IMPACTS OF FIRE IN OAK SAVANNA ECOSYSTEMS OF THE SOUTHWESTERN BORDERLANDS REGION

by

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A Dissertation Submitted to the Faculty of the

SCHOOL OF NATURAL RESOURCES AND THE ENVIRONMENT

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY
WITH A MAJOR IN WATERSHED MANAGEMENT

In the Graduate College

THE UNIVERSITY OF ARIZONA

2011

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

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ACKNOWLEDGEMENTS

First of all, I would like to express my deep gratitude and appreciation to my advisor, Dr. Peter F. Ffolliott, for his support, inspiration and encouragement through my entire graduate studies. I have not only learned from him on advanced scientific knowledge, more importantly, I have also been influenced by his unique scientific approach and attitude toward academic research. Specially, I want to express my appreciation for his generous and continuous support when I moved to Kentucky and had to continue my doctoral study remotely. I believe what I learned from him will continue to benefit me in my future academic career.

My thanks also go to members of my committee, Dr. Phillip D. Guertin, Dr. Gerald J. Gottfried, and Dr. Leonard F. DeBano for reading my dissertation and providing constructive comments that have benefited my doctoral studies.

I would like to thank to Cody L. Stropki and Aaron T. Kauffman. We have worked together on Cascabel Watersheds Project for four years. I had great discussions with them covering a variety of subjects about school, research, and life, and we also encourage each other during the process of pursuing our graduate degrees.

I am also very grateful to the School of Natural Resources and the Environment for proving a quality study and work atmosphere.

Last, but not least, to my husband, Junfeng Zhu, my son, Chandler Zhu, my daughter, Bailey Hui Zhu, for their love and support which I always need.

DEDICATION

To my mother: Peng Suzhen and

my father: Chen Yushan

TABLE OF CONTENTS

LIST OF TABLES……………..…………..…………………………………….….…8
LIST OF FIGURES…………………..……..…………………………..…...…...…9
ABSTRACT……………………………….…………………………...………...…10
INTRODUCTION……………………………..….…………………………………11
Dissertation Format………………...11
Research Problem………………………..……….………………………….…….…11
Study Area………………………………...……………………….....................15
Study Protocols…………….…………………...…………………………...…...19
Streamflow and Precipitation..………………………...………….....................20
Channel Sediment………………………………..…………………….……..…20
Side-Slope Soil Movement..21
Water Repellency...………………….……………………..………………...…22
Tree Overstories………..……………………….……………….…...................22
Herbaceous Understories……………………….....……………………....……23
Loadings of Flammable-Fuel Fractions…..……………………….……………......23
Ground Cover……….………….………………………………….…………….…24
Mammals……………..24
Birds……………………….…………………………..…………….……..….…24
Fire Severity…………....……….…………………………..………………...……26
Prescribed Burning Treatments and the Wildfire………………………………..........26
RESPONSIBILITIES……….…………….……………………………..…..……….29
PRESENT STUDY…..…………..…...…………………………………..…..……….30
Pre-Fire Study Results…………………...……………..……………………......30
Hydrology………………...………………………..……………………………..30
Sedimentation……………………………………..…………….……………..…..31
Transpiration………………...……………………......…………………….…32
Side-Slope Soil Movement……..……………………..……………......................33
Tree Overstories……………………………………..…………………….......35

TABLE OF CONTENTS-*Continued*

Herbaceous Understories......36
Loadings of Flammable-Fuel Fractions......37
Ground Cover......38
Post-Fire Study Results......38
Fire Severity and Water Repellency......38
Side-Slope Soil Movement......39
Tree Overstories......40
Agave......42
Ground Cover......43
Birds......45

CONCLUSIONS......47

MANAGEMENT IMPLICATIONS......48

ACKNOWLEDGMENTS......49

REFERENCES......50

APPENDIX A: A GEOGRAPHICALLY-REFERENCED MULTIPLE-RESOURCE DATA MANAGEMENT SYSTEM FOR THE OAK SAVANNAS OF THE MALPAI BORDERLANDS REGION......55

APPENDIX B: FIRE EFFECTS ON TREE OVERSTORIES IN THE OAK SAVANNAS OF THE SOUTHWESTERN BORDERLANDS REGION......74

APPENDIX C: SPECIES AND BIRD NUMBERS IN OAK SAVANNAS OF THE SOUTHWESTERN BORDERLANDS REGION INCLUDING EFFECTS OF BURNING......109

LIST OF TABLES

Table 1: Physiographic characteristics of the Cascabel Watersheds…………..……...…18

LIST OF FIGURES

Figure 1: Map of the Cascabel Watersheds location and layout of 12 watersheds (Ffolliott et al. 2008a)……………………………………………………………………..…..17

Figure2: Burning events of the Cascabel Watersheds (developed by Carolyn Williams, Tonto National Forest)…………………………..…………………………………28

Figure 3: Average percentages and 90 percent confidence intervals of plant material, litter, bare soil, and bedrock in the ground cover of the Cascabel Watersheds before (spring 2007) and after (spring 2009) the burning events……………………………………..…44

ABSTRACT

Changes in natural fire regime caused by drought, overgrazing and an aggressive fire suppression policy have caused declines in biological diversities, reduction in herbaceous productivity, "unnaturally high" tree densities, and accumulations of flammable surface fuels in the oak savannas of the Southwestern Borderlands Region. Re-introducing a more natural fire regime into the oak savannas in this region is expected to improve or reverse these landscape changes and, in doing so, improve landscape productivity and biological diversity. Twelve small watersheds in the oak savannas on the eastern slope of the Peloncillo Mountains of southwestern New Mexico were established to provide a basis to enhance the level of knowledge of the oak savanna ecosystems in the region and to determine the effects of cool-season and warm-season prescribed burning treatments on the natural resources and ecosystem functioning of oak savanna communities in the region. A wildfire on five watersheds added another dimension to the study. All of the three burning events were low severity fires. The information monitored before and after the burns consisted of hydrologic processes including streamflow and precipitation, channel sediment, side-slope soil movement (both soil erosion and soil deposition), post-fire water repellency, and ecological components including tree overstories, canopy cover, herbaceous understories, loadings of flammable fuel fractions, ground cover, and mammals and birds.

INTRODUCTION

Dissertation Format

This dissertation consists of an INTRODUCTION and SUMMARY with three published or publishable manuscripts in the appendices. The first manuscript (Appendix A) entitled "A Geographically-Referenced Multiple-Resource Data Management System for the Oak Savannas of the Malpai Borderlands Region" was published in Hydrology and Water Resources in Arizona and the Southwest (2009) 39: 59-64. The second manuscript (Appendix B) entitled "Fire Effects on Tree Overstories in the Oak Savannas of the Southwestern Borderlands Region" is in press as a Research Paper to be published by the Rocky Mountain Research Station, U.S. Forest Service, Fort Collins, Colorado. The third manuscript (Appendix C) entitled "Species and Bird Numbers in Oak Savannas of the Southwestern Borderlands Region Including Effects of Burning" has been accepted for publication in the Journal of the Arizona-Nevada Academy of Science.

Research Problem

Frequent fires occurred on the Borderlands Region of Arizona, New Mexico, and Mexico prior to the establishment of European-American settlements in the 1880s, and played a significant role in the ecological functioning of the regional oak ecosystems and adjacent grassland communities. Fires were caused by lightning storms during the pre-monsoon season or were ignited by Native Americans either purposely to improve hunting success or in warfare or accidently. The typical fire season on the Southwestern Borderlands

Region is late spring or early summer (prior to the summer monsoon season) when the region is characterized with high lightning incidences, accumulations of dry vegetation, high ambient temperatures, and low relative humilities (Baisan and Swetnam 1990). Large fires often occurred in the region when fine fuels accumulated during a wet period that was followed by a dry period which favored the fire ignition and spread (Kaib et al. 1999, McPherson and Weltzin 2000). A 230 - year record (1650-1880) of the occurrences of fire in the Southwestern Borderlands Region indicated that average fire intervals were 4 to 8 years for grasslands, 3 to 7 years for canyon pine-oak stands, and 4 to 9 years for mixed-conifer forests (Kaib et al. 1999).

The natural fire regime on the Southwestern Borderlands Region had been altered mostly due to drought and overgrazing since 1880s when cattle ranching became primary agricultural industry in this region (Hadley et al. 1999). Overgrazing by large herds of cattle caused dramatic declines in grass cover and, as a result, the fires could not readily spread due to lack of continuous surface fuels. An aggressive fire suppression policy by land management agencies, lasting more than 100 years, was another major factor contributing to fire regime alteration of this area. Land management agencies started to aggressively suppress all fires, even when the fires were deemed beneficial to the ecosystems, from the beginning of the 20th century when the overgrazing impacts began to moderate (Gottfried et al. 2009). A study of fire history reconstructions from fire-scars based on tree-ring records from seven mountains in Arizona and Mexico showed that fire occurrences largely ceased in Arizona in the early of 20th century but were continually recorded in adjacent Mexican forests (Kaib et al. 1999).

The natural fire regime maintained the grassland ecosystems and prevented the encroachment of woody vegetation and subsequently reduced accumulations of woody fuels in the region. However, fire regime alterations combined with global climatic changes, which include increased cycles of drought and abundant precipitation and the shift from predominant summer precipitation to predominant winter precipitation, have caused significant alterations in the regional vegetative structure (McPherson and Weltzin 2000). When wet periods occurred following drought, establishment of C3 woody species was favored on the open area created by drought and they increased their dominance because fire was not longer the controlling factor to limit establishment and growth (McPherson and Weltzin 2000). Consumption and transportation of edible woody vegetation seeds by cattle also contributed the spread of woody species (McPherson and Weltzin 2000). Encroachment of woody vegetation into the grasslands and open woodlands on the Southwestern Borderlands Region has resulted in declines in biological diversity and a loss of herbaceous productivity. It is also possible that the continued encroachment of woody plants could eventually affect regional economic viability and result in the subdivisions of ranch properties and even the loss of the way of life for ranchers. Another potential issue caused by fire regime fluctuation is that the landscape would become more susceptible to high severity wildfire due to accumulated fuels.

Ranchers and land management agencies have agreed that re-introducing natural fire regimes into the Borderlands Region could improve or reverse these changes and, as a result, improve landscape productivity and biological diversity. Re-introduction of natural fire might restore the historic biological diversity of the region by reducing the density of woody species, restoring habitats for wildlife, improving watershed stability, hydrologic function, and herbaceous cover, and creating a fuel mosaic that would allow fire to resume a more natural role in ecosystem functions (McDonald 1995).

Prescribed burning is a proposed ecological management practice to restore and maintain natural processes in oak savanna ecosystem on Southwestern Borderlands Region by local ranchers and land management agencies. The oak savanna community is located in the interface between the higher-elevation oak woodlands and lower-elevation desert grasslands and shrub communities. Oak savannas, compared with oak woodlands, are more open in standing structure and have higher herbaceous production and less density of woody vegetation. A woodland, as specified by the 1973 UNESCO Formation Classification, is an ecosystem with dominant trees greater than 16 feet in height and a canopy cover of greater than 40 percent, while a savanna is a grassland with a tree cover of less than 10 percent (Barbour et al. 1980). Oak woodlands and savannas combined occupy more than 30,888 square miles in the southwestern United States and northern Mexico (Gottfried et al. 2007a). However, less knowledge of ecological, hydrological and environmental characterizations is available for oak savannas than for oak woodlands. Therefore, one of the major objects of this research is to gain the baseline information of ecological, hydrological and environmental characterizations of oak savanna ecosystem in the Southwestern Borderlands Region (Gottfried et al. 2007a).

Ranchers and land management agencies expect that planned prescribed-burning treatments could reduce woody species density, increase herbaceous plant production, and create vegetative mosaics on the oak savanna landscape in the region. Prior to broad application, however, research must address how the seasonal prescribed burning treatments (cool season burning and warm season burning) of varying severities affect the natural resources and ecosystem functioning.

Twelve small watersheds in the oak savannas on the eastern slope of the Peloncillo Mountains of southwestern New Mexico were established by the Rocky Mountain Research Station of the U.S. Forest Service and its cooperators to enhance the baseline knowledge of oak savanna ecosystems in the Borderlands Region. The objective was to determine how seasonal prescribed burning treatments affect the natural resources and ecosystem functioning in oak savanna communities in the region (Gottfried et al. 2007a).

Study Area

These twelve watersheds, known as the Cascabel Watersheds, are located on the eastern slope of the Peloncillo Mountains of southwestern New Mexico and are largely within the Douglas Ranger District of the Coronado National Forest and adjunct to the Diamond A Ranch in New Mexico (Figure 1). The Cascabel Watersheds represent the oak savanna ecosystem in the Southwestern Borderlands Region and are ideal for a replicated paired-watershed study due to their common location, accessibility, relative sizes, distinct channel formations, and similar vegetation characteristics.

The Cascabel Watersheds are located between 5,380 and 5,590 ft in elevation. The twelve individual watersheds range from about 20 to almost 60 acres in size; the aggregate area of the Cascabel Watersheds is 453 acres (Table 1). The long-term precipitation records at the weather station at the Cascabel Ranch Headquarters indicate that the average annual precipitation is 21.8 ± 1.2 (mean ± [$t_{0.10}$ * standard error]) inches with more than one-half of the precipitation occurring in the summer monsoon season from June 15 through September 30. However, a drought has impacted the Southwestern United States since the middle 1990s and the average annual precipitation during this drought period has been 14.9 inches on the study area (Ffolliott et al. 2008a). The bedrock geology of the study area is Tertiary rhyolite lava overlain by Oligocene-Miocene conglomerates and sandstone, and the parent material is rhyolite-a fine-grained volcanic rock (Youberg and Ferguson 2001). The common soils of the area of the Peloncillo Mountains are Typic Haplustalfs, mesic, deep, gravelly loam compacted or deep very cobbly sandy-loam gullied. Soils are classified as Lithic Argustolls, Lithic Haplustrolls, or Lithi c Ustorthents and are generally less than 20 inches to bedrock (Robertson et al. 2002).

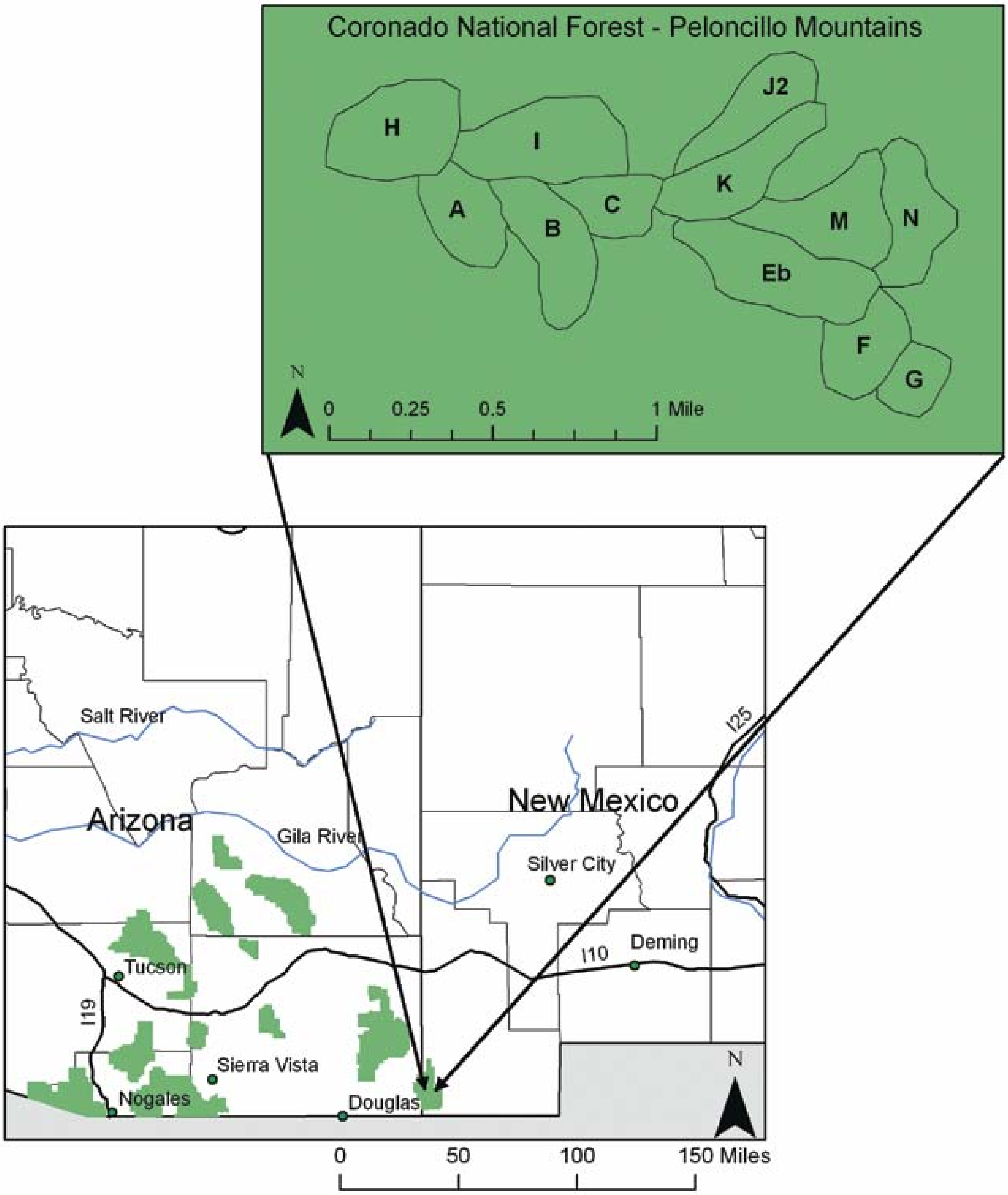

Figure 1: Map of the Cascabel Watersheds location and layout of 12 watersheds (Ffolliott et al. 2008a).

Table 1: Physiographic characteristics of the Cascabel Watersheds.

Watershed Name	Area (acre)	Plot Interval (feet)	Baseline Angle	Aspect	#ofPlots	Burning Events
A	31.5	80	N10W	South	34	Warm-season prescribed burning
B	38.8	90	N15W	South	36	Wildfire
C	27.9	160	N0	South	31	Cool-season prescribed burning
E	59.3	240	N0	South	42	Warm-season prescribed burning
F	32.3	120	N11E	South	31	Warm-season prescribed burning
G	18.8	85	N26E	South	37	Wildfire
H	48.5	150	S34W	North	35	Cool-season prescribed burning
I	52.4	160	S53W	North	34	Wildfire
J	31.0	80	S45W	North	32	Wildfire
K	41.1	80	S53W	North	38	Cool-season prescribed burning
M	41.8	110	S21W	North	35	Wildfire
N	29.6	70	S0	North	37	Cool-season prescribed burning

Study Protocols

There are six watersheds on north side of the ridge along the Cascabel Watersheds drain into Walnut Creek while six watersheds drain to south into Whitmire Creek. The groupings of six watersheds were initially divided into two groups of three (Gottfried et al. 2007b). Each of the four sets was scheduled for the two prescribed burning treatments watersheds and an untreated control treatment watershed. The Cascabel Watersheds contain 421 permanent sampling plots with 35 to 45 permanent plots on each watershed. These plots are located along transects perpendicular to the main stream system and situated from ridge to ridge with an interval between the plots ranging from 70 to 240 feet depending on the size and configuration of the watershed (Table 1).

