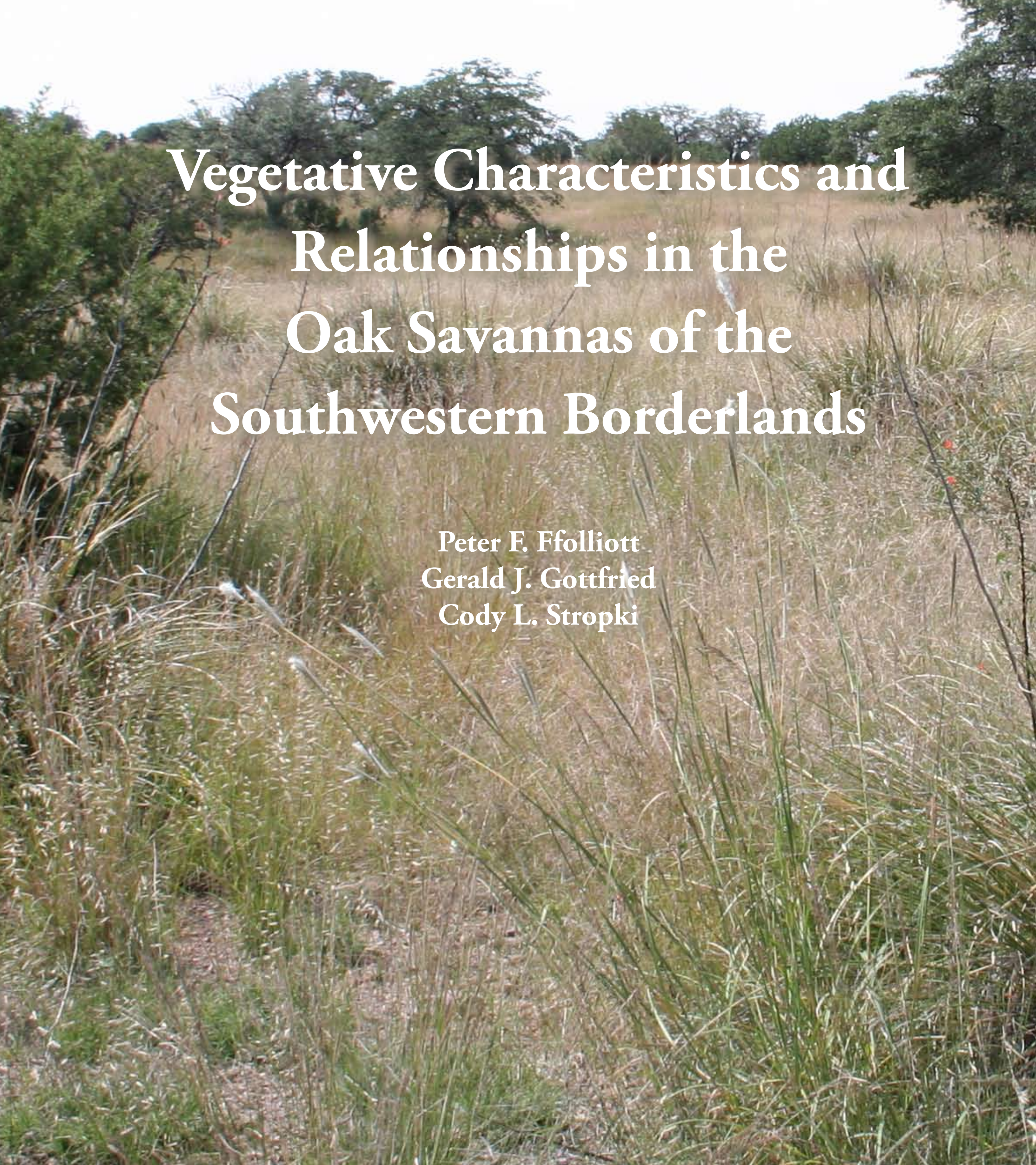


Vegetative Characteristics and Relationships in the Oak Savannas of the Southwestern Borderlands

Peter F. Ffolliott
Gerald J. Gottfried
Cody L. Stropki

United States Department of Agriculture
Forest Service
Rocky Mountain Research Station
Research Paper RMRS-RP-74
November 2008

Ffolliott, Peter F.; Gottfried, Gerald J.; Stropki, Cody L. 2008. **Vegetative characteristics and relationships in the oak savannas of the Southwestern Borderlands.** Research Paper RMRS-RP-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 16 p.

