucca baccata*
Greythorn	*Ziziphus obtusifolia*
GRASSES	
Cane Bluestem	*Bothriochloa barbinodis*
Poverty Threeawn	*Aristida divaricata*

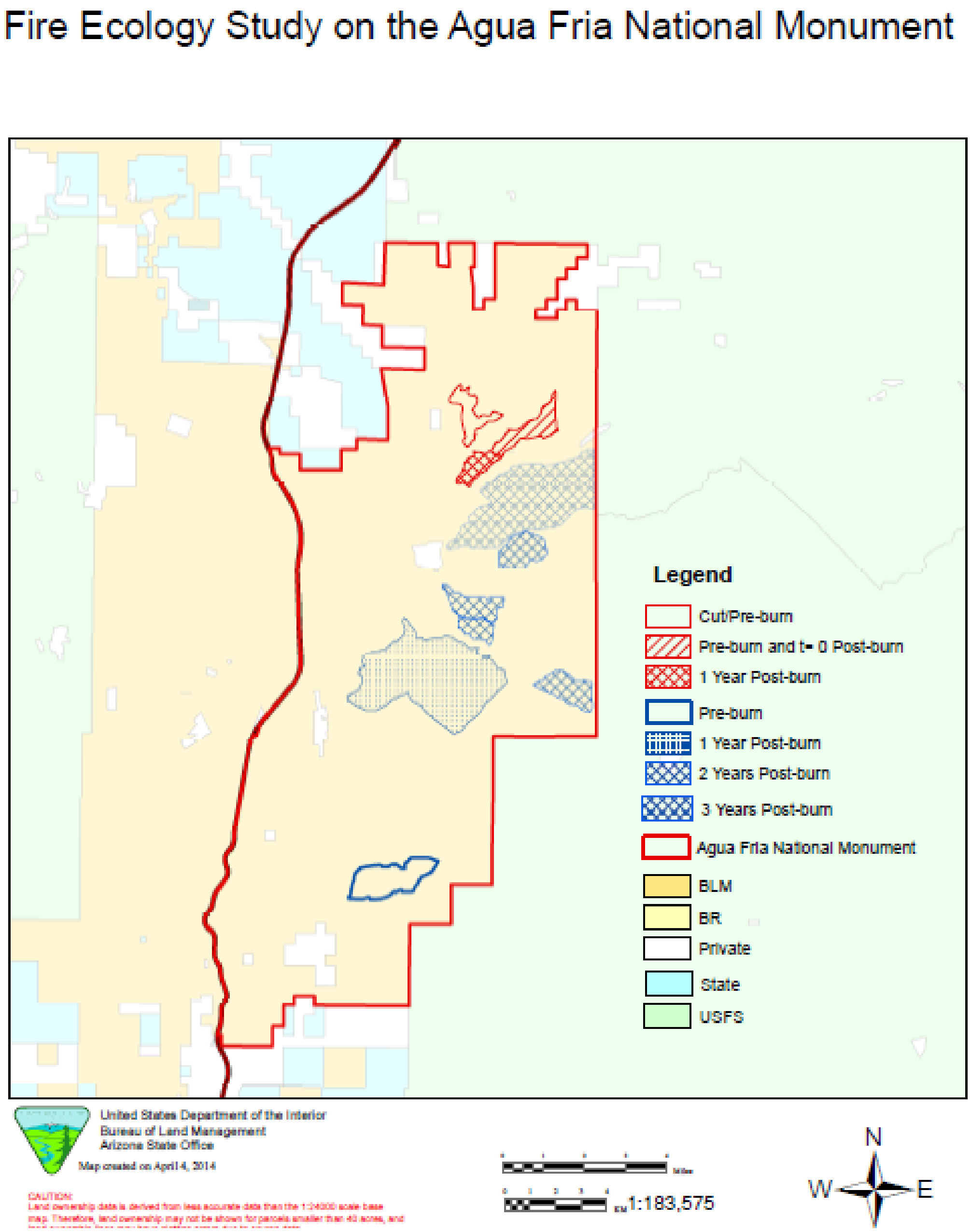
Purple Threeawn	*Aristida purpurea*
Sixweeks Threeawn	*Aristada adscensionis*
Wild Oats	*Avena fatua*
Black Grama	*Bouteloua eriopoda*
Sideoats Grama	*Bouteloua curtipendula*
Field Brome	*Bromus japonicas*
Red Brome	*Bromus rubens*
California Brome	*Bromus carinatus*
Ripgut Brome	*Bromus diandrus*
Salt Grass	*Distichlis spicata*
Squirreltail	*Elymus elymoides*
Fluffgrass	*Erioneuron pilosum*