Information that was obtained during the pre-treatment period and continued through the post-treatment monitoring include hydrological and ecological characterizations. Hydrologic components include streamflow and precipitation, channel sediment, side-slope soil movement (both soil erosion and soil deposition), and post-fire water repellency. Ecological components measurements consist of the tree overstories inventories, canopy cover, herbaceous understories, loadings of flammable fuel fractions, ground cover, selected mammals, and birds. The field measurement procedures are described below.

Streamflow and Precipitation

A 9-inch Parshall flume with a capacity of 4.03 cfs (cubic feet per second) to measure common low flows and a larger 3-foot or 4-foot flume with capacities of either 42.7 or 57.5 cfs, respectively, was installed on each of the 12 watersheds (Gottfried et al. 2007b). These values assume that the flume is running at 90% of full depth. Pre-installation calculations based on a 10-year return interval and occurrence of a 2.8-inch rainfall in a 24 hour period were used to determine the flume size (Gottfried et al. 2000). Replogle long-throated flume replaced the small Parshall flume to increase the accuracy of measuring low flows (Gottfried et al. 2007b). Two completed weather stations were installed on the Cascabel Watersheds, one at the western edge of the area (Watershed H) and the other on a north facing side-ridge in the middle of the study area (Watershed J). The variables measured include precipitation, wind speed, humidity, and temperature. Six recording tipping bucket precipitation gauges were established throughout the Cascabel Watersheds to supplement the precipitation records (Gottfried et al. 2007b).

Channel Sediment

Permanent channel cross-section stations and a sediment dam were installed to measure any changes in sedimentation caused by the treatments on each Cascabel Watersheds (Gottfried et al. 2007b). The dam walls, which are tied into the channel walls, are about 2 to 3 feet in height. An opening was constructed on each dam in order to minimize streamflow retention. A total of 11 surveying lines, tied to a permanent benchmark, were established on each basin to conduct periodical measurements using a surveyor's level and rod. The WinXSPRO program (Hardy et al. 2005) and the average end area method (Dendy et al. 1979) were used to calculate volumes and volume differences between periods. Pebble counts of surface deposits were measured behind the sediment dams.

Side-Slope Soil Movement

Soil erosion and soil deposition were measured seasonally in the spring and fall seasons to characterize soil movements following periods of winter and summer rains. The erosion-pin method was applied to measure side-slope soil movement. Implementation of this method involved installing three erosion pins around every third plot, with two pins located 6-feet upslope and one pin located 6-feet downslope of a plot center. Soil movement was measured by the distance from the cap of a pin to the soil surface (soil erosion) or the accumulation of soil on top of the cap (soil deposition). When there was no measurable change in the soil surface beneath the cap, we assumed that the magnitudes of soil erosion and deposition in the time interval between the measurements were equal or that (what is less likely) neither erosion nor deposition occurred in the time interval. After the measurements were taken, the erosion pins were re-set to be flush with the soil surface to facilitate subsequent measurements. Measurements obtained from the three pins surrounding a plot were averaged to estimate soil movement on the plot, and the plots soil movements on a watershed were then averaged to describe side-slope soil movement on a watershed-basis. Local bulk density measurements were used to convert measurements of average soil loss to erosion rates in terms of tons/acre.

Water Repellency

The water-drop penetration method (Letey et al. 2000) was used to determine occurrence of water repellent soils on sampling plots. After removing litter, duff and other organic debris to expose mineral soil, a drop of distilled water was placed on the soil surface. The time for the drop of water to penetrate into the soil was recorded. Since the precise location of a water repellent layer at the plot, if a layer existed, was not known, this procedure was repeated. Then the longer of the two times recorded was applied to the National Wildfire Coordinating Group (Clark 2001) to determine the levels of water repellency: no repellency; slight repellency - less than 10 seconds for a drop of water to penetrate the soil surface; moderate repellency - 10 to 40 seconds for a drop of water to penetrate the soil surface; or strong repellency - more than 40 seconds for a drop of water to penetrate the soil surface.

Tree Overstories

One-quarter-acre plots were established to determine tree species and species compositions and to measure tree characteristics in terms of diameter root collar (drc) for single stem trees or equivalent diameter root collar (edrc) for multiple stemmed trees (Chojnacky 1988). Total heights of trees were also measured to provide a basis of calculating timber volume. Sampled trees were grouped into three size-classes of saplings being 1.0 to 4.9 inches drc (edrc), medium trees 5.0 to 8.9 inches drc (edrc), and large trees of 9.0 inches drc (edrc) and larger.

Herbaceous Understories

The production (standing biomass) of the herbaceous understory was estimated seasonally in 9.6-ft^2 circular plots at each sampling plot by the weight-estimate procedure originally outlined by Pechanec and Pickford (1937). The estimated green weight was converted to actual oven-dry weight in lbs/acre with appropriate correction factors. Seasonal (spring and fall) species composition and the estimated production of grasses, forbs, and shrubs were recorded. The spring estimates represented the production of early growing plants which are largely favored by temperature and antecedent soil water derived largely from late fall and winter precipitation events, while the fall estimates reflected the production of the late-growing plants which are more affected by the summer monsoonal rains (McPherson 1992, 1997). Grasses and forbs were totaled to estimate total herbage production. Production of shrubs in the understory was also estimated.

Loadings of Flammable-Fuel Fractions

Loadings of flammable-fuel fractions were measured at the sample plots on the Cascabel Watersheds. These fractions consist of standing trees (alive and dead), downed woody materials (sound and decaying logs, branches, and twigs), herbaceous biomass (grass, forbs, and shrubs), and organic matter represented by the litter and duff layers. Loadings of standing trees were estimated by converting cubic-foot volumes of standing trees to oven-dry weights by species-specific gravity (wood density) values for the tree species tallied on the study area. Loadings of the downed woody materials and organic matter fractions were estimated by counting the intersections of downed woody materials with a vertical sampling plane that resembles a guillotine dropped through the accumulated fuels (Brown et al. 1982).

Ground Cover

Ground cover percentages of plant material, litter, bare soil (including cobble, gravel, and stones), and bedrock were estimated in a 12-by-18 inches rectangular frame placed at three equally spaced locations within 3 feet of the sampling plots. Ground cover measurements are important ecological characteristic since they have been used to predict hillslope soil erosion rates (Renard et al. 1997) and indicate the successional status of vegetative communities on a site (Bedell 1998).

Mammals

The presence of Coues white-tallied deer (*Odocoileus virginianus couesi*) and desert cottontail (*Sylvilagus auduboni*) was measured seasonally (spring and fall) by counting fecal pellets on 40.5 m^2 circular plots centered over each sampling location. The fecal deposits by these mammals were cleared from the plot after each counting, and, therefore, the seasonal use of the habitats on a watershed could be estimated.

Birds

Seasonal (spring and fall) species and numbers of birds sighted in a 5-minute observation period on the watersheds were recorded to obtain avifauna data (Ralph et al.1995). Bird tallies were made between 0800 and 1130 hours on clear or partly cloudy days when minimal wind movement exists. These tallies were started a few minutes after the observer arrived at a sampling location to minimize the observer's moving disturbances. Observations of bird species and numbers of birds were tallied at only every third sample plot (1, 4, 7, etc.) on the watersheds throughout the study because of the small size of the individual watersheds, the short intervals (from 70 to 240 feet) between the plots, and the mobility of birds in the area.

Species richness, species diversity and species evenness were calculated to determine the ecological diversity of birds on the Cascabel Watersheds. Species richness was the number of species tallied. Species diversity (Shannon and Weaver 1948) was calculated by:

$$H' = -\sum_{i=1}^{S} pi \ \ln(pi)$$

where pi is the proportion of the *i*th species in a population of birds comprised of s species. Larger (H') values represent higher species diversities. Species evenness (Shannon and Weaver 1948) indicated how equally abundant the species were and was calculated by

$$E = H'/\ln s$$

Larger (E) values are equated with more equally abundant species on a site with values approaching 1 representing higher levels of evenness and, therefore, higher ecological diversity on the watersheds.

Fire Severity

A system that relates fire severity to the soil-resource response to burning (Hungerford 1996) was the basis for classifying severities of the cool-season and warm-season prescribed burning treatments and the wildfire at the 421 sample plots on the watersheds. This system of classifying fire severities relates post-fire appearance of litter, duff, and woody material and soil conditions to discrete classes of severity ranging from low to medium to high. Classifications of fire severity at the sample plots were extrapolated to a watershed-basis to determine the percentages of each of the Cascabel Watersheds that were unburned or burned at low, moderate, or high fire severities.

Prescribed Burning Treatments and the Wildfire

How seasonal prescribed burning treatments and burning intensities affect the oak savanna ecosystem on the Cascabel Watershed needed to be addressed. Many ranchers and land management agencies prefer the natural warm-season (May-October) prescribed-burning, while others would like to have low severity, cool-season (November-April) burning in the early spring or winter. A major concern for cool season burning is the possibility of severe soil surface erosion because cool season burning might leave soil surface bare without a protective cover, and most native herbaceous species germinate and grow during the summer monsoon period. Severe warm-season burning, however, could consume vegetation and litter, create water repellant soil, and (perhaps) affect the condition of wildlife habitats. A hot warm season burn could also kill large standing trees and shrubs that are nesting sites or thermal or hiding cover for some important or endangered wildlife species (Gottfried et al. 2007a).

The study on the Cascabel Watersheds was designed to burn four watersheds in the warm season, burn four watersheds in the cool season, and leave four watersheds as unburned controls. After the required calibration, four watersheds with cool-season prescribed fire treatment were burned in early March 2008. Three of the four watersheds with the warm-season prescribed fire treatment were burned on May 20, 2008 and the burn on fourth watershed was postponed because of shifting weather conditions. However, the remaining unburned warm-season watershed and the four control watersheds were all burned because unpredicted wind gusts up to 60 mph occurred on the morning of May 21, 2008. The resulting wildfire, designated the Whitmire Wildfire, spread beyond the Cascabel Watersheds boundaries and burned almost 4,000 acres. Therefore, the original research plan of evaluating prescribed warm season and cool season burning treatments in relation to unburned control watersheds had to be modified. Researchers are currently evaluating the effects of the cool-season and warm-season prescribed fires and the warm-season wildfire on the Cascabel Watersheds (Figure 2).

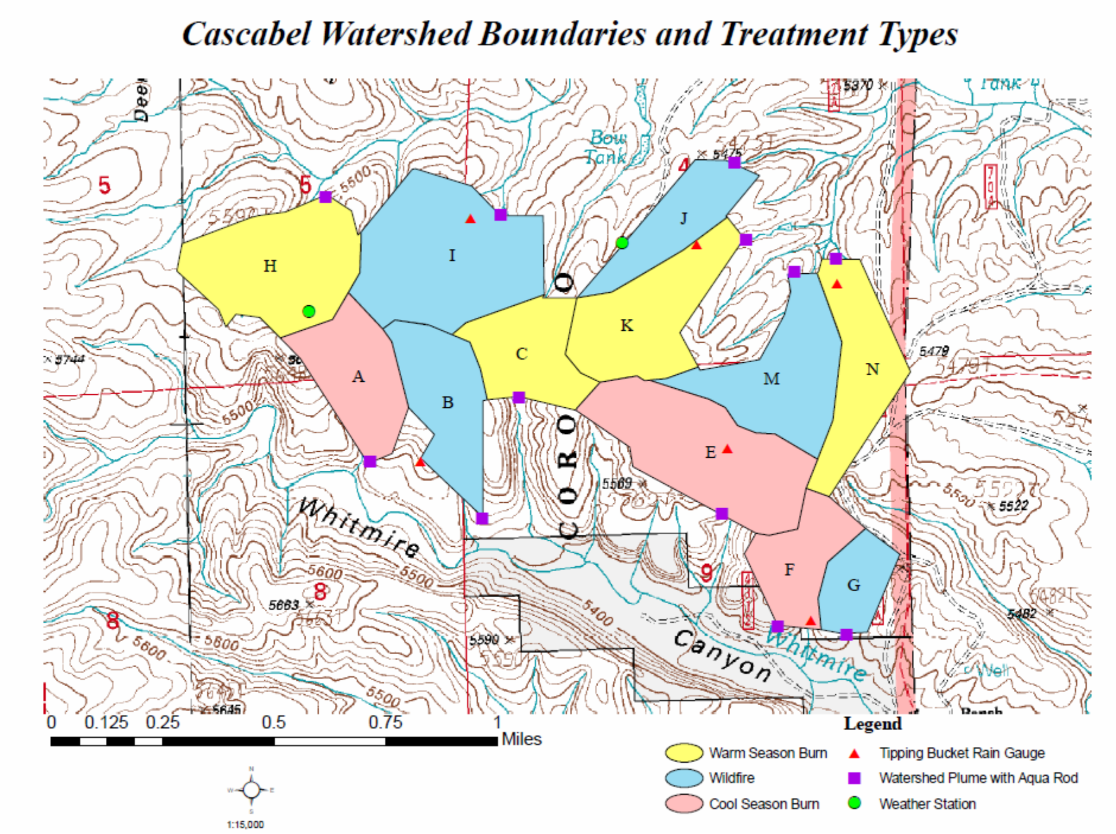

Figure2: Burning events of the Cascabel Watersheds (developed by Carolyn Williams, Tonto National Forest)

RESPONSIBILITIES

The Cascabel Watersheds Project is supported by Southwestern Borderlands Ecosystem Management Unit of the Rocky Mountain Research Station, U.S. Forest Service, Fort Collins, Colorado, and the Arizona Agricultural Experiment Station, University of Arizona, Tucson, Arizona. I started participating in this research project in 2007. The team of researchers from the School of Natural Resources and the Environment has been in charge of collecting field measurements on side-slope soil movement including erosion and deposition, tree overstories, canopy cover, herbaceous understories, loadings of flammable-fuel fractions, ground cover, mammals, and birds. We also evaluated fire severity and the occurrence of water repellency soil after the burning events. A geographically referenced multiple-resource database management system has been developed to enable researchers, managers, and other stakeholders to store, interpret, and analyze data sets of the Cascabel Watersheds with relative ease. I have been in charge of developing and maintaining this database management system, and cooperated in collecting field data and generating the necessary data summaries and statistical analyses.

PRESENT STUDY

The Cascabel Watersheds Project is a long-term comprehensive study that has produced many papers and reports. This chapter presents brief summaries of the more important information obtained on the oak savanna ecological, hydrological, and environmental characteristics and burning impacts on the oak savannas ecosystem in the Borderlands Region.

Pre-Fire Study Results

Hydrology

Gottfried et al. (2006 and 2007b) studied the hydrology of the Cascabel Watersheds. The weather station located on watershed J indicated that the average of precipitation for years 2002 through 2006 was 15.99 ± 2.77 inches with 54 percent of the total occurring in the July through September growing season. About 43 percent of total precipitation occurred in summer during the three driest years, however, while 53 and 75 percent of total precipitation occurred in summer in the two wettest years, respectively. These researchers reported that fifty-one peak runoff events had been recorded by at least one of the 12 watersheds since 2001. Between 70 and 80 percent of the storms occurring on Watersheds C, and E on the south-facing slope and watersheds I, and K on the north facing slope had been recorded. Watersheds E, I, and K produced the highest average peak flow, with the largest average peak flow of 7.88± 2.35 cfs (cubic feet per second) being recorded on watershed K based on 38 events since 2001. Watershed N had the smallest average peak flow of 2.92 ± 1.36 cfs based on 30 events. The measurements of side-slope erosion and sediment were made on watershed A and adjacent watershed I (Figure 1). Total side-slope erosion during the periods after the winter of 2004-2005 and after the summer monsoons of 2005 was 20.7 tons/acre on watershed A and 22.3 tons/acre on watershed I. Sediment measured behind the dams from 2003 to 2006 was 347.4 and 190.3 cubic feet on watershed A and watershed I, respectively.

Sedimentation

Koestner et al. (2008) evaluated changing bedload conditions on four of the Cascabel Watersheds (A, F, H, and N), which are located on the eastern and western extremes of the study area (Figure 1). These four watersheds were selected to study the differences in bedload conditions and total precipitation in terms of aspect and east/west orientation. Bedload is the sediment transported along channel bed by a combination of sliding, rolling, and saltation. Bedload is strongly influenced by channel cover and channel morphological characteristics. The initial channel substrate cover survey was conducted on these four Cascabel Watersheds in 2003. The substrate cover (consisting of rock, fine alluvium sediment, coarse alluvium sediment, vegetation, woody debris and other) was conducted along line transects in 100 m increments upstream from the sediment weir through the reach of the watersheds until a distinct channel could not be determined (including side channels). Elevation changes in channel gradient across transect were also surveyed by using a stadia rod and surveying level to determine cross-sectional formation. Five cross-sections from each of the four watersheds were modeled by entering cross-section data into a stream-channel modeling program named Mike 11 with the two separate years between 2002 and 2006. The authors found that the two watersheds (A and H) situated on the western portion of the study area had similar bedload trend while no similar trend was observed for the eastern side watersheds (F and N). More sediment transport and accumulation were observed on the two watersheds of western portions (A and H). The cross-section analysis indicated that the topography and size of each of the four watersheds, physical channel condition and landscape orientation were the major variables impacting morphological change over time. It was also observed from cross-section analysis that bedload condition changes matched the variation in precipitation data very well.

Transpiration

Ffolliott et al. (2008b) applied sap-flow method to estimate oak trees' transpiration to better understand the general water budget of an open oak ecosystem. Instantaneous transpiration was measured on 16 Emory oak trees, locating on two transects oriented perpendicular to the main stream-channel on each of two Cascabel Watersheds (E and I). Two of the trees were situated on the southerly aspect and two trees on the northerly aspect of each transect for a total of 8 measured trees on each of the two watersheds. Instantaneous transpiration of these 16 oak trees, ranging from 6 to 14 inches in drc, was measured in the late spring, summer, and early fall of 2004. Then, the measured instantaneous transpiration was converted to approximations of daily transpiration.

The researchers applied the relationship between annual transpiration and the drc of oak trees in the oak woodlands from the Huachuca Mountains (Ffolliott and Gottfried 1999) to extrapolate the estimated daily transpiration to annual transpiration in oak savannas on the Cascabel Watersheds. This study concluded that the estimated annual transpiration of nearly 4.8 area-inches of oak trees in the oak savannas on the Cascabel Watersheds was 60 percent of the annual transpiration in a stand of mature oak trees in the oak woodlands on the Huachuca Mountains (Ffolliott and Gottfried 1999, Ffolliott et al. 2003). Since these two oak ecosystems are generally similar in the past and present land-use practices imposed on them, the authors concluded that smaller oak trees in the oak savanna might attribute to the lower annual transpiration on the Cascabel Watersheds. This study also indicated that the annual transpiration of the oak trees on the Cascabel Watersheds was approximately 30 percent of annual precipitation of 17.7 inches which was an arbitrary annual precipitation value selected in earlier studies in the oak woodlands on the Huachuca Mountains (Ffolliott 2004).

Side-Slope Soil Movement

Hillslope soil erosion can lower the productivity of upland sites and adversely impact water quality and downstream (off-site) areas, therefore, the soil characteristics of the Cascabel Watersheds need to be known. The initial hillslope soil erosion on the Cascabel Watersheds were measured in 2004 following the monsoon season of that year (Ffolliott et al. 2006), and subsequent pre-fire measurements were made following the winter rains and monsoon (Kauffman et al. 2007) by applying the erosion-pin method discussed above. The studies indicated that large variations were observed in seasonal and annual soil erosion rates, and the relationships of these rates with precipitation patterns, physiographic features of the watersheds (size, configuration, slope position, slope percent, slope aspect, and stream channel network), and other conditions were not evident, which may need long-term measurements to detect if they exist.

Ffolliott et al. (2010a) reported that average soil erosion for the spring measurements through the pre-fire study period was 15.7 tons/acre and that the average for fall measurements was 13.4 tons/acre on the Cascabel Watersheds. Average soil deposition was 4.6 tons/acre for spring measurements and 7.9 tons/acre for the fall measurements. These researchers also reported that there were no consistent patterns in the seasonal magnitudes of side-slope soil movements relative to rainfall amounts, rainfall intensities, rainfall amounts necessary to generate overland flows of water, and sequencing of the rainfall events. However, they found that there was a significant relationship between side-slope soil movement and hillslope position. Seasonal soil erosion averaging 9.8 tons/acre on the upper slope was generally lower than either the middle or lower slope which averaged 16.0 and 17.1 tons/acre, respectively. Seasonal soil deposition averaged 8.5 tons/acre on the lower slope while it averaged 5.4 tons/acre on the upper and middle slope combined. It was also found that seasonal soil erosion on slopes in excess of 25 percent averaged 19.4 tons/acre. This was higher than soil erosion averaging of 11.8 tons/acre on the lesser slopes. The measured soil movement on north facing aspects was greater than that on south facing aspects, which could not be explained.

Tree Overstories

Studies of vegetative characteristics of oak savannas on the Cascabel Watersheds and comparison with oak woodland on the south slope of the Huachuca Mountains (Ffolliott and Gottfried 2005, Ffolliott et al. 2008a) provide comprehensive floral information including tree overstories, herbaceous understories, flammable fuel loadings and ground cover. The sampling procedures were discussed above. The studies reported that there were seven tree overstories species including Emory oak (*Quercus emoryi*) (60.1 percent of all trees tallied), alligator juniper (*Juniperus deppeana*) (15.3 percent), Arizona white oak (*Q. arizonica*) (11.9 percent), Toumey oak (*Q. toumeyi*) (4.4 percent), minor components of border pinyon (*Pinus discolor*) (5.6 percent), redberry juniper (*J. coahuilensis*) (2.0 percent), and the tree form of mesquite (*Prosopis velutina*) (0.7 percent) on oak savannas on the Cascabel Watersheds. Four tree overstories species were tallied in oak woodland on the south slope of the Huachuca Mountains, including Emory oak (89.3 percent), Arizona white oak (8.7 percent), scattered alligator juniper (1.3 percent), and border pinyon (0.7 percent).

These studies indicated that the average numbers of medium, large and total trees in the oak savannas were statistically significant less than in the woodlands, while no difference in numbers of saplings between the two oak ecosystems. The estimated annual growth rate of the tree overstory was 0.069 ± 0.023 ft^3/acre in the oak savannas. In comparison, tree growth in the more dense oak woodlands was 0.11 ± 0.016 ft^3/acre. The annual timber growth pattern was relatively “fast” in the early and middle stages but became negligible when trees were getting older. This was observed in both of oak ecosystems by analyzing increment cores collected from a total of 42 trees in the two oak ecosystems. The spatial distributions of tree overstories on the oak savannas (coefficient of variation = 7.98) had higher variability than trees tallied in oak woodlands (coefficient of variation = 1.08).

Herbaceous Understories

Ffolliott and Gottfried (2005) and Ffolliott et al. (2008a) reported that herbaceous understories species compositions were largely similar on both oak ecosystems. Perennial grasses included blue (*Bouteloua gracilis*), sideoats (*B. curtipendula*), slender (*B. repens*), and hairy (*B.hirsuta*) grama, bullgrass (*Muhlenbergia emersleyi*), common wolfstail (*Lycurus phleoides*) and Texas bluestem (*Schizachyrium cirratum*). Forb species included mariposa lily (*Calochortus* spp.), verbena (*Verbena* spp.), and lupine (*Lupinus* spp.). Half-shrubs and shrubs were beargrass or sacahuista (*Nolina microcarpa*), fairyduster (*Calliandra eriophylla*), common sotol (*Dasylirion wheeleri*), pointleaf manzanita (*Arctostaphylos pungens*), Fendler's ceanothus (*Ceanothus fendleri*), Mexican cliffrose (*Purshia mexicana*), and the shrub forms of oak species and mesquite. Succulents included Palmer's century plant (*Agave palmeri*) and banana yucca (*Yucca baccata*).

Pre-burning estimates of herbage production (2003-2007) indicated that the average production of early growing herbaceous plants was 139.7 ± 5.4 lbs/acre on the Cascabel Watersheds, while production was 306.7 ± 9.4 lbs/acre for late growing plants.

Comparison of late-growing herbaceous production between the two oak ecosystems in 2005, which was the only season with available measurements for both oak ecosystems, indicated that oak savannas (265.0 ± 12.1 lbs/acre) had significantly higher production of late growing plants than the denser oak woodlands (155.9 ± 23.6 lbs/acre).

Loadings of Flammable-Fuel Fractions

Total loading of flammable fuels including standing trees, downed woody materials, and herbaceous biomass fractions before the burning events was 2.98 ± 1.89 tons/acre in the oak savannas, while total loading of these fractions in the oaks woodlands was 6.28 ± 1.24 tons/acre (Ffolliott et al. 2008a). Ffolliott et al. (2008c) also studied the flammable fuel loadings in the pine-oak forests and oak woodlands and savannas of the Madrean Province located at the convergence of the Sonoran, Chihuahuan, Madrean, and Rocky Mountain biogeographic regions and the Sierra Madre Occidentalis and Rocky Mountain ranges. The "downed woody fraction" of fuel loadings was the main fraction of interest of this paper. Fuel loadings (downed woody fraction) were measured on a randomly situated 2.5 acre grid of 25 systematically located plots established at equally spaced intervals on each study site (Ffolliott et al. 2008a). Three categories of fuel loading were arbitrarily assigned: "smaller fuels" up to 1 inch in diameter, "larger fuels" greater than 1 inch in diameter and "coarse woody debris" all fuels >3 inches in diameter. The authors reported that smaller fuels in the Emory oak savannas were less common than in the pine-oak forests and Emory oak woodlands, while no difference in smaller fuels between the pine-oak forests and Emory oak woodlands. The larger fuels were similar among the three ecosystems.

Ground Cover

Percentages of bare soil, rock, litter and plant material ground cover before the burning events measured in spring 2007 on the Cascabel Watersheds were 12.6, 33.3, 29.7 and 24.4, respectively (Ffolliott et al. 2008a).

Post-Fire Study Results

Fire Severity and Water Repellency

Stropki et al. (2009) studied fire severities by applying Hungerford's classification system discussed above. The researchers found that 95 percent of the plots on the watersheds experiencing either of the two prescribed burning treatments were exposed to low severity burning or were unburned, while the remaining 5 percents of plots were exposed to moderate burning. About 5 percent of plots on watersheds experiencing Whitmire Wildfire were not exposed to burning; nearly 75 percent of plots were classified as low severity burning and the remaining 20 percent were exposed to moderate severity burning. None of plots on the Cascabel Watersheds was observed to have experienced high severity burning. Pockets of high severity fire, however, occurred on some burning sites where heavy fuel loading had accumulated before the fires (Neary et al. 2008). It was concluded that the Cascabel Watersheds were exposed to low severity burning during the prescribed burning treatments and the wildfire.

Stropki et al. (2009) also evaluated water repellent soils on each of the 421 sampling plots on the Cascabel Watersheds after the burnings. They reported that 90 percent of plots did not exhibit water repellency, 5 percent of the plots occurred slight water repellency and a level of either moderate or strong levels of water repellency was measured on the remaining plots.

Side-Slope Soil Movement

Ffolliott et al. (2010a) determined the effects of the prescribing burning treatments and wildfire on the soil erosion and deposition in the hillslope of the Cascabel Watersheds. The first post-fire side-slope soil movement on watersheds with cool-season burning treatments was measured in spring 2008, approximately two months following the prescribed fire. Soil erosion measured on these watersheds shortly after the prescribed burning averaged 21.8 tons/acre while erosion averaged 13.4 tons/acre before the burning. However, the initial increase in post-fire soil erosion was only short-lived and erosion measured following the summer rains of 2008 and in 2009 was similar to the average of pre-burning soil erosion. Soil deposition measured in fall of 2008 on the watersheds experiencing the wildfire averaged 7.6 tons/acre, which was significantly different from the pre-fire average of 5.8 tons/acre on these watersheds. However, the measurements of soil deposition on these watersheds in spring and fall of 2009 were similar to pre-fire average.

Post-fire soil erosion and deposition measured in the fall of 2008 and spring and fall of 2009 was mostly similar to the corresponding pre-fire averages. This might be explained by the absence of widespread water repellent soils after the burning events which consequently caused little change in the overland flows of water necessary to transport soil particle downslope. The authors concluded that the low severity prescribed burning treatments and wildfire had relatively little effect on soil erosion and deposition in oak savannas on the Cascabel Watersheds.

Tree Overstories

Ffolliott et al. (Appendix B) evaluated the effects of cool-season and warm-season prescribed burning treatments and the wildfire on tree overstories in oak savannas on the Cascabel Watersheds. The post-fire measurements of tree overstories were delayed until the spring of 2009 to "allow" these effects of to be "fully" expressed. The researchers studied the initial survival, levels of crown damage, species compositions and densities, annual growth rates, basal sprouting and spatial distributions of trees following these three burning events. Some sampling procedures of tree overstories survey were discussed above. Crown damage to the tallied trees was classified as follows: no crown damage; less than 1/3 of the crown killed or scorched; between 1/3 and 2/3 of the crown killed or scorched; and more than 2/3 of the crown killed or scorched. Convection heating from surface fire was assumed to be the primary cause of crown damage to the trees due to the open tree overstories and low severity surface burnings on the Cascabel

Watersheds. Tree species, size class, level of crown damage and the status of basal sprouting were determined following the burning events.

The authors reported that nearly 79 percent of the trees (all species and size classes combined) tallied on the watersheds before the prescribed burning treatments and wildfire survived the burning events initially, with 80 percent of the oak trees (all three species and all size classes combined) surviving and 76 percent of the juniper trees (both species and all size classes combined) surviving. Species richness of the tree overstories was not impacted by the burns, with seven tree species tallied both before and after the burnings.

There were no differences in numbers of saplings or medium trees (all tree species combined) in the respective crown-damage classes. The number of large trees (all tree species combined) with 1/3 or more of their crowns killed or scorched by the burning events was greater than the number of large trees undamaged or that suffered damage to less than 1/3 damage of their crowns. This was attributed by the “large accumulations” of flammable fuels at the base of these trees before the burns. The density was reduced by 20 percent in the numbers and 15 percent in the volumes of trees (all species and size classes combined). There were 86 percent of the large trees, 88 percent of the medium trees, and 50 percent of the small trees with all tree species combined surviving the burns.

The estimated annual growth-rate of the tree overstories following the burning events was 0.056 ± 0.017 ft^3/acre, which was statistically similar to the estimate of 0.069 ± 0.023 ft^3/acre before the burns. Basal sprouting occurred on 37.4 percent of surviving oak trees (three species combined) while basal sprouting occurred on 11.0 percent of the juniper trees (both species combined). There was no consistent relationship observed between basal sprouting by trees after the burning events and the size of either the oak or juniper trees. There were also no significant relationships of basal sprouting by trees (all species combined) to the crown-damage classes with the exception of basal sprouting of trees with greater than 2/3 of their crowns either killed or scorched by the burns. The spatial distributions of trees (all species and size classes combined) were not impacted by the burning events on the Cascabel Watersheds.

Agave

Ffolliott et al. (2010b) studied the occurrence and production of *Agave palmeri* on the Cascabel Watersheds following three burning events. Since there was no corresponding information before the burning events, this paper only reported on the status of *Agave palmeri* following the burns. Occurrence was noted and the production of *Agave palmeri* was estimated in the fall of 2009 by applying the same sampling procedure as for herbaceous measurement. Since the occurrence and production (standing biomass) of *Agave palmeri* measured on the Cascabel Watersheds following the three burning events were similar, the respective data sets were pooled to describe the occurrence and production of *Agave palmeri* on the watersheds at the time of sampling. This study reported that *Agave palmeri* was found on 54 of the 417 sampling plots. Distribution was random and non-normal on the Cascabel Watersheds after the burning. There was no relationship of occurrence of *Agave palmeri* to topography (slope position, slope percent, or aspect) and surface condition (percent of rockiness, bare soil, or plant cover). The presences of the tree, shrubs or herbaceous plants on the plots were not related to the occurrence of *Agave palmeri*.

Ffolliott et al. (2010b) also reported that the average production (standing biomass) of *Agave palmeri* on the Cascabel Watersheds after the burnings was 0.25 lbs/acre, which was a fraction of one percent of the average production (134.2 lbs/acre) of all understory plants in fall of 2009. The range of average production of *Agave palmeri* on the individual Cascabel Watersheds was from a trace to almost 16.7 lbs/acre. The production levels of *Agave palmeri* was not related with either of watershed characteristics and production of the other plant species in the 9.6 ft^2 plots.

Ground Cover

The percentages of bare soil, rock, litter and plant material ground cover after the burning events measured in spring 2009 were 7.4, 42.1, 17.1 and 33.4, respectively (Figure 3). The fires consumed significant amount of litter, and also increased downed woody materials (including twigs and branches) which attributed an increase in plant material component.

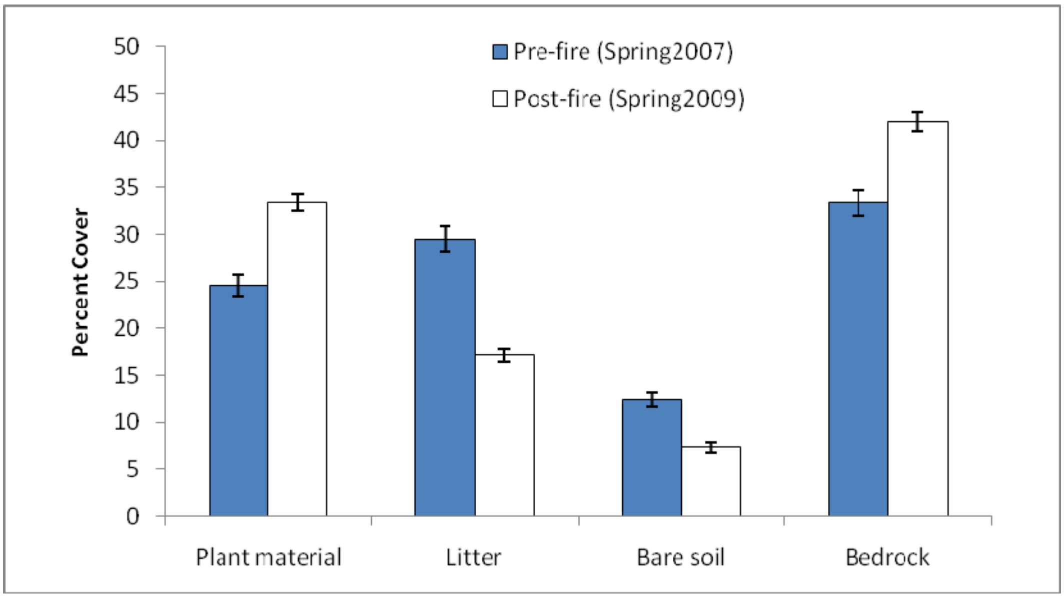

Figure 3: Average percentages and 90 percent confidence intervals of plant material, litter, bare soil, and bedrock in the ground cover of the Cascabel Watersheds before (spring 2007) and after (spring 2009) the burning events.

Birds

Oak savannas on the Borderlands Region provide food, cover, and sites for nesting, roosting, and perching for a diversity of bird species. Ffolliott et al. (2010) (Appendix C) studied the bird species, numbers of birds, and their diversities in the naturally occurring (unburned) oak savannas on the Cascabel Watersheds. This paper also described the effects of cool-season and warm-season prescribed burning treatments and the wildfire on bird species and numbers of birds on the Cascabel Watersheds. Sampling procedures were discussed above. Observations of birds before the burns were made in the spring and fall from 2003 through 2007. Tallies obtained in the fall of 2008 and in the spring and fall of 2009 were used to determine the effects of these burning events on bird species and number of birds. No records of birds were obtained in the spring of 2008 because of the warm-season prescribed burning treatment and the wildfire.

The authors reported that there were more bird species and numbers of birds tallied in the fall observations than the spring for both before and after the burning events with the exception of 2003, when there was little difference in the seasonal tallies. This may be attributed by a more abundant food supply in the summer months (as indicated by the fall tallies) than in the winter months (as signified by the spring counts). Some of the bird species were recorded only in few numbers while other species were observed more frequently in larger numbers throughout the study. Some neotropical migratory birds, tallied on the Cascabel Watersheds, typically breed in temperate climates and winter in tropical environments and use a diversity of habitats along their migration routes to obtain the resources needed for reproduction and survival. The cool-season and warm season prescribed burning treatments and wildfire had relatively little effect on the bird species and numbers of birds on the Cascabel Watersheds, which could be explained by little effect of the three burns events on the initial survival, crown damage, and basal sprouting of trees in the overstory (Appendix B).

CONCLUSIONS

Since all Cascabel Watersheds were exposed to low severity burning during the prescribed burning treatments and the wildfire, the effects of these burning events on ecosystems and hydrologic functioning were similar, relatively minor, and short-lived. Soil erosion and soil deposition measured after the fires were different from pre-burnings conditions. However, the initial changes were short-lived, and soil erosion and deposition measured in the fall of 2008 or spring and fall of 2009 were mostly similar to the corresponding pre-burning averages. Impacts of prescribed burning treatments and the wildfire on tree overstories were similar and relatively small. Effects on initial survival, levels of crown damage, species compositions and densities, annual growth rates, basal sprouting and spatial distributions of trees were relatively minor and were mostly inconsequential in terms of future management implications. Significant changes were observed in ground cover component percentages after the burning, with increases in plant material and bedrock, and decreases in litter and bare soil. The cool-season and warm season prescribed burning treatments and the wildfire had relatively little effect on the bird species and numbers of birds on the Cascabel Watersheds. Other evaluations of burnings impacts in oak savanna ecosystems on the Cascabel Watersheds, such as on herbaceous (forage) plants and wildlife populations and habitats, are currently underway, and will be published in the future.