FORBS	
Tapertip onion	*Allium acuminatum*
Weakleaf bur ragweed	*Ambrosia confertiflora*
Fiddleneck	*Amsinckia menziesii*
White sagebrush	*Artemesia ludoviciana*
Spider milkweed	*Asclepias asperula*
Locoweed	*Astragalus muttalis*
Chuckwalla's delight	*Bebbia juncia*
Spreading fleabane	*Erigeron divergens*
Desert trumpet	*Eriogonum inflatum*
Redstem filaree	*Erodium cicutarium*
Wolly bluestar	*Erastrum diffusum*
Rattlesnake weed	*Euphorbia albomarginata*
Wildcarrot	*Dacus pusillus*
Tansymustard	*Descurainnia pinnata*
Bluedicks	*Dichelostemma capitatum*
Scarlet beeblossom	*Gaura coccinea*
Goldfields	*Lasthenia gracillis*
Plains flax	*Linum puberulum*
Thurber's mustard	*Lepidium thurberi*
Foothill deervetch	*Lotus humistratus*
Desert rock pea	*Lotus rigidus*
Arizona lupine	*Lupinus arizonicus*
Bajada lupine	*Lupinus concinnus*
Tansyaster	*Machaeranthera tanacetifolia*
Blackfoot daisy	*Melampodum leucanthurm*

Yellow sweet clover	*Melilotus officinalis*
Rough medodora	*Menodora scabra*
Lobeleaf groundsel	*Packera multilobata*
Scorpionweed	*Phacelia distans*
Wolly plantain	*Plantago patagonica*
Slender poreleaf	*Porophyllum gracile*
Desert senna	*Senna covesii*
Twinleaf senna	*Senna bauhinioides*
Spreading sida	*Sida abutifolia*
Silverleaf nightshade	*Solanum elaeagnifolium*
Wirelettuce	*Stephanomeria pauciflora*
Desert globemallow	*Sphaeralcea ambigua*
Scarlet globemallow	*Sphaeralcea coccinea*
London rocket mustard	*Sisymbrium irio*
Tall tumblemustard	*Sisymbrium altissimum*
Leafybract aster	*Symphyotrichum foliaceum*
Fiveneedle pricklyleaf	*Thmophylla pentachaeta*
Desert chicory	*Rafinesquia neomexicana*
Bigbract verbena	*Verbena bracteata*

CACTI AND SUCCULANTS	
Staghorn cholla	*Cylindropuntia acanthocarpa*
Pencil cholla	*Cylindropuntia arbuscula*
Christmas cholla	*Cylindropuntia leptocaulis*
Whipple cholla	*Cylindropuntia whipplei*
Beaver tail prickly pear	*Opuntia basilaris*
Engelmann's prickly pear	*Opuntia engelmannii*
Hedgehog cactus	*Echinocereus engelmannii*
Perry's agave	*Agave parryi*
Toumey's agave	*Agave toumeyana*
Beargrass	*Nolina microcarpa*

MAP



Map 1: Study locations, 2012, of Agua Fria National Monument with broadcast treatment units labeled in blue and juniper treatments labeled in red.