MANAGEMENT IMPLICATIONS

The information obtained from the Cascabel Watersheds studies should be valuable to management agencies and ranchers since limited knowledge of ecological, hydrological and environmental characterizations are available for oak savannas in Southwestern Borderlands Region. Managers, who are interested in re-introducing natural fire regimes into oak savannas in this region, might use results from those burning events on the Cascabel Watersheds as "initial guideline" due to the small amount of information available on prescribed burning effects in the region. However, the results from the Cascabel Watersheds studies should be considered as case studies. It is unknown if the burning effects would be similar if low severity prescribed burning were applied on other sites in oak savannas in the region. It is also unknown whether fire effects would be similar in magnitude if low severity prescribed burning treatments are repeated on the Cascabel Watersheds. Additional evaluations of prescribed burning treatments with varying (higher) severity, varying frequencies and varying seasons are needed in order to broadly re-introduce a more natural fire regime to oak savanna ecosystems in the Southwestern Borderlands Region.

ACKNOWLEDGMENTS

This research and the preparation of this dissertation were supported by the Southwestern Borderlands Ecosystem Management Unit of the Rocky Mountain Research Station, Phoenix, Arizona and the Arizona Agricultural Experiment Station, University of Arizona, Tucson, Arizona. Supplemental funding was provided by the Air, Water, and Aquatic Environment Program of the Rocky Mountain Research Station, Flagstaff, Arizona. The Douglas Ranger District of the Coronado National Forest was responsible for the burning treatments.

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APPENDIX A:

A GEOGRAPHICALLY-REFERENCED MULTIPLE-RESOURCE DATA MANAGEMENT SYSTEM FOR THE OAK SAVANNAS OF THE MALPAI BORDERLANDS REGION

By

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Published in

Hydrology and Water Resources in Arizona and the Southwest
2009

ABSTRACT

Twelve watersheds in the oak savannas on the eastern side of the Peloncillo Mountains in the Southwestern Borderlands Region of New Mexico are being monitored to document the ecological and hydrologic characteristics, and (eventually) to determine the effects of burning treatments on this ecosystem. Ecological components monitored include tree overstories, loadings of fuel fractions, and occurrence of mammals and bird numbers and diversity. Hydrologic components monitored are streamflow regimes, soil erosion and deposition, and sedimentation. Watershed descriptors include for each watershed its designation, size, orientation, streamflow network, monitoring network and protocols, and physiographic characteristics. The geographically-referenced data sets are incorporated into the system to facilitate their spatial interpretations.

STRUCTURE OF SYSTEM

Twelve watersheds from 20 to 60 acres in size were established on the eastern slope of the Peloncillo Mountains in Southwestern New Mexico by the Rocky Mountain Research Station, U.S. Forest Service and their cooperators. These watersheds contain 421 permanent sampling plots, with 35 and 45 permanent sampling plots on each watershed. These plots are located along transects perpendicular to the main stream system and situated from ridge to ridge with an interval between the plots ranging from 70 to 240 feet depending on the size and configuration of the watershed.

The primary objective of the research on these watersheds is to determine the effects of burning treatments on the ecological and hydrologic dynamics in the oak savannas of the Southwestern Borderlands. A secondary objective is to gather baseline data to learn more about the ecological, hydrologic, and environmental characteristics of this ecosystem in the region (Gottfried et al. 2007).

A geographically-referenced multiple-resource data management system is under development to enable researchers, managers, and other stakeholders to store, interpret, and analysis datasets from the Cascabel watersheds with relative ease. The geo-spatial database (Figure 1) has been developed using Microsoft Access to manage and retrieve the datasets.

Data sets fall into three general categories: watershed descriptors, biological characteristics, and hydrological characteristic. Watershed descriptors describe the characteristics for each watershed including its designation, size, orientation, streamflow network, monitoring network and protocols, and physiographic characteristics. Biological components monitored are tree overstories, canopy cover, herbaceous understories, loadings of fuel fractions, ground cover, and mammals and birds. Hydrologic components include streamflow regimes, soil movement (both soil erosion and soil deposition), water repellency, sedimentation, and water quality (chemical) constituents.

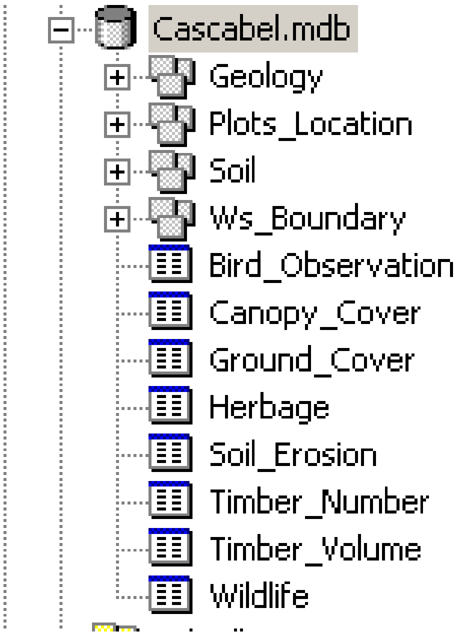

Figure 1: Outlook of Geodatabase

Global positioning system measurements have been taken to spatially reference the sampling plots, watersheds boundaries, and stream channels. As a result, geographically-referenced data can be incorporated into the data management system to facilitate spatial interpretations. Figure 2 shows the geodatabase named Cascabel.mdb including examples of feature data sets and tables (Geology, Soil, Plots_Location and Ws_Boundary). The feature data set of Plots_Location, for example, comprises 12 point feature classes describing the location of sampling plots on each watershed, while the feature data set of Ws_Boundary contains 12 polygon feature classes describing the boundary of each watershed. ARC GIS software is used to display the spatial distribution of data sets by joining the tables to feature classes based on the common fields they possess.

DATA SETS IN SYSTEM

Watershed Descriptors

Table 1 and Table 2 describe the physiographic characteristics of the watersheds and sampling plots. These tables are related by the common field presented in WatersehdName. The table of Plot_Physiography is also associated with other tables that contain field measurements based on sampling plots by the common field of LocationID.

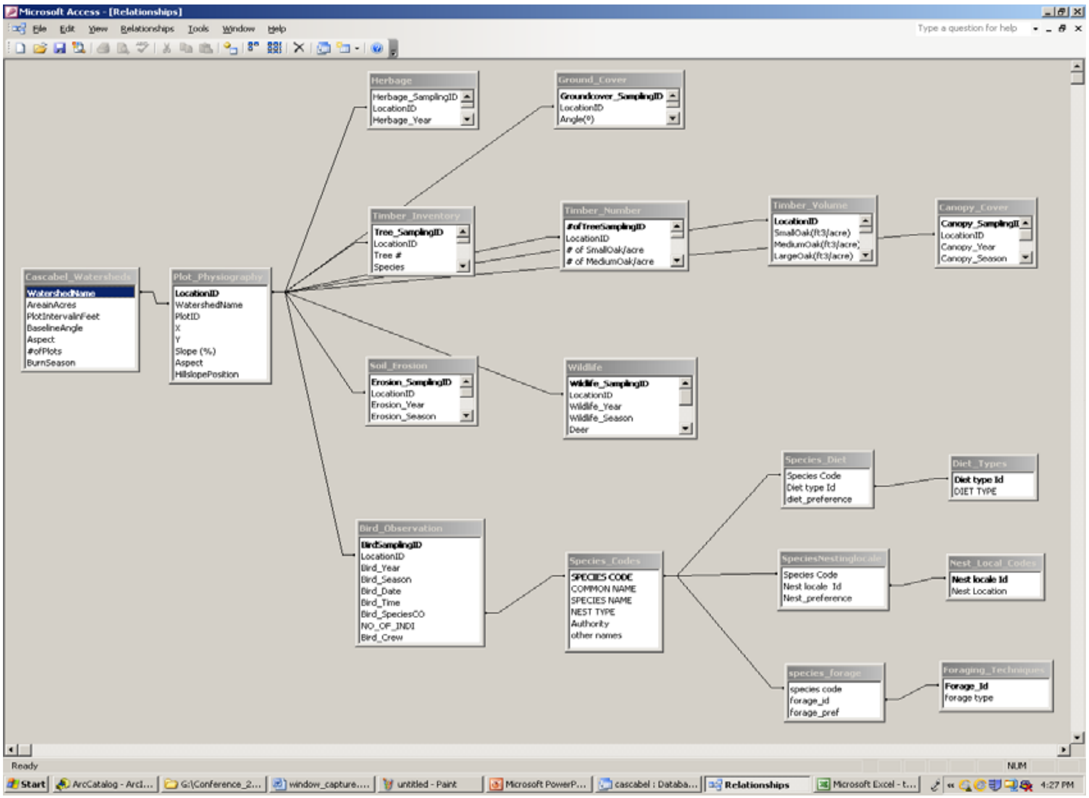

Figure 2: Outlook of the Related Database of Cascabel.mdb.

Table 1: Cascabel Watersheds

Watershed Name	Area (Acres)	Plot Interval (Feet)	Baseline Angle	Aspect	#ofPlots
A	31.5	80	N10W	South	34
B	38.8	90	N15W	South	36
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
N	29.6	70	S0	North	37

Table 2: Plot Physiography

Location ID	Watershed Name	PlotID	X	Y	Slope (%)	Aspect	Hillslope Position
A-01	A	1	-108.9915583	31.5334944	10	E	U
A-02	A	2	-108.9911694	31.5335556	0	S	L
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
N-37	N	37	-108.9727583	31.5331389	15	NE	L

Biological Characteristics

Tree Overstories

One-quarter-acre plots were established to measure species compositions and tree characteristics in terms of diameter root collar for single stem trees, equivalent diameter root collar for multiple stemmed trees, and total height. The tree overstory component of the database is displayed in Figure 3. The field data are transcribed into a table called Timber_Inverntori, where the field data can be summarized by number of trees, basal area, and volume per acre. Canopy cover measured in percent closure is also included in the data.

Herbaceous Understories

The production (biomass) of the herbaceous understory is estimated seasonally at each sampling plot by the weight-estimate procedure originally outlined by Pechanec and Pickford (1937) in 9.6-ft^2 circular plots. Seasonal (spring and fall) species composition and the estimated production of grasses, forbs, and shrubs are recorded. The three categories of grasses, forbs, and shrubs are summed together to determine total herbage production. An example of how the records of Herbage_Production are displayed is shown in Table 3.

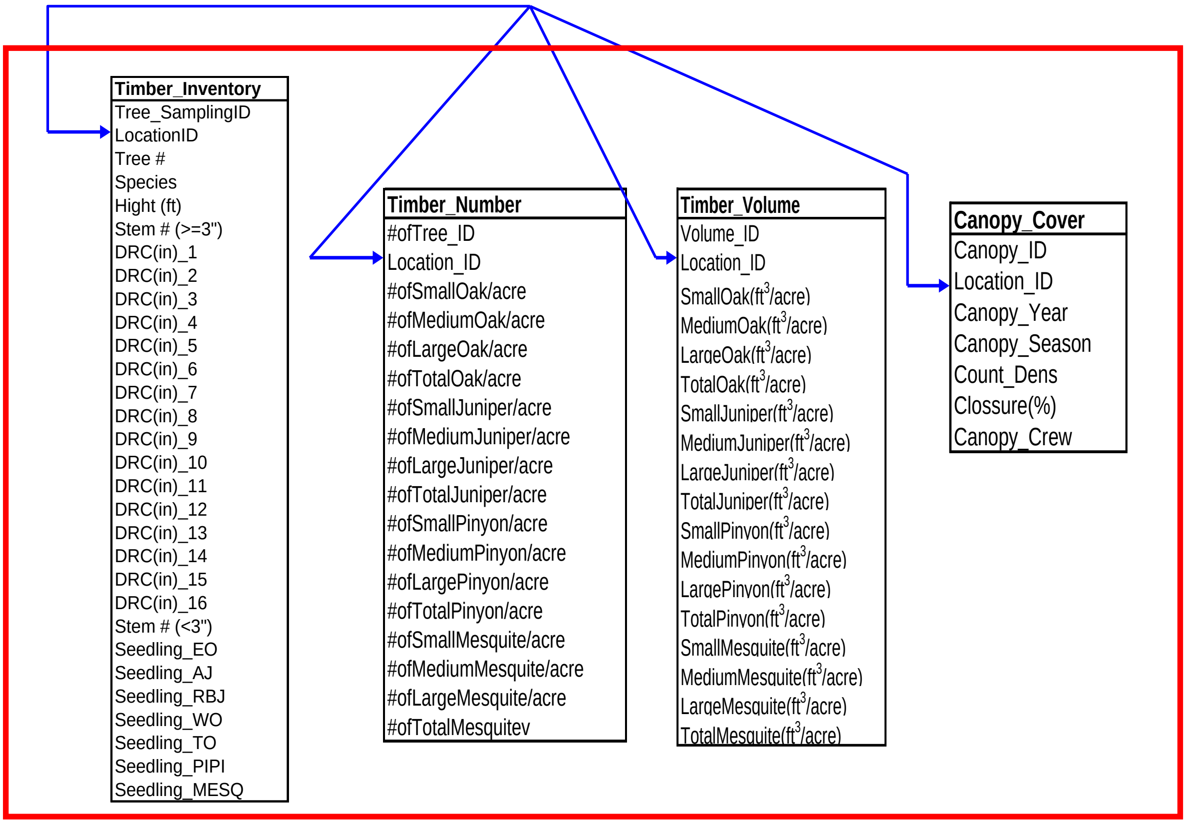

Figure 3: Tree Overstory Component in the database.

Table 3: Herbage Production

Herbage Sampling ID	Location ID	Herbage Year	Herbage Season	Total (lbs/acre)	Grass (lbs/acre)	Forbs (lbs/acre)	Shrubs (lbs/acre)	Herbage Crew
1	A-01	2004	Spring	20.6	20.6	0	0	CLS
2	A-02	2004	Spring	103	97.85	5.15	0	CLS
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
3672	N-37	2007	Fall	230	161	69	0	CLS

Loadings of Fuel Fractions

Loadings of fuel fractions on the Cascabel Watershed have been measured. These fractions are the standing trees, herbaceous understories, downed woody material, and organic matter represented by the litter and duff layers. The fractions consisting of standing trees and herbaceous understories are estimated through interpretations of these respective components of the data management system. Estimates of the downed woody materials and organic matter fractions are obtained by the methods of Brown et al. (1982).

Ground Cover

The percentages of plant material, litter, bare soil and bedrock on the ground surface are estimated annually at each of sampling plot. These measurements are often indictors of hillslope erosion rates (Renard et al.1997) and the successional status of vegetative communities (Bedell 1988). Ground cover is estimated in a rectangle frame of 12-by-18 inches placed at three equally spaced locations within 3 feet of the sampling plots. Table 4 shows how the records in the table of Ground_Cover are displayed within the system.

Table 4: Ground Cover

Ground cover Sampling ID	Location ID	Angle (º)	Ground cover Year	Ground cover Season	Bare Soil (%)	Rock (%)	Litter (%)	Plant Material (%)	Ground cover Crew
1	A-01	0	2007	spring	0	55	15	30	HC
2	A-01	120	2007	spring	0	90	10	0	HC
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
1266	N-37	240	2007	spring	0	0	90	10	CLS

Mammals

The presence of mammals is measured seasonally by counting fecal pellet on [40.5 m2] circular plots centered over each sampling location. The mammals recorded are deer, cottontail, and coyote. The fecal deposits are cleared from the plot after each counting and, therefore, the seasonal use of the habitats on a watershed can be estimated. Table 5 displays the records in the wildlife section of the database.

Avifauna

Species and numbers of birds sighted in a 5-minute observation period at every third plot on the watersheds is the method used to obtain avifauna data (Ralph et al.1995). Bird tallies are made between 0800 and 1130 hours on clear or partly cloudy days when minimal wind movement exists. The table Bird_Observation presents the time and location of the tallies. An avifauna sub-database (Figure 4) was developed to enable a user of the system to retrieve comprehensive information for each bird species tallied. Examples of the information that is available on this sub-database are the species scientific name, common name, diet type, forage technique, and nesting location.

Table 5: Wildlife

Wildlife Sampling ID	Location ID	Wildlife Year	Wildlife Season	Deer	Cotton tail	Coyote	Other	Wildlife Crew
1	A-01	2003	Fall	2	45	0	0	WJ
2	A-02	2003	Fall	0	0	0	0	WJ
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
3339	N-37	2006	Fall	0	0	0	0	AK&CLS

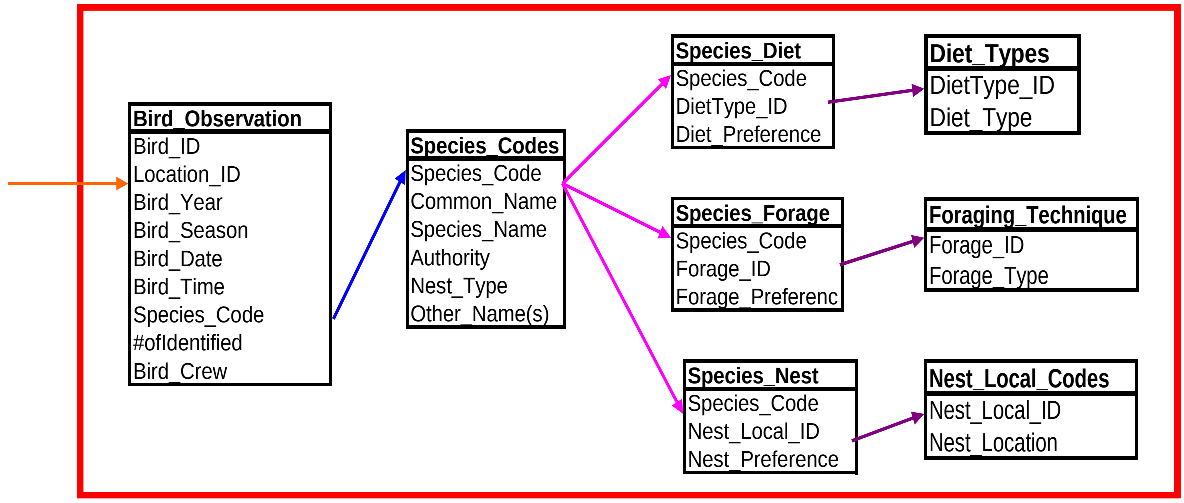

Figure 4: Avifauna sub-database developed by Beth Willaims.

Hydrologic Characteristics

The hydrological components in data management system at this time are soil movement in terms of soil erosion and soil deposition. Other hydrological components to eventually be incorporated into the system include the characteristics of streamflow regimes, channel cross-sections, sediment accumulations, and channel erosion-degradation.

Soil erosion and soil deposition were measured seasonally (spring and fall) using the erosion-pin method. Implementation of this method involved the installation of three erosion pins around every third plot with two pins located 6-feet upslope and one pin is located 6-feet downslope of a plot center. Soil movement is measured by the distance from the cap of a pin to the soil surface (soil erosion) or the accumulation of soil on top of the cap (soil deposition). After of the measurements are taken, the erosion pins are re-set to be flush with the soil surface to facilitate the subsequent measurements. Table 6 displays records in the table of Soil_Erosion, with positive measurements representing soil erosion, negative measurements representing soil deposition, and a number of 0 implying soil erosion and deposition are equivalent at the pin location during that sampling time.

Table 6: Soil Movement

Erosion Sampling ID	Location ID	Erosion Year	Erosion Season	Pin1 Depth (mm)	Pin2 Depth (mm)	Pin3 Depth (mm)	Erosion Comments	Erosion Crew
1	A-01	2004	Fall	7	0	8		CLS&DVZ
2	A-04	2004	Fall	7	-	-	Pins 2 and 3 not found replaced	CLS&DVZ
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
1314	N-37	2008	Fall	1	0	1		AK

RETRIEVAL OF DATA AND OTHER INFORMATION

These data sets contained in the data management system sets make Cascabel.mdb a comprehensive geo-spatial database. One-to-one or one-to-many relationships are created within all the tables on the system, with established relationships enabling a user to move data from more than one table to satisfy a request for information request. The tables are related with each other through pathways and through relationships between any two tables that possess either a one-to-one or one-to-many relationship. Retrieval of data is made by a function of QUERY in the MS Access. A query posed to the data management system by a user navigates through all of the tables to find and list all of the records that satisfy the question asked (Habraken 2000). The format of the query results in the form of a table that can be helpful when further analysis is needed.

ACKNOWLEGEMNT

This research and preparation of this paper were supported by the Southwestern Borderlands Ecosystem Management Unit of the Rocky Mountain Research Station, U.S. Forest Service, Phoenix, Arizona, and the Arizona Agriculture Experiment Station, University of Arizona, Tucson, Arizona.

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APPENDIX B:

FIRE EFFECTS ON TREE OVERSTORIES IN THE OAK SAVANNAS OF THE SOUTHWESTERN BORDERLANDS REGION

By

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In Final Processing

Research Paper Published by the Rocky Mountain Research Station,
U.S. Forest Service, Fort Collins, Colorado
2011

ABSTRACT

Effects of cool-season and warm-season prescribed burning treatments and a wildfire on tree overstories in oak savannas on the Cascabel Watersheds of the Southwestern Borderlands Region are reported in this paper. Information on the initial survival, levels of crown damage, species compositions and densities, annual growth rates, and basal sprouting following these burning events is presented. Impacts of the fires on spatial distributions of trees in the overstories are also described. These events were all low fire severities. As a consequence, effects of the prescribed burning treatments and the wildfire on tree overstories of the watersheds were similar and, therefore, the data sets were pooled. Effects of these fires on the tree overstories were largely minor and often insignificant in terms of future management implications.

Keywords: Fire effects, oak savannas, prescribed burning, southwestern United States, tree overstories, wildfire

CONTENTS

Introduction

Cascabel Watersheds

Prescribed Burning Treatments and the Wildfire

Fire Severities

Study Protocols

- Sampling Basis
- Tree Overstory Measurements
- Analytical Procedures

Results and Discussion

- Initial Survival of Trees
- Crown Damage
- Densities
- Annual Growth
- Basal Sprouting
- Spatial Distributions of Trees

Conclusions

Management Implications

Acknowledgments

References

INTRODUCTION

Fire was a natural part of the ecosystems of the Southwest Borderlands before Euro-American settlement of the region. Fires caused by lightning activity in the spring and early summer before the onset of monsoon rains limited establishment of trees and maintained a landscape diversity of grasslands, savannas, and woodlands. Tree-ring evidence suggests that fires occurred every 5-to-10 years in the ecosystems long the United States-Mexico border prior to settlement (Kaib and others 1999). However, natural fire frequencies, their burning characteristics, and subsequent impacts of ecosystem resources have been altered since the late 1800s, largely because of past livestock grazing practices that removed significant portions of the fire-carrying herbaceous vegetation and past (aggressive) fire suppression policies of management agencies (Edminster and others 2000, Fulé and Covington 1995). These past practices and policies have resulted in "unnaturally high" tree densities on many sites, making trees more susceptible to insects, diseases, and stand-replacing wildfire and a decline in herbaceous plants in the understories. Excessive accumulations of flammable surface fuels are also found in the region and mesquite (*Prosopis*) and other woody plants have invaded many otherwise productive grasslands.

As a consequence of the generally undesirable conditions often encountered, land management agencies with support from their collaborators including private organizations and local stakeholders are interested in re-introducing "more historical fire regimes" into many of the ecosystems in the region (Edminster and Gottfried 1999, Gottfried and others 2000, 2007; Gottfried and Edminster 2005). Included among these ecosystems are the oak savannas, a plant community situated between the higher-elevation and more densely stocked oak woodlands and lower-elevation grassland and shrub communities. However, managers need more information about the impacts of burning on ecosystem resources in the oak savannas before they can initiate such a program. A first step in the general process of obtaining this information is evaluating the effects of prescribed burning treatments on these ecosystems resources. One of the more important ecosystem resources are the tree overstories.

Effect of cool-season and warm-season prescribed burning treatments and a wildfire on tree overstories in the oak savannas of the Malpai Borderlands, an area of approximately 802,750 acres within the larger Southwestern Borderlands Region, is the focus of this paper. The information presented should be useful in developing management strategies necessary for a re-introduction of “more natural fire regimes” into the oak savannas to increase site productivity and landscape diversity while maintaining environmental integrity.

CASCABEL WATERSHEDS

Twelve small watersheds, ranging from 20 to almost 60 acres in size, in the Peloncillo Mountains of southwestern New Mexico (Gottfried et al. 2000, Gottfried and Edminster 2005) collectively comprised the study areas (fig. 1). The areal aggregation of these watersheds, called the Cascabel Watersheds, is 451.3 acres. The watersheds are

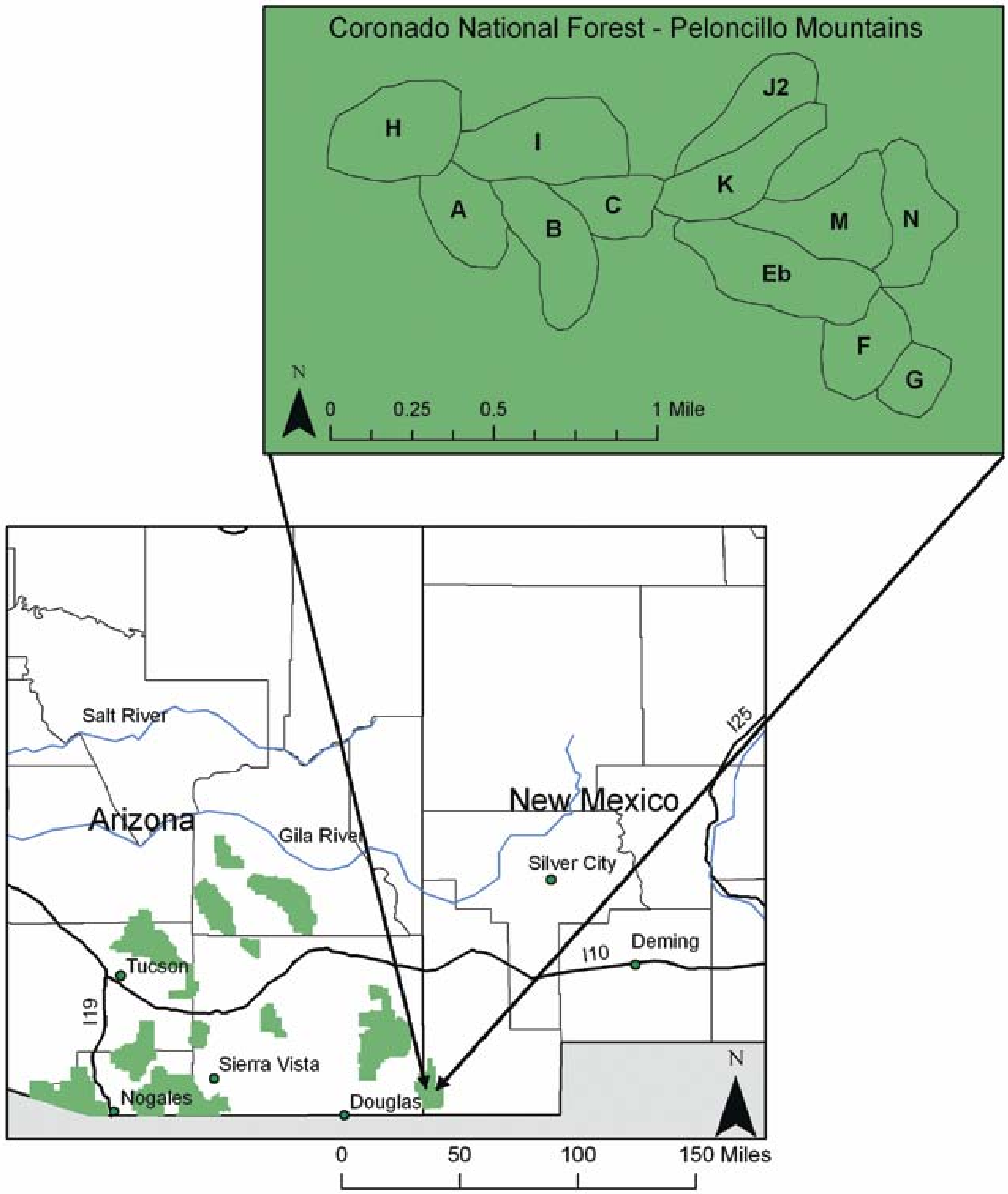

Figure 1. The Cascabel Watersheds (arrow) are located in the oak savannas of the Malpai Borderlands, an area of approximately 802,750 acres within the larger Southwestern Borderlands Region (from Ffolliott and others 2008b).

situated between 5,380 and 5,590 feet in elevation. The nearest long-term precipitation station indicates that annual precipitation averages 23.5 inches, with nearly one-half of the precipitation occurring in the summer monsoonal season. However, a prolonged drought was impacting the area from the middle of the 1990s continued through the time of the burning events on the watersheds. Precipitation during this drought period averaged 14.9 inches annually.

Emory oak (*Quercus emoryi*) was the dominant tree species in the overstories on the watersheds before the burns followed by alligator juniper (*Juniperus deppeana*). Intermingling Arizona white (*Q. arizonica*), and Toumey *(Q. toumeyi*) oak, redberry juniper (*J. coahuilensis*), border pinyon (*Pinus discolor*), and the tree-form of mesquite (*Prosopis velutina*) were minor overstory components (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). The term **tree overstories** refers to these tree species regardless of their respective size or position in the canopy in this paper.

Perennial grasses were blue (*Bouteloua gracilis*), sideoats (*B. curtipendula*), slender (*B. repens*), and hairy *(B. hirsuta*) grama; and bullgrass (*Muhlenbergia emersleyi*), common wolfstail (*Lycurus pheoides*), and Texas bluestem (*Schizachyrium cirratum*). Forbs species of mariposa lily (*Calochortus* spp.), verbena (*Verbena* spp.), and lupine (*Lupinus* spp.) were minor components of the understory plants. Beargrass (*Nolina microcarpa*), fairyduster (*Calliandra eriophylla*), common sotol (*Dasylirion wheeleri*), manzanita (*Arctostaphylos pungens*), Fendler's ceanothus (*Ceanothus fendleri*), and Mexican cliffrose (*Purshia mexicana*) were among the occasional half-shrub and shrubs.

Shrub-forms of mesquite were present on many sites. Palmer's century plant (*Agave palmeri*) and banana yucca (*Yucca baccata*) were scattered succulents on rocky slopes. Annual plants were largely absent.

Geologic, physiologic, and hydrologic characteristics of the Cascabel Watersheds are described elsewhere by Gottfried and others (2000, 2007), Hendricks (1985), Neary and Gottfried (2004), Osterkamp (1999), Robertson and others (2002), Vincent (1998), and Youberg and Ferguson (2001). Bedrock geology is Tertiary rhyolite overlain by Oligocene-Miocene conglomerates and sandstone. Soils are classified as Lithic Argustolls, Lithic Haplustrolls, or Lithic Ustorthents. These shallow soils are generally less than 20 inch to bedrock. Streamflow originating on the watersheds is intermittent with the larger flows generated by storms of high-intensity rainfall (Gottfried and others 2006).

PRESCRIBED BURNING TREATMENTS AND THE WILDFIRE

The original objective of the research program on the Cascabel Watersheds was to evaluate the effects of warm-season (May through October) and cool-season (November through April) prescribed burning treatments on the natural resources of the watersheds including the tree overstories. It was anticipated that these evaluations would be compared to control (unburned) watersheds in determining these fire effects. Following the required watershed calibration period, four of the watersheds were burned during the cool-season in early March 2008. Three of the four watersheds to be burned in the warm-season were burned on May 20, 2008 with burning of the fourth watershed delayed until at a later date because of shifting weather conditions. However, wind gusts up to 60 mph on the morning of May 21, 2008 blew firebrands onto the remaining watershed scheduled for warm-season burning and the four control watersheds. The resulting wildfire, designated the Whitmire Wildfire, crossed the boundary lines of the watersheds and spread beyond these watersheds to burn almost 4,000 acres. The original objective of the research on the Cascabel Watersheds had to be modified, therefore, to evaluate the effects of cool-season and warm-season prescribed burning treatments and Whitmire Wildfire on tree overstories of the watersheds.

FIRE SEVERITIES

A system that relates fire severity to the soil-resource response to burning (Hungerford 1996) was the basis for classifying severities of the cool-season and warm-season prescribed burning treatments and the wildfire at the 421 sample plots on the watersheds (see below). This system of classifying fire severities relates post-fire appearance of litter, duff, and woody material and soil conditions to discrete classes of severity ranging from low to medium to high. Details of the system are found in DeBano and others (1998), Neary and others (2005), and Wells and others (1979). Classifications of fire severity at the sample plots were extrapolated to a watershed-basis to determine the percentages of each of the Cascabel Watersheds that were unburned or burned at low, moderate, or high fire severities.

Extrapolations to a watershed-basis indicated that 85 percent of the four watersheds experiencing the cool-season prescribed burn had been exposed to a low severity fire; a moderate fire severity had occurred on 5 percent of the watersheds; and the remaining 10 percent of the watersheds were unburned (Stropki and others 2009). Spatial distributions of fire severities on the watersheds experiencing the warm-season prescribed burn and wildfire were similar to the distributions of fire severities of the cool-season burn (fig. 2). It was concluded, therefore, that the Cascabel Watersheds (collectively) had been exposed to low fire severities by the three events. Occurrence of these low fire severities was attributed largely to the discontinuous and generally limited accumulations of flammable fuels before the burns (Ffolliott and others 2006, 2008a) and the relatively high wind-speeds during burning events (M. Harrington, 2010, personal correspondence).

A high fire severity was not observed on the sample plots. However, there were scattered sites on the watersheds where high fire severities occurred where pockets of "heavy accumulations" of litter, duff, and other organic debris had built up before the burning events (Neary and others 2008).

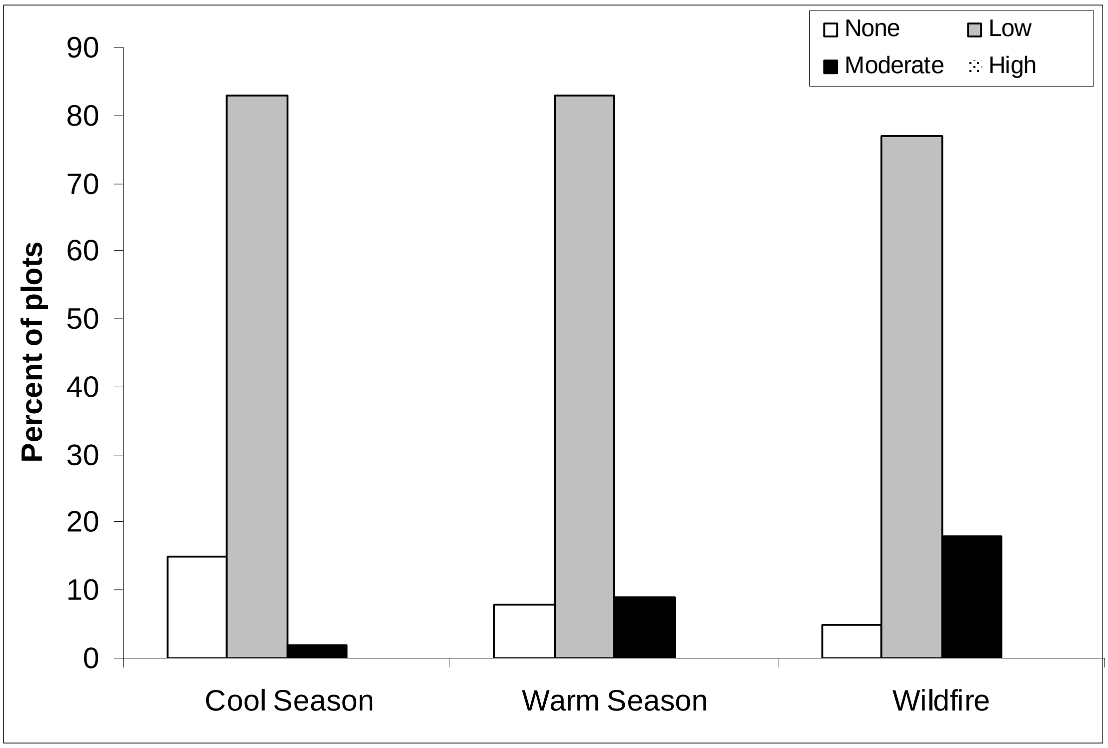

Figure 2. Fire severities of the cool-season and warm-season prescribed burning treatments and the Whitmire Wildfire on the Cascabel Watersheds (from Stropki and others 2009). Fire severities shown are based on a classification system relating fire severity to the soil-resource response to burning (Hungerford 1996).

STUDY PROTOCOLS

Sampling Basis

On each of the Cascabel Watersheds, between 35 and 45 sample plots were located along transects perpendicular to the main stream system and situated from ridge to ridge to provide the sampling basis to obtain data on ecosystem resources. Intervals between the plots varied with the size and configuration of the watershed sampled. A total of 421 sample plots were established on the watersheds. This sampling design was used to the collect data necessary to determine effects of the prescribed burning treatments and wildfire on the tree overstories. It has also been the sampling-basis for collecting data sets in other studies of the ecosystem resources on the watersheds (including Ffolliott and Gottfried 2005, Ffolliott and others 2005, 2008b, Gottfried and others 2007, Stropki and others 2009).

It was necessary to delay the measurements of the effects of the prescribed burning treatments and wildfire on the tree overstories until the spring of 2009 to "allow" these effects of to be "fully" expressed. A one-to-two-year delay in determining the effects of fire on oak trees, the dominant trees in the overstories of the Cascabel Watersheds, had been recommended earlier by Plumb (1980) who investigated the response of California oak species to fire. Mortality of oak trees in this California study was observed up to two-to-three years following a fire.

Oak species on the Cascabel Watersheds become “drought-deciduous” in prolonged periods of drought. Because the Southwestern Borderlands region was experiencing drought conditions before, during, and following the three burning events on the watersheds, it was also necessary that measurements of fire effects be delayed until “post-fire foliage” was observed on the trees to distinguish effects of the burning events from effects of the prevailing drought conditions. Furthermore, post-fire basal sprouting of the tree species on the watersheds can be initiated up to one year after a fire (Caprio and Zwolinski 1992) and, importantly, the extent of this “reproductive mechanism” was necessary in determining the future sustainability of post-fire tree overstories.

Tree Overstory Measurements

Measurements to evaluate effects of the burning events on tree overstories were obtained on trees tallied on 1/4-acre plots centered over the established sample-plot locations. Diameters at the root collar (drc) of single-stemmed trees surviving the burning events were measured while equivalent diameters at the root collar (edrc) were measured on multiple-stemmed trees following the procedures outlined by Chojnacky (1988). These measurements had also been obtained in earlier studies of tree overstories on the watersheds (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). A relationship between drc (edrc) and total height of the trees developed in the earlier studies was deemed appropriate for constructing a local volume table (Avery and Burkhart 2001) to estimate volumes of the tree overstories following the burns. Tallied trees were grouped into size-classes corresponding to those specified by O'Brien (2002) to describe the tree resources of the "woodland types" of Arizona. Saplings were trees 1.0 to 4.9 inches drc (edrc), medium trees were 5.0 to 8.9 inches drc (edrc), and large trees 9.0 inches drc (edrc) and larger.

Crown damage to the tallied trees was classified as follows:

$ No crown damage.

$ Less than 1/3 of the crown killed or scorched.

$ Between 1/3 and 2/3 of the crown killed or scorched.

$ More than 2/3 of the crown killed or scorched.

It was unknown if the damage to tree crowns had resulted from convection heat of a surface fire or a crown fire that spread from one tree to another tree independent of a surface fire. Crown damage can also be caused by fire-impingement to the tree bole. Because of the open tree overstories on the Cascabel Watersheds, and because the three burning events on the watersheds were largely surface fires, convection heating from surface fire was assumed to be the primary cause of crown damage to the trees.

Annual volume growth of trees in the overstories (all species combined) was estimated by applying the variable-density yield table (Fowler and Ffolliott 1995) procedure followed in the earlier studies of tree overstories on the watersheds (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). This yield table presents estimates of cubic-foot volume per acre as a function of stand age, site quality values (Callison 1988), and tree overstory density in square feet of basal area per acre. Pre- and post-fire estimates of volumes obtained by this procedure were compared to determine the effects of the prescribed burning treatments and wildfire on one-year volume growth.

Basal sprouting by trees was recorded in terms of species, size class, and the level of crown damage to determine its status following the burning events. Many of the tree species inhabiting the oak ecosystems in the Southwestern Borderland region are capable of reproducing vegetatively with basal sprouting as the most common mechanism (Borelli and others 1994, Ffolliott 2002, McPherson 1992, 1997). It was not possible to adequately evaluate the effects of the burns on basal sprouting, however, because occurrences of basal sprouting had not been tallied before the burning events occurred. Such a comparison with unburned trees could have been made if the control watersheds had not burned.

Spatial distributions of the tree overstories following the burning events were compared to pre-fire spatial distributions (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) to determine the effects of the burning events on overstory stocking conditions. The respective pre- and post-fire coefficients of variation for the different parameters were the basis for making these comparisons.

Analytical Procedures

Tallied trees grouped by size-classes (O'Brien 2002) were evaluated to determine the effects of the burning events on initial survival, crown damage, densities, and basal sprouting of trees at a 0.10 level of significance. Because the three size classes (saplings, medium, and large trees) were nested within the overall tests of all of the size-classes in the tree overstories, individual tests of the three size-classes were evaluated separately by a Bonferroni adjustment to maintain the overall 0.10 level of significance. Pre-burning measurements of tree overstories on the watersheds had been analyzed by the same protocols (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). Respective confidence intervals for pre- and post-fire annual growth estimates were compared at a 0.10 level of significance. Coefficients of variation for the pre- and post-fire spatial distributions of trees were also compared at a 0.10 level of significance. The number of tree species (species richness) and species evenness (how equally abundant species are) before and after the three burning events (Magurran 2004) were indicative of effects of the burns on ecological diversity of the tree overstories.

RESULTS AND DISCUSSION

The data sets collected on the watersheds experiencing the prescribed burning treatments and wildfire were statistically similar. This finding was not surprising, however, because all Cascabel Watersheds had been exposed to low fire severities (Stropki and others 2009). Therefore, the respective data sets were combined to evaluate effects of the three burning events on the tree overstories.

Initial Survival of Trees

Almost 79 percent of the trees (all species and size classes combined) tallied on the watersheds before the prescribed burning treatments and wildfire (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) survived the burning events initially (fig. 3). More specifically, 80 percent of the oak trees (all three species and all size classes combined) survived the burns while 76 percent of the juniper trees (both species and all size classes combined) survived. Border pinyon trees and the tree-form of mesquite were too few in number on the watersheds to effectively evaluate their respective survival. Oak trees continued to dominate in the overstories on the watersheds after the burning events followed (in descending order) by juniper trees, border pinyon trees, and the tree-form of mesquite.

Seven tree species were tallied on the watersheds before the burning events (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) and seven species were present after the events. Species richness of the tree overstories, therefore, was not impacted by the prescribed burning treatments. One species, Emory oak, was "especially abundant" both before and after the burns, however, indicating a low ecological diversity of tree overstories trees on the watersheds.

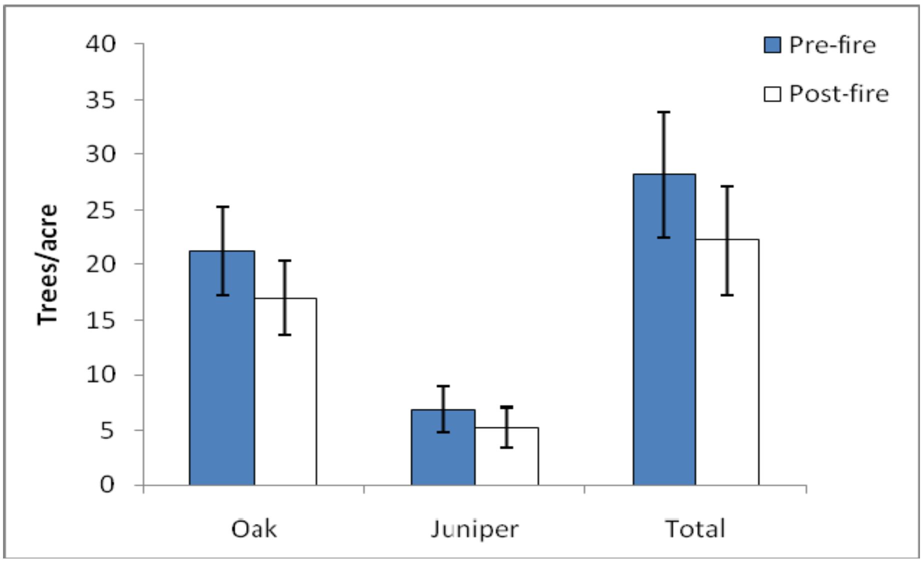

Figure 3. Average numbers of oak trees (three species combined) and juniper trees (both species combined) per acre and 90 percent confidence intervals before (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) and after the prescribed burning treatments and the wildfire on the Cascabel Watersheds. Border pinyon trees and the tree-form of mesquite were too few in numbers to include in the figure.

Crown Damage

The numbers of oak (three species combined) and juniper (both species combined) are shown in relation to their observed crown-damage classes in figure 4. The crowns of 80 percent of the surviving oak trees were killed or scorched by the burning events with 30 percent of these trees suffering damage to less than 1/3 of their crowns, 45 percent with damage to 1/3 to 2/3 of their crowns, and 25 percent with damage to more than 2/3 of their crowns. The crowns of 80 percent of the surviving juniper trees suffered damaged by the burns with 37 percent of these trees exhibiting damage to less than 1/3 of their crowns, 53 percent with damage to 1/3 to 2/3 of their crowns, and 10 percent with damage to more than 2/3 of their crowns. Crown damage to border pinyon trees and the tree-form of mesquite was not evaluated in the study because of their limited occurrence on the watersheds. The levels of crown damage observed to the trees surviving the burning events on the Cascabel Watersheds could be indicative what one might expect following a low severity surface fire in the oak savannas of the region.

With all tree species considered together, there were no differences in the numbers of saplings or medium trees in the respective crown-damage classes. However, the number of large trees with 1/3 or more of their crowns killed or scorched by the burning events was greater than the number of large trees that were undamaged or suffered damage to less than 1/3 damage of their crowns. The more severe damage to the crowns of large trees was attributed largely to the “large accumulations” of flammable fuels at the base of these trees before the burns.

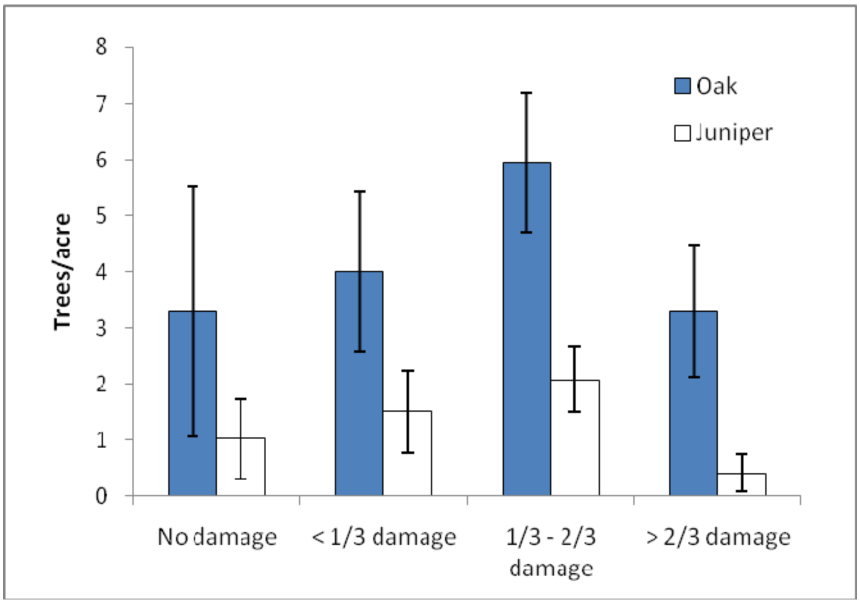

Figure 4. Levels of crown damage suffered by oak trees (three species combined) and juniper trees (both species combined) on the Cascabel Watersheds as a result of the prescribed burning treatments and wildfire. Border pinyon trees and the tree-form of mesquite were too few in numbers to include in the figure.

Trees with crowns that have been killed or severely scorched by the burning events (that is, more than 2/3 of their crowns damaged) often die eventually. (According to Fowler and Sieg [2004] in their review of criteria for predicting post-fire tree mortality, trees in montane forests of the western regions of the United States with severely scorched crowns frequently suffer mortality.) However, it is possible that many of these trees were not root-killed and, therefore, are capable of producing basal sprouts in the future.

Densities

There was a reduction of almost 20 percent in the numbers and about 15 percent in the volumes of trees (all species and size classes combined) in relation to the numbers and volume of trees before the burning events occurred (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) as a consequence of the burns. Some tree species and size classes, for example, oak and juniper trees in the two largest size classes, appeared to be more "resilient" to burning than others in terms of density reductions.

Numbers of Trees

Paralleling the frequencies of occurrence of trees in the overstories on the Cascabel Watersheds prior to burning (Ffolliott and Gottfried 2005, Ffolliott and others 2008b), oak (three species combined) dominated the numbers of trees after the burning events followed by juniper trees (both species combined) as shown earlier in figure 3. While not presented in this figure, the number of juniper trees surviving the burns was greater than the numbers of either border pinyon trees or the tree-form of mesquite following the burns.

A greater number of large trees (all species combined) survived the prescribed burning treatments and wildfire than either the medium or small trees (fig. 5). However, there also were a greater number of large trees on the Cascabel Watersheds before the burning events occurred (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). In terms of percentages of the surviving trees, 86 percent of the large trees, 88 percent of the medium trees, and 50 percent of the small trees survived the burns.

Volumes of Trees

A local volume table based on values calculated by Chojnacky (1988) was applied in converting the numbers of trees per acre following the burning events to corresponding estimates of cubic-foot volumes. These values had also been used in estimating the volumes of trees before burning occurred (Ffolliott and Gottfried 2005, Ffolliott and others 2008b).

Effects of the burning events on volumes of oak and juniper trees (all size classes combined) in comparison to the volumes before the burning events (Ffolliott and Gottfried 2005, Ffolliott and others 2008b) are shown in top of figure 6. The dominance of oak relative to juniper trees on the Cascabel Watersheds is evident in this portion of the figure. Both of the tree species lost (essentially) the same percentage of their volumes

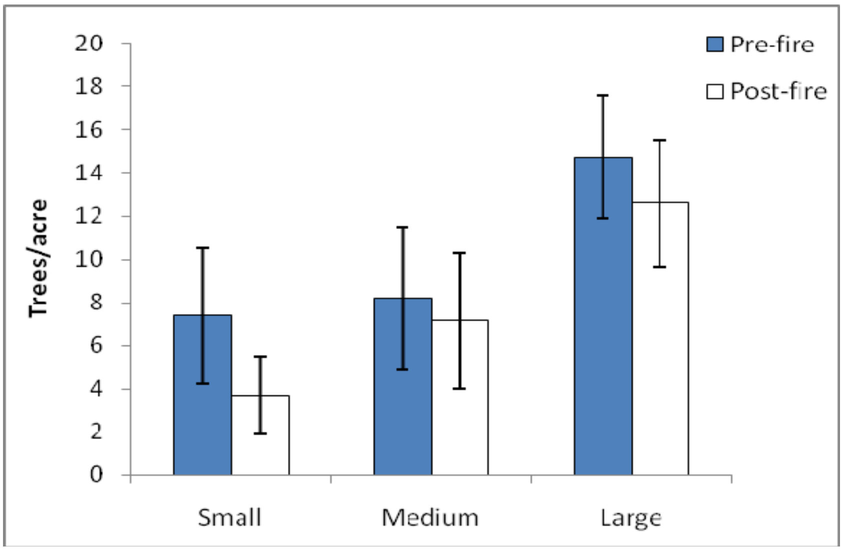

Figure 5. Average numbers of trees (all species combined) per acre trees by size classes and 90 percent confidence intervals before and after the prescribed burning treatments and the wildfire on the Cascabel Watersheds. Border pinyon trees and the tree-form of mesquite were too few in numbers to include in the figure.

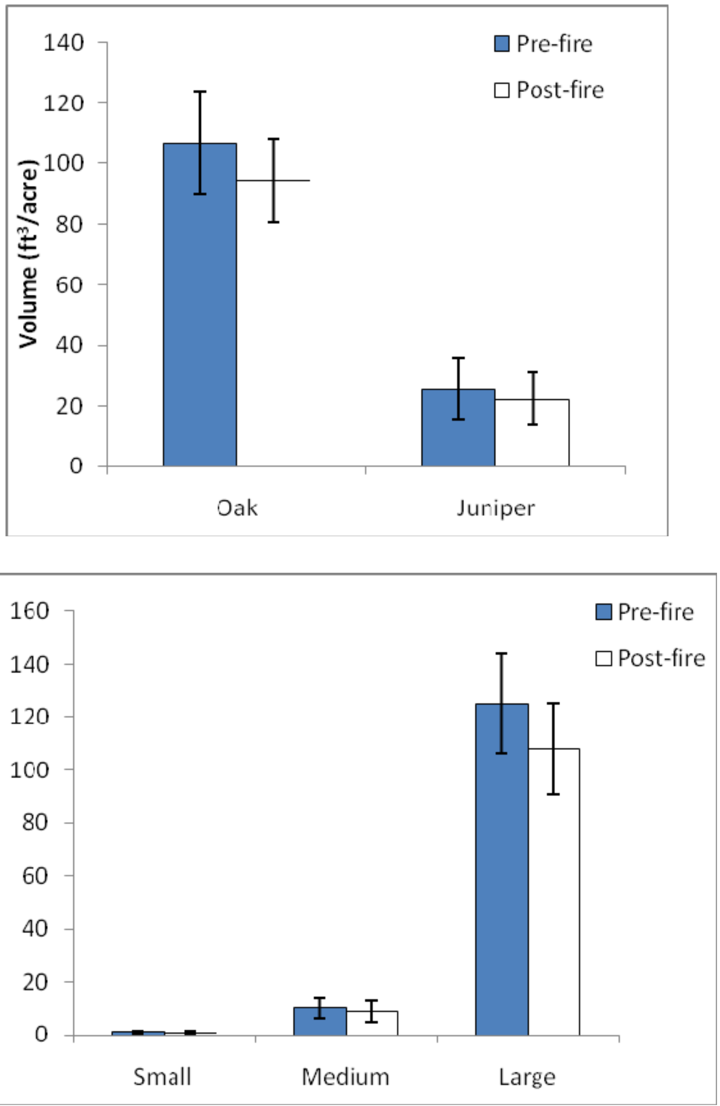

Figure 6. Impacts of the prescribed burning treatments and the wildfire on volumes of oak trees (three species combined) and juniper trees (both species combined) on the Cascabel Watersheds by species (top) and size classes (bottom). Scales of the Y-axis are unique for each portion of the figure. Border pinyon trees and the tree-form of mesquite were too limited in volume to include in the figure.

in the burns, however, with oak trees losing 12 percent and juniper trees losing 13 percent of their respective volumes. Volumes of border pinyon trees and the tree-form of mesquite lost to the burns were insignificant.

Not surprisingly, the volume of large trees (three oak species and both juniper species combined) after the burning events was greater than the volumes of trees in the small and medium trees as shown in the bottom of figure 6. In terms of percentages, the volume of small trees before the burns was reduced by 12 percent, the volume of medium trees by 11 percent, and the volume of large trees by 14 percent. The small differences in the volumes before and after the burning are attributed to the low fire severities of these events.

Annual Growth

In estimating the annual growth of the trees (all species and size classes combined) following the three burning events, changes in the values of independent variables in the variable-density yield table relative to the values of these variables applied in obtaining the pre-fire estimates of annual growth were the values for stand age and tree overstory density. The stand age had increased and the tree overstory density has been reduced by the burns. (Site quality values remained unchanged in this study as these values are not impacted by short-term disturbances such as the occurrence of fire.) The appropriate changes in stand age and tree overstory density were made accordingly.

The estimated annual growth-rate of 0.056 ± 0.017 ft^3/acre (mean ± standard error) of the tree overstories following the burning events was statistically similar to the estimate of 0.069 ± 0.023 ft^3/acre before the burns (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). Both of these estimates of annual growth were less than one percent of the respective tree volumes. This finding was expected, however, because trees in the oak ecosystems of the Southwestern Borderlands region grow slowly, rarely exceeding a fraction of a cubic-foot annually (Ffolliott 2002, McClaran and McPherson 1999, McPherson 1992, 1997).

Basal Sprouting

Basal sprouting by the same tree species found on the Cascabel Watersheds is often observed following "high severity" burning events in the region (Caprio and Zwolinski 1992, Ffolliott 2002, McPherson 1992, 1997, Niering and Lowe 1984). However, basal sprouting of these tree species on the Cascabel Watersheds was relatively surprisingly limited after the prescribed burning treatments and wildfire because (perhaps) of the low fire severities of the burns. Basal sprouting by the surviving oak trees (three species combined) was observed on 37.4 percent of the trees while basal sprouting occurred on 11.0 percent of the surviving juniper trees (both species combined). Basal sprouting by the border pinyon trees and the tree-form of mesquite was inconsequential.

Relationships between basal sprouting by trees after the burning events and the size of either the oak or juniper trees were inconsistent. While there were no differences in the presence or absence of basal sprouting by small and medium trees after the burns, basal sprouting by large trees was less frequently observed than on the small and medium trees. The large and likely older trees might have been “less vigorous” than the smaller trees before the burns, and, as a consequence, their capabilities to sprout following the burns limited.

Relationships of basal sprouting by trees (all species combined) to the crown-damage classes were insignificant with the exception of basal sprouting of trees with greater than 2/3 of their crowns either killed or scorched by the burns. More trees suffering this level of crown damage sprouted than did not sprout. Many of these trees (apparently) had not been root-killed by the burning events and, as a result, were capable of reproducing vegetatively by basal sprouting following the burns.

The extent that basal sprouting of the trees on the Cascabel Watersheds after the burning events will impact on the future sustainability of the overstories not known. Developing a “more complete picture” of effects of the burns on the post-fire basal sprouting of trees was not possible because information on pre-fire basal sprouting of the trees was not available. However, only limited basal sprouting before the burning events is a possibility. Caprio and Zwolinski (1992) found “frequent and vigorous” basal sprouting by Emory oak trees on burned sites following a wildfire of unknown severity in the Santa Catalina Mountains of southeastern Arizona while basal sprouting by the trees on adjacent unburned sites was nil.

Spatial Distributions of Trees

Spatial distributions of trees in the oak savannas are generally more variable than in the more densely stocked oak woodlands at higher elevations (Ffolliott and Gottfried 2005, Ffolliott and others 2008b). However, the spatial distributions of trees (all species and size classes combined) in the overstories on the Cascabel Watersheds were not impacted by the burning events. The pre-fire heterogeneous stocking of the trees on the watersheds was also unchanged by the burns. Openings of varying sizes, shapes, and orientations that are interspersed within tree overstories of the oak savannas remained intact.

CONCLUSIONS

The prescribed burning treatments and wildfire in the oak savannas on the Cascabel Watersheds were all low fire severities. It was not surprising, therefore, that the effects of these burning events on tree overstories of the watersheds were similar. Effects of these burns on initial tree survival, crown damage to the trees, and basal sprouting were mostly inconsequential in terms of future management implications. Changes in tree compositions and densities and annual growth rates in comparison to pre-fire conditions were also relatively minor.

Whether effects of fire on tree overstories in the oak savannas that are reported in this paper would be similar in magnitude with repeated prescribed burning treatments of low fire severity on the Cascabel Watersheds is unknown. It is also unknown what these effects might be if prescribed burning treatments of low fire severities were imposed on other sites in the oak ecosystems of the Southwestern Borderlands region. A “hotter” fire might produce different results. However, ignitions of the warm-season prescribed burning of May 20, 2008 were approaching the threshold for initiating prescribed burning treatments in the region. The results presented in this paper, therefore, should be considered case studies.

MANAGEMENT IMPLICATIONS

The information presented in the paper should be useful to managers interested in re-introducing “more historical fire regimes” into the oak savannas of the Southwestern Borderlands region. The over-crowding of tree overstories, concurrent decrease in herbage (forage) production, loss of critical wildlife habitats, and large accumulations of flammable fuels currently found on many sites could be alleviated (to some extent) by scheduling prescribing burning treatments at regular intervals. Managers might use results from the burning events on the Cascabel Watersheds as “initial guidelines” since there is relatively little information available on the effects of prescribed burning treatments on ecosystem resources in the oak savannas. However, these managers should also recognize that prescribed burning treatments of low fire severities on other sites in oak ecosystems of the region might not produce results similar to those on the Cascabel Watersheds. Additional evaluations of prescribed burning treatments of varying severities and seasonal timing on ecosystem resources are needed to formulate appropriate management strategies to achieve the desired benefits. A change in protocols for implementing prescribed burning treatments might have to be considered to facilitate successful ignitions under less restrictive weather and fuel conditions to achieve ecosystem-improvement goals.

Evaluations of prescribed burning treatments of varying frequencies and timing should also include studies of the entire array of ecosystem resources available. In addition to tree overstories, these evaluations should include herbaceous (forage) plants, wildlife populations and habitats, soil resources and sediment production, and flows of water from upland watersheds. Such efforts are currently underway on the Cascabel Watersheds (Gottfried and others 2007). It is also necessary that management agencies, private organizations, and local stakeholders collaborate to obtain "more natural fire regimes" in the Southwestern Borderlands region.

ACKNOWLEDGMENTS

The research results presented in this paper were supported by the Southwestern Borderlands Ecosystem Management Unit of the Rocky Mountain Research Station, U.S. Forest Service, Phoenix, Arizona; and the Arizona Agricultural Experiment Station, University of Arizona, Tucson, Arizona.

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APPENDIX C:

SPECIES AND BIRD NUMBERS IN OAK SAVANNAS OF THE SOUTHWESTERN BORDERLANDS REGION INCLUDING EFFECTS OF BURNING

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Accepted

Journal of the Arizona-Nevada Academy of Science
2011

ABSTRACT

Oak savannas of the Southwestern Borderlands region provide food, cover, and sites for nesting, roosting, and perching for a diversity of bird species. The results of a five-year (2003-2007) study of bird species, numbers of birds, and their diversities in the naturally occurring (unburned) oak savannas of the region are reported in this paper. Effects of cool-season and warm-season prescribed burning treatments and a wildfire on bird species and numbers of birds sighted on the same study area after these burning events are also presented. These effects were difficult to isolate, however, because of the large variability in the tallies of bird species and numbers of birds obtained throughout the study.

INTRODUCTION

Oak savannas of the Southwestern Borderlands region provide food, cover, and sites for nesting, roosting, and perching for a diversity of bird species. Open oak savannas of scattered trees are situated between the higher-elevation and denser Mexican oak-pine and oak (encinal) woodlands and the lower-elevation grassland and desert-shrub communities (Ffolliott and Gottfried 2008). Therefore, many of the birds inhabiting these interfacing ecosystems are also observed in the oak savannas. The results of a five-year (2003-2007) study of the bird species, numbers of birds, and their diversities in the naturally occurring oak savannas of the Southwestern Borderlands region are reported in this paper. Effects of cool-season and warm-season prescribed burning treatments and a wildfire on the birds observed on the same study area after these burning events are also presented.

STUDY AREA

Twelve watersheds ranging from 20 to almost 60 acres in size located in the Peloncillo Mountains of southwestern New Mexico (Gottfried et al. 2007) collectively comprised the study area. The areal aggregation of these watersheds - the Cascabel Watersheds - is 451.3 acres. The watersheds are situated between 5,380 and 5,590 feet in elevation. The nearest long-term weather station indicates that annual precipitation averages 21.8 ∀1.2 (mean ∀ standard error) inches with one-half of this precipitation occurring in the summer monsoonal season. However, the prolonged drought that was impacting the area from the middle of the 1990s continued past the burning events on the watersheds to the end of the study with the average precipitation in this drought period of 14.9 inches annually.

Emory oak (*Quercus emoryi*) was the dominant tree species in the overstories on the watersheds before the burning events followed by alligator juniper (*Juniperus deppeana*). Intermingling Arizona white (*Quercus arizonica*), and Toumey (*Quercus toumeyi*) oak, redberry juniper (*Juniperus coahuilensis*), border pinyon (*Pinus discolor*), and the tree-form of mesquite (*Prosopis glandulosa* var. *torreyana*) were minor overstory components (Ffolliott et al. 2008). Perennial grasses in the understories included blue (*Bouteloua gracilis*), sideoats (*Bouteloua curtipendula*), slender (*Bouteloua repens*), and hairy (*Bouteloua hirsuta*) grama; and bullgrass (*Muhlenbergia emersleyi*), common wolfstail (*Lycurus pheoides*), and Texas bluestem (*Schizachyrium cirratum*). Forbs species of mariposa lily (*Calochortus* spp.), verbena (*Verbena* spp.), and lupine (*Lupinus* spp.) were minor components of the understory plants. Beargrass (*Nolina microcarpa*), fairyduster (*Calliandra eriophylla*), common sotol (*Dasylirion wheeleri*), manzanita (*Arctostaphylos pungens*), Fendler's ceanothus (*Ceanothus fendleri*), and Mexican cliffrose (*Purshia mexicana*) were among the shrubs. Shrub-forms of oak and mesquite were also present on many sites. Palmer's century plant (*Agave palmeri*) and banana yucca (*Yucca baccata*) were succulents scattered on rocky slopes. Annual plants were largely absent.

Geologic, physiologic, and hydrologic characteristics of the Cascabel Watersheds have been described by Hendricks (1985), Vincent (1998), Osterkamp (1999), Youberg and Ferguson (2001), Robertson et al. (2002), Neary and Gottfried (2004), and Gottfried et al (2007). Bedrock geology of the watersheds is Tertiary rhyolite overlain by Oligocene-Miocene conglomerates and sandstone. Soils are classified as Lithic Argustolls, Lithic Haplustrolls, or Lithic Ustorthents. These shallow soils are generally less than 20 inch to bedrock. Streamflow originating on the watersheds is intermittent with the larger flows generated by storms of high-intensity rainfall (Gottfried et al. 2006).

PRESCRIBED BURNING TREATMENTS AND WILDFIRE

Land management agencies with support from their collaborators are interested in re-introducing a more natural fire regime into the Southwestern Borderlands region including the oak savannas. Natural fire frequencies, their burning characteristics, and their impacts on the ecosystem resources of the region have been altered since the late 1800s, largely because of past livestock grazing practices that removed significant portions of the fire-carrying herbaceous vegetation and past (often aggressive) fire suppression policies of the land management agencies (Fulé and Covington 1995, Edminster et al. 2000). A first step in the attempt to re-introduce a more natural fire regime was evaluating the effects of prescribed burning treatments on the ecosystem resources including bird species and numbers of birds. The original objective of the research program on the Cascabel Watersheds, therefore, was to evaluate the effects of cool-season (November through April) and warm-season (May through October) prescribed burning treatments on ecosystem resources of the oak savannas. These evaluations would be then compared to control (unburned) watersheds in determining the burning effects.

Following the required watershed calibration period, four of the watersheds were burned in the cool-season in early March 2008. Three of the four watersheds to be burned in the warm-season were burned on May 20, 2008 with burning of the fourth watershed delayed until at a later date because of shifting weather conditions. However, wind gusts up to 60 mph occurring on the morning of May 21, 2008 blew firebrands onto the remaining watershed scheduled for warm-season burning and the four control watersheds. The resulting wildfire - the Whitmire Wildfire - crossed the boundary lines among the Cascabel Watersheds and then spread beyond these watersheds to burn approximately 4,000 acres. As a consequence of this wildfire, the original objective of research on the Cascabel Watersheds had to be modified to evaluate the impacts of cool-season and warm-season prescribed burning treatments and the Whitmire Wildfire on the ecosystem resources.

FIRE SEVERITIES

A system that relates fire severity to the soil-resource response to burning (Hungerford 1996) was used to classify the resulting severities of the cool-season and warm-season prescribed burning treatments and the wildfire at sample plots on the watersheds (see below). This system relates the post-fire appearance of litter, duff, and woody material and soil conditions to discrete classes of fire severity ranging from low to medium to high. Details of the system are found in Wells et al. (1979), DeBano et al. (1998), and Neary et al. (2005). Classifications of fire severity at the sample plots were then extrapolated to a watershed-basis to determine the percentages of each of the watersheds that were unburned or burned at low, moderate, or high severities.

It was found that 85 percent of the four watersheds experiencing the cool-season prescribed burn had been exposed to a low severity fire; a moderate fire severity was observed on 5 percent of the watersheds; and the remaining 10 percent of the watersheds were unburned (Stropki et al. 2009). Distributions of the fire severities on the watershed exposed to the warm-season prescribed burn and wildfire were similar to the distributions of fire severities of the cool-season burn. It was concluded, therefore, that the Cascabel Watersheds (collectively) had been exposed to low severity fire by the three burning events. The low fire severities were attributed largely to the mostly small and scattered accumulations of flammable fuels before the burns (Ffolliott et al. 2006) and the relatively high wind-speeds during burning (M. Harrington, 2010, personal correspondence).

STUDY PROTOCOLS

Sampling Basis

On each of the Cascabel Watersheds, between 35 and 45 sample plots have been located along transects perpendicular to the main stream system and situated from ridge to ridge to obtain data on the ecosystem resources. Intervals between the sample plots varied with the size and configuration of the watershed sampled. A total of 421 sample plots were established on the twelve watersheds. However, because of the small size of the individual watersheds, the short intervals (from 70 to 240 feet) between the plots, and the mobility of birds in the area, observations of bird species and numbers of birds were tallied at only every third sample plot (1, 4, 7, etc.) on the watersheds throughout the study.

Bird Observations

Bird species and numbers of birds sighted in 5-minute observations at each sample plot were tallied by established procedures (Ralph et al. 1995, Braun 2005). The counts began a few minutes after the observer arrived at a plot to minimize the effects of disturbances caused by the observer moving to the plot. Most of the observations were made between 0800 and 1130 hours on consecutive days of clear or partly cloudy conditions with a minimum of wind movement. One exception to this protocol occurred in the spring of 2009 when recurring rainstorms and accompanying cloudy and windy conditions continuously disrupted the tallying of birds on the watersheds. These tallies were obtained intermittently within a three-week period as a consequence.

Observations of birds before the prescribed burns treatments and wildfire occurred were made in the spring and fall from 2003 through 2007. Effects of these burning events on bird species and number of birds were determined by tallies obtained in the fall of 2008 (approximately six and four months after the cool-season burn and the warm-season burn and the wildfire, respectively.) and in the spring and fall of 2009. Tallies of birds were not obtained in the spring of 2008 because of the warm-season prescribed burning treatment and wildfire.

Ecological Diversity

Ecological diversity has become a central theme of ecology with measures of ecological diversity also serving as indicators of the "well being" of an ecosystem (Magurran 1988). No matter how it is measured, however, ecological diversity embodies two fundamental indices that are species richness (the number of species) and species evenness (how equally abundant the species are). High species evenness, that is, when the species of an area are virtually equal in abundance, is equated with high ecological diversity.

Species richness of the birds tallied on the Cascabel Watersheds was determined for each of the observation periods in the study. Knowledge of species richness was supplemented by calculating a number representing species diversity (MacArthur and MacArthur 1961). This number (*H'*) (Shannon and Weaver 1948) was calculated by:

$$H' = -\sum_{i=1}^{S} p_i \ln (p_i)$$

where p_i is the proportion of the *i*th species in a population of birds comprised of *s* species.

Larger (*H'*) values represent higher species diversities.

Evenness (*E*) of the bird species tallied was calculated by

$$E = H'/\ln s$$

Larger (E) values are equated with more equally abundant species on a site with values approaching 1 representing higher levels of evenness and, therefore, higher ecological diversity on the watersheds.

RESULTS AND DISCUSSION

Bird Species and Numbers of Birds

Bird species and numbers of birds tallied in the spring and fall observations before the prescribed burning treatments and wildfire and the observations of following these burning events occurred are summarized in Tables 1 and 2, respectively. These summaries represent a “snap-shot picture” of the birds on the Cascabel Watersheds at the time of their observation. Grouping the observed bird species by guilds (associations) based on their exploitation of available habitat resources (Ehrlich et al. 1988) was not meaningful because of the large variability in their observations throughout the study.

Some of the species tallied in the study were neotropical migratory birds that typically breed in temperate climates and winter in tropical environments (Block et al. 1992). These birds use a diversity of habitats along their migration routes to obtain the resources needed for reproduction and survival. The oak savannas provide many of these habitats.

Table 1. Species (according to Sibley 2000) and bird numbers sighted on the Cascabel Watersheds in the spring observations of 2003-2007 and 2009. Counts of birds of unknown species are excluded from the table.

		Number of observations					
ID	**Species name**	**2003**	**2004**	**2005**	**2006**	**2007**	**2009**
1	Arizona woodpecker (*Picoides arizonae*)	0	0	1	0	0	0
2	Ash-throated flycatcher (*Myiarchus cinerascens*)	0	7	17	11	1	0
3	Barn swallow (*Hirundo rustica*)	0	0	1	0	0	0
4	Brown-crested flycatcher (*Myiarchus tyrannulus*)	0	0	2	0	0	0
5	Bewick's wren (*Thryomanes bewickii*)	0	0	11	0	0	11
6	Black phoebe (*Sayornis nigricans*)	0	0	0	4	0	0
7	Bridled titmouse (*Baeolophus wollweberi*)	0	0	9	1	0	0
8	Bushtit (*Psaltriparus minimus*)	33	0	4	9	0	0
9	Canyon towhee (*Pipilo fuscus*)	0	0	1	4	0	0
10	Chihuahuan raven (*Corvus cryptoleucus*)	0	0	0	0	8	7
11	Chipping sparrow (*Spizella passerina*)	0	0	1	0	0	0
12	Cooper's hawk (*Accipiter cooperii*)	0	0	1	0	0	0
13	Common nighthawk (*Chordeiles minor*)	8	3	0	0	0	0
14	Common raven (*Corvus corax*)	1	1	6	8	0	0
15	Dusky-capped flycatcher (*Myiarchus tuberculifer*)	8	0	1	0	0	0
16	Gambel's quail (*Callipepla gambelii*)	2	0	0	0	0	0
17	Gould's turkey (*Melaeagris gallopavo mexicanas*)	10	0	0	0	0	0
18	Hawfinch (*Coccothraustes coccothraustes*)	0	0	0	0	1	0
19	House finch (*Carpodacus mexicanus*)	0	0	3	0	0	0
20	Juniper titmice (*Baceolophus ridgwayi*)	21	0	0	0	48	1
21	Lesser goldfinch (*Carduelis psaltria*)	0	0	2	1	0	0

22	Mexican jay (*Aphelocoma ultramarina*)	24	24	40	12	20	10
23	Mourning dove (*Zenaida macroura*)	17	26	13	4	1	0
24	Northern cardinal (*Cardinalis cardinalis*)	2	5	0	0	0	0
25	Northern mockingbird (*Mimus polyglottos*)	10	1	1	18	2	0
26	Phainopepla (*Phainopepla nitens*)	1	0	0	0	0	0
27	Prairie falcon (*Falco mexicanus*)	0	0	1	1	0	0
28	Rufous-crowned sparrow (*Aimophila ruficeps*)	0	0	3	0	0	0
29	Rock wren (*Salpinces obsoletus*)	0	0	6	0	0	0
30	Red-tailed hawk (*Buteo jamaicensis*)	6	3	1	1	0	0
31	Say's phoebe (*Sayornis saya*)	1	1	0	4	0	0
32	Scott's oriole (*Icterus parisorum*)	0	3	4	0	3	2
33	Scaled quail (*Callipepla squamata*)	20	0	0	0	0	1
34	Spotted towhee (*Pipilo maculatus*)	0	0	3	2	0	0
35	Turkey vulture (*Cathartes aura*)	6	34	42	20	20	27
36	Violet-green swallow (*Tachycineta thalassina*)	0	0	1	0	0	0
37	White-throated swift (*Aeronautes saxatalis*)	0	0	1	0	0	0
Total		170	108	176	100	104	59

Table 2. Species (according to Sibley 2000) and bird numbers sighted on the Cascabel Watersheds in the fall observations of 2003-2009. Counts of birds of unknown species are excluded from the table.

		Number of observations						
ID	**Species name**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
1	Acorn woodpecker (*Melanerpes formicivorus*)	0	0	0	1	2	2	0
2	American kestrel (*Falco sparverius*)	0	0	0	6	6	7	3
3	American robin (*Turdus migratorius*)	0	0	0	0	0	0	1
4	Arizona woodpecker (*Picoides arizonae*)	0	2	0	9	14	9	30
5	Audubon's warbler (*Dendroica coronata auduboni*)	0	0	0	0	0	0	8
6	Barn swallow (*Hirundo rustica*)	0	0	0	0	2	0	0
7	Bewick's wren (*Thryomanes bewickii*)	0	0	5	83	26	48	34
8	Blue-gray gnatcatcher (*Polioptila caerulea*)	0	0	0	4	0	4	0
9	Black vulture (*Coragyps atratus*)	0	0	0	0	1	0	0
10	Brewer's blackbird (*Euphagus cyanocephalus*)	0	0	0	0	0	0	1
11	Brewer's sparrow (*Spizella breweri*)	0	0	0	0	0	3	2
12	Bridled titmouse (*Baeolophus wollweberi*)	0	0	4	20	51	32	20
13	Broad-tailed hummingbird (*Selasphorus platycercus*)	0	0	0	0	2	0	0
14	Band-tailed pigeon (*Patagioenas fasciata*)	0	0	0	0	0	2	0
15	Black-throated gray warbler (*Dendroica nigrescens*)	0	0	0	1	3	1	0
16	Bushtit (*Psaltriparus minimus*)	84	0	0	79	50	30	0
17	Cassin's kingbird (*Tyrannus vociferans*)	0	4	8	15	23	2	1
18	Canyon towhee (*Pipilo fuscus*)	0	0	0	5	4	2	19
19	Canyon wren (*Catherpes mexicanus*)	0	0	0	0	0	0	6
20	Cassin's sparrow (*Aimophila cassinii*)	0	0	0	1	0	0	0
21	Canyon towhee (*Pipilo fuscus*)	0	0	0	0	0	4	0
22	Cassin's vireo (*Vireo cassinii*)	0	0	0	1	0	0	0

23	Cedar waxwing (*Bombycilla cedrorum*)	0	32	0	0	0	0	0
24	Chihuahuan raven (*Corvus cryptoleucus*)	0	0	0	4	3	11	0
25	Chipping sparrow (*Spizella passerina*)	0	104	269	355	446	476	400
26	Cooper's hawk (*Accipiter cooperii*)	0	0	0	0	0	2	2
27	Common nighthawk (*Chordeiles minor*)	4	0	0	0	0	0	0
28	Common poorwill (*Phalaenoptilus nuttallii*)	0	0	0	1	0	0	0
29	Common raven (*Corvus corax*)	8	24	32	9	28	46	53
30	Crissal thrasher (*Toxostoma crissale*)	0	0	0	3	0	0	9
31	Dark-eyed junco (*Junco hyemalis*)	0	0	0	0	0	0	18
32	Eastern bluebird (*Sialia sialis*)	0	0	0	0	0	3	0
33	Eastern meadowlark (*Sturnella magna*)	0	0	0	2	0	0	0
34	Gambel's quail (*Callipepla gambelii*)	0	0	0	0	1	0	0
35	Gray-headed junco (*Junco hyemalis var. dorsalis*)	0	214	28	0	0	0	252
36	Great horned owl (*Bubo virginianus*)	0	0	0	2	0	0	0
37	Gila woodpecker (*Melanerpes uropygialus*)	1	0	0	0	0	0	0
38	Golden eagle (*Aquila chrysaetos*)	0	0	0	0	0	0	1
39	Grasshopper sparrow (*Ammodramus savannarum*)	0	0	0	1	0	0	1
40	Green-tailed towhee (*Pipilo chlorurus*)	0	0	0	2	0	0	0
41	Gambel's white-crowned Sparrow (*Zonotrichia leucophrys*)	0	0	0	0	0	0	2
42	Hepatic tanager (*Piranga flava*)	0	0	0	1	0	0	0
43	House finch (*Carpodacus mexicanus*)	0	3	2	13	2	10	25
44	Horned lark (*Eremophila alpestris*)	0	0	0	0	0	0	3
45	Hutton's vireo (*Vireo huttoni*)	0	0	0	1	0	1	0
46	Juniper titmice (*Baceolophus ridgwayi*)	16	0	3	5	2	3	6
47	Lazuli bunting (*Passerina amoena*)	0	0	0	0	0	1	0

48	Lesser goldfinch (*Carduelis psaltria*)	0	0	0	11	4	39	6
49	Lincoln's sparrow (*Melospiza lincolnii*)	0	0	0	0	0	3	0
50	Mexican chickadee (*Poecile sclateri*)	0	0	0	0	0	1	0
51	Mexican jay (*Aphelocoma ultramarina*)	27	34	55	71	111	56	67
52	MacGillivray's warbler (*Oporornis tolmiei*)	0	0	0	0	2	0	0
53	Mourning dove (*Zenaida macroura*)	1	5	2	13	11	98	0
54	Montezuma's quail (*Cyrtonyx montezumae*)	2	0	0	0	4	0	0
55	Northern cardinal (*Cardinalis cardinalis*)	0	0	0	0	0	0	1
56	Northern flicker (*Colaptes auratus*)	0	5	10	88	45	9	18
57	Northern goshawk (*Accipiter gentilis*)	0	0	0	0	0	2	0
58	Northern harrier (*Circus cyaneus*)	0	0	1	1	2	3	0
59	Oak titmouse (*Baeolophus inornatus*)	0	0	0	0	0	0	1
60	Orange-crowned warbler (*Vermivora celata*)	0	0	0	0	0	2	0
61	Oregon junco (*Junco hyemalis var. thurberi*)	0	3	10	0	0	0	25
62	Osprey (*Pandion haliaetus*)	0	0	0	0	0	1	0
63	Peregrine falcon (*Falco peregrinus*)	0	0	0	1	0	0	0
64	Phainopepla (*Phainopepla nitens*)	4	3	4	3	0	0	6
65	Pine siskin (*Carduelis pinus*)	0	0	0	0	0	0	8
66	Prairie falcon (*Falco mexicanus*)	0	0	2	0	0	0	2
67	Pyrrhuloxia (*Cardinalis sinuatus*)	0	0	0	0	15	0	0
68	Ruby-crowned kinglet (*Regulus calendula*)	0	0	0	8	5	1	20
69	Rufous-crowned sparrow (*Aimophila ruficeps*)	0	0	3	29	118	32	43
70	Red-naped sapsucker (*Sphyrapicus nuchalis*)	0	1	1	2	0	2	3
71	Rock wren (*Salpinces obsoletus*)	0	0	3	9	10	7	3
72	Red-shafted flicker (*Colaptes auratus*)	0	0	0	0	0	0	45

73	Red-tailed hawk (*Buteo jamaicensis*)	0	3	9	13	14	5	5
74	Red winged black bird (*Agelaius phoeniceus*)	0	0	0	4	0	0	0
75	Say's phoebe (*Sayornis saya*)	0	0	0	1	0	1	0
76	Scott's oriole (*Icterus parisorum*)	0	0	0	8	1	0	0
77	Scaled quail (*Callipepla squamata*)	10	0	0	0	0	0	0
78	Spotted towhee (*Pipilo maculatus*)	0	0	0	20	4	0	7
79	Sharp-shinned hawk (*Accipiter striatus*)	0	0	0	1	0	4	3
80	Swainson's hawk (*Buteo swainsoni*)	0	0	0	0	0	2	0
81	Townsend's solitaire (*Myadestes townsendi*)	0	0	0	0	0	0	2
82	Townsend's warbler (*Dendroica townsendi*)	0	0	0	0	1	0	0
83	Tuffed titmouse (*Parus bicolor*)	0	0	0	1	0	0	0
84	Turkey vulture (*Cathartes aura*)	0	0	0	33	37	25	0
85	Vesper sparrow (*Pooecetes gramineus*)	0	0	0	4	0	7	1
86	Violet-green swallow (*Tachycineta thalassina*)	0	0	0	0	23	3	0
87	Warbling vireo (*Vireo gilvus*)	0	0	0	1	3	0	0
88	White-breasted nuthatch (*Sitta carolinensis*)	0	0	0	0	0	3	1
89	White-crowned sparrow (*Zonotrichia leucophrys*)	0	0	0	0	0	26	0
90	Western bluebird (*Sialia mexicana*)	0	4	0	0	0	0	61
91	Western kingbird (*Tyrannus verticalis*)	0	0	0	0	0	19	0
92	Western meadowlark (*Sturnella neglecta*)	0	0	0	0	0	0	80
93	Wild turkey (*Meleagris gallopavo*)	0	0	0	0	1	8	8
94	Wilson's warbler (*Wilsonia pusilla*)	0	0	0	0	1	0	0
95	Yellow-rumped warbler (*Dendroica coronata*)	0	0	0	6	2	35	0
96	Yellow warbler (*Dendroica petechia*)	0	0	0	0	2	0	0
97	Zone-tailed hawk (*Buteo albonotatus*)	0	0	0	0	4	0	0

Totals	157	441	451	952	1086	1093	1313

Some of the bird species were tallied only occasionally in few numbers throughout the study, while other species were observed more frequently in larger numbers. Tallies of the bird species in larger numbers were attributed mainly to the large flocks of birds that had flown onto the watersheds before their observation. These birds were concentrated mostly in the vicinity of a few closely clustered sample plots with no discernible pattern in their location on the watersheds.

Before the Burning Events

Bird species tallied infrequently and sighted in only few numbers (< 10 counts of the species on the watersheds in an observation period) before the prescribed burning treatments and wildfire included (but not limited to) the acorn woodpecker (*Melanerpes formicivorus*), barn swallow (*Hirundo rustica*), eastern meadowlark (*Sturnella magna*), northern harrier (*Circus cyaneus*), prairie falcon (*Falco mexicanus*), and yellow warbler (*Dendroica petechia*). These tallies suggest the transient nature of many of the bird species on the watersheds.

Several bird species were tallied in larger numbers only once in either the spring, fall, or both seasons before the burning events with fewer or no observations of the species at other times. Included in these tallies were the house finch (*Carpodacus mexicanus*), lesser goldfinch (*Carduelis psaltria*), Oregon junco (*Junco hyemalis* var. *thurberi*), spotted towhee (*Pipilo maculatus*), and violet-green swallow (*Tachycineta thalassina*). Other bird species were observed in larger numbers several times in either the spring, fall, or both seasons before the burns. Among these species were the ash-throated flycatcher (*Mylarchus cinerascens*), Bewick's wren (*Thryomanes bewickii*), bridled titmouse *(Baceolophus wollweberi*), bushtit *(Psaltriparus minimus*), Cassin's kingbird (*Tyrannus vociferans*), chipping sparrow (*Spizella passerina*), common raven (*Corvus corax*), gray-headed junco (*Junco hyemalis* var. *dorsalis*), Mexican jay (*Aphelocoma ultramarina*), mourning dove (*Zenaida macroura*), northern flicker (*Colaptes auratus*), northern mockingbird (*Mimus polyglottos*), rufous-crowned sparrow (*Almophila ruficeps*), red-tailed hawk (*Bufeo jamaicensis*), scaled quail (*Callipepla squamata*), and turkey vulture (*Cathartes aura*).

Following the Burning Events

Several species tallied in larger numbers more than once before the prescribed burning treatments and wildfire continued to be sighted in large numbers after the burning events. Included with this group of species were the Bewick's wren, bridled titmouse, bushtit, common raven, chipping sparrow, gray-headed junco, lesser goldfinch, Mexican jay, mourning dove, northern flicker, rufous-crowned sparrow, and turkey vulture.

Some bird species not observed before burning events were tallied in few numbers after the burns. These species included the American robin (*Turdus migratorius)*, Brewer's blackbird (*Euphagus breweri*), Mexican chickadee (*Poecile sclateri*), oak titmouse (*Baceolophus inormatus*), and osprey (*Pandion haliaetus*). Other species not tallied before the burning events were observed in larger numbers after the burns. Among these species were the dark-eyed junco (*Junco hyemalis*), pine siskin (*Carduelis pinus*), red-shafted flicker (*Colaptes auratus*), white-crowned sparrow (*Zonotrichia leucophrys*), and western kingbird (*Tyrannus verticalis*).

Effects of Burning Events

Whether the sightings of bird species only after the prescribed burning treatments and wildfire were a response to these burning events is unknown. The large variability in the tallies of bird species and numbers of birds obtained throughout the study could have "masked" the effects of the burns. Furthermore, movements of birds onto the Cascabel Watersheds following the burning events in relation to their movements before the burns might not have been significantly altered because of the low fire severities of the burning events. The burns, for example, had little effect on the initial survival, crown damage, and basal sprouting of trees in the overstory (Ffolliott et al., In press). There were no meaningful relationships between the tallies of bird species and numbers of birds either before or after the burns and the habitats conditions (vegetation, physiography, ground cover, etc.) surrounding the sample points. The authors of this paper concluded, therefore, that the prescribed burning treatments and wildfire on the Cascabel Watersheds had relatively little effect on the bird species or numbers of birds on the watersheds.

Seasonal Patterns

More bird species and numbers of birds were tallied in the fall observations than the spring both before and after the burning events with the exception of 2003, when there was little difference in the seasonal tallies. The few birds tallied in the spring of 2009 was attributed to the recurring rainstorms and cloudy conditions encountered when movements of birds onto and away from the Cascabel Watersheds was probably erratic. These adverse conditions also hindered identification of some of the species of birds sighted at this time.

That more bird species and numbers of birds were tallied in the fall than in the spring was likely the result of a more abundant food supply in the summer months (as indicated by the fall tallies) than in the winter months (as signified by the spring counts). The reason for the increasing numbers of birds observed in the fall as the study progress is unknown. Some of the bird species that were tallied in the fall were not seen in the spring and vice versa.

Species Richness, Species Diversities and Evenness

Species richness, species diversities, and evenness of the birds tallied in the spring and fall observations are presented in Tables 3 and 4, respectively. The values presented in these tables suggest that prescribed burning treatments and wildfire has little consistent effect of the ecological diversity of the Cascabel Watersheds (as measured by species richness and species evenness) or species diversities.

Species richness in both the spring and fall observation before the burning events was variable with little seasonal or annual pattern in the numbers of species sighted.

Table 3. Species richness, species diversities, and evenness of birds observed on the Cascabel Watersheds in the spring observations of 2003-2007 and 2009.

	2003	2004	2005	2006	2007	2009
Species richness	16	11	26	15	9	7
Species diversity	2.387	1.789	2.458	2.324	1.501	1.478
Species evenness	0.861	0.746	0.754	0.858	0.683	0.759

Table 4. Species richness, species diversities, and evenness of birds observed on the Cascabel Watersheds in the fall observations of 2003-2009.

	2003	2004	2005	2006	2007	2008	2009
Species richness	10	15	19	47	41	48	46
Species diversity	1.504	1.599	1.577	2.491	2.329	2.431	2.582
Species evenness	0.653	0.590	0.535	0.647	0.627	0.628	0.674

However, the numbers of species tallied in the spring were less than the average counts of bird species obtained in the Mexican oak-pine and oak woodlands of southeastern Arizona by Block et al. (1992) in the breeding seasons (March through June) of 1986, 1987, and 1988. Trees in the oak ecosystems studied by Block and his colleagues are denser (closer together) than trees in the oak savannas on the Cascabel Watersheds and the average precipitation amounts at the time of their study were closer to the normal conditions for the borderland region.

The large numbers of species tallied in the fall of 2006, about 18 months before the cool-season burn, and continuing in the counts after the burning events to the end of the study was the only difference of note in the numbers of species in the fall tallies either before or after the burning events. The reason for these large numbers of tallied species is unknown. Earlier tallies of the numbers of species in the fall were smaller.

The only spring tally of the number of bird species following the burning events in 2009 was less than the numbers of species in all of the spring tallies before the burns. The small number of species that were observed in the spring of 2009 was a likely consequence of the adverse conditions encountered when these tallies were made. The numbers of species in the fall tallies after the burning events were similar to the numbers obtained before the burns in the fall of 2007 and 2006. Moreover, the tallies of species in these fall observations were all larger than the fall counts prior to 2006.

Species diversities of birds in both the spring and fall were variable before and after the burning events with the following exception. Species diversities in the fall observations after the burns were largely the same as species diversities before the burning events in the fall of 2007 and 2006. The reason for this similarity is unknown. Parenthetically, the general pattern of species diversities was similar to the pattern of species richness in this same time period. Evenness of bird species tallied before and after the burns was also variable. Moreover, the values of evenness when coupled with the values for species richness suggest little change in ecological diversity as a result of the burning events.

CONCLUSIONS

This paper presents "snap-shot" summaries of the bird species, numbers of birds, and their diversities in the oak savannas on the Cascabel Watersheds before and after cool-season and warm-season prescribed burning treatments and a wildfire. The tallies before the burning events are assumed to be indicative of the occurrences of birds in naturally occurring oak savannas of the Southwestern Borderland region within the drought conditions encountered. While the effects of the burns on these birds were difficult to isolate, the authors of this paper concluded that the burning events on the Cascabel Watersheds had relatively little effect on the bird species or numbers of birds observed on the watersheds. The Cascabel Watersheds are small both individually and (collectively) in aggregate, and, therefore, it is likely that some of the birds sighted throughout the study had flown into the watersheds from the surrounding oak savannas and other ecosystems in the vicinity. Nevertheless, the results obtained in this study provide a case study of the bird species, numbers of birds, and their diversities before and after cool-season and warm-season prescribed burning treatments and a wildfire in the oak savannas of the region.

ACKNOWLEDGMENTS

The research results presented in this paper were supported by the Southwestern Borderlands Ecosystem Management Unit of the Rocky Mountain Research Station, U.S. Forest Service, Phoenix, Arizona, and the Arizona Agricultural Experiment Station, University of Arizona, Tucson, Arizona.

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