Abstract

In this paper, we describe species compositions, densities patterns, and annual growth rates of the tree overstory; species compositions, seasonal production of grasses, forbs, and shrubs, and the utilization of forage species by herbivores; loading of flammable fuel fractions; and ground cover conditions of "representative" oak savannas. Although much has been learned about the ecological, hydrologic, and environmental characteristics of the oak (encinal) woodlands of the Southwestern Borderlands in recent years, comparable information for the lower-elevation oak savannas is also necessary to enhance the knowledge of all oak ecosystems in the region. Oak savannas are more open in stand structure than are the more extensive oak woodlands and, as a consequence, a higher level of herbaceous production might be expected in this ecosystem than in the oak woodlands. A comparative analysis with oak woodlands is also presented wherever possible.

Keywords: Oak savannas, tree overstory, herbaceous understory, species compositions, growth and production

The Authors

Peter Ffolliott is a professor with the School of Natural Resources, University of Arizona, Tucson, Arizona.

Gerald Gottfried is a research forester with the Rocky Mountain Research Station, U.S. Forest Service, Phoenix, Arizona.

Cody Stropki is a research associate with the School of Natural Resources, University of Arizona, Tucson, Arizona.

You may order additional copies of this publication by sending your mailing information in label form through one of the following media. Please specify the publication title and series number.

Fort Collins Service Center

Telephone	(970) 498-1392
FAX	(970) 498-1122
E-mail	rschneider@fs.fed.us
Web site	http://www.fs.fed.us/rm/publications
Mailing address	Publications Distribution Rocky Mountain Research Station 240 West Prospect Road Fort Collins, CO 80526

Rocky Mountain Research Station
240 W. Prospect Road
Fort Collins, Colorado 80526

Contents

Vegetative Characteristics and Relationships in the Oak Savannas of the Southwestern Borderlands

Peter F. Ffolliott, Gerald J. Gottfried, and Cody L. Stropki

Introduction

Much has been learned about the ecological, hydrologic, and environmental characteristics of the oak (encinal) woodlands of the Southwestern Borderlands in recent years. Ecological and hydrologic relationships of these woodland communities have been studied by a number of investigators (DeBano and others 1995; Ffolliott 1999, 2002; Gottfried and others 2005, 2007a; McClaran and McPherson 1999; McPherson 1992, 1997; and others). However, comparable information for the lower-elevation oak savannas is also necessary to enhance the knowledge of all oak ecosystems in the region. Oak savannas are situated in the transition (interface) between higher-elevation oak woodlands and lower-elevation desert grasslands and shrub communities. While Niering and Lowe (1984), working in the Santa Catalina Mountains, described this band of vegetation as "open woodlands," we prefer the term "oak savannas" to differentiate this ecosystem from the more extensive oak woodlands. Oak savannas are more open in stand structure than the oak woodlands and, as a consequence, a higher level of herbaceous production might be expected in this ecosystem than occurs in the oak woodlands. Species compositions, densities patterns, and annual growth rates of the tree overstory; species compositions, seasonal production of grasses, forbs, and shrubs, and the utilization of forage species by herbivores; loading of flammable fuel fractions; and ground cover conditions of "representative" oak savannas are described in this paper. A comparative analysis with oak woodlands of the region is also presented wherever possible.

Study Areas

Twelve watersheds on the eastern side of the Peloncillo Mountains in southwestern New Mexico comprised the study area for describing the vegetation in the oak savannas. These watersheds, ranging from about 20 to almost 60 acres in size, were established by the Rocky Mountain Research Station, U.S. Forest Service and its cooperators to evaluate the impacts of prescribed burning on the ecological and hydrologic characteristics of the oak savannas in the region (Gottfried and others 2000, 2005; Neary and Gottfried 2004). The aggregate area of these watersheds, called the Cascabel Watersheds, is 451 acres. They are located in the Malpai Borderlands in the eastern part of the Coronado National Forest on the western edge of the Animas Valley (fig. 1). The Malpai Borderlands are found within, and are representative of, the larger Southwestern Borderlands region.

The watersheds are 5,380 to 5,590 ft in elevation. Records from the long-term precipitation station at the Cascabel Ranch headquarters indicate that annual precipitation in the vicinity of the watersheds averages 21.8 ± 1.2 inches, with more than one-half falling in the summer monsoonal season from late June through early September. However, a prolonged drought impacted the Southwestern Borderlands and, more generally, the southwestern United States from the middle 1990s through the study period when the baseline data presented in this paper were collected. The annual precipitation in this drought averaged 14.9 inches. Geological, edaphic, and hydrologic characteristics have been described by Hendricks (1985), Vincent (1998), Osterkamp (1999), Gottfried and others (2000, 2005, 2007b), Youberg and Ferguson (2001), Roberston and others (2002), and Neary and Gottfried (2004). The bedrock geology is Tertiary rhyolite overlain by Oligocene-Miocene conglomerates and sandstone. Soils are classified as Lithic Argustolls, Lithic Haplustrolls, or Lithic Ustorthents. These soils are generally less than 20 inches to bedrock. Streamflow originating in the oak savannas is mostly intermittent in nature, although large flows can follow high-intensity rainfall events (Gottfried and others 2006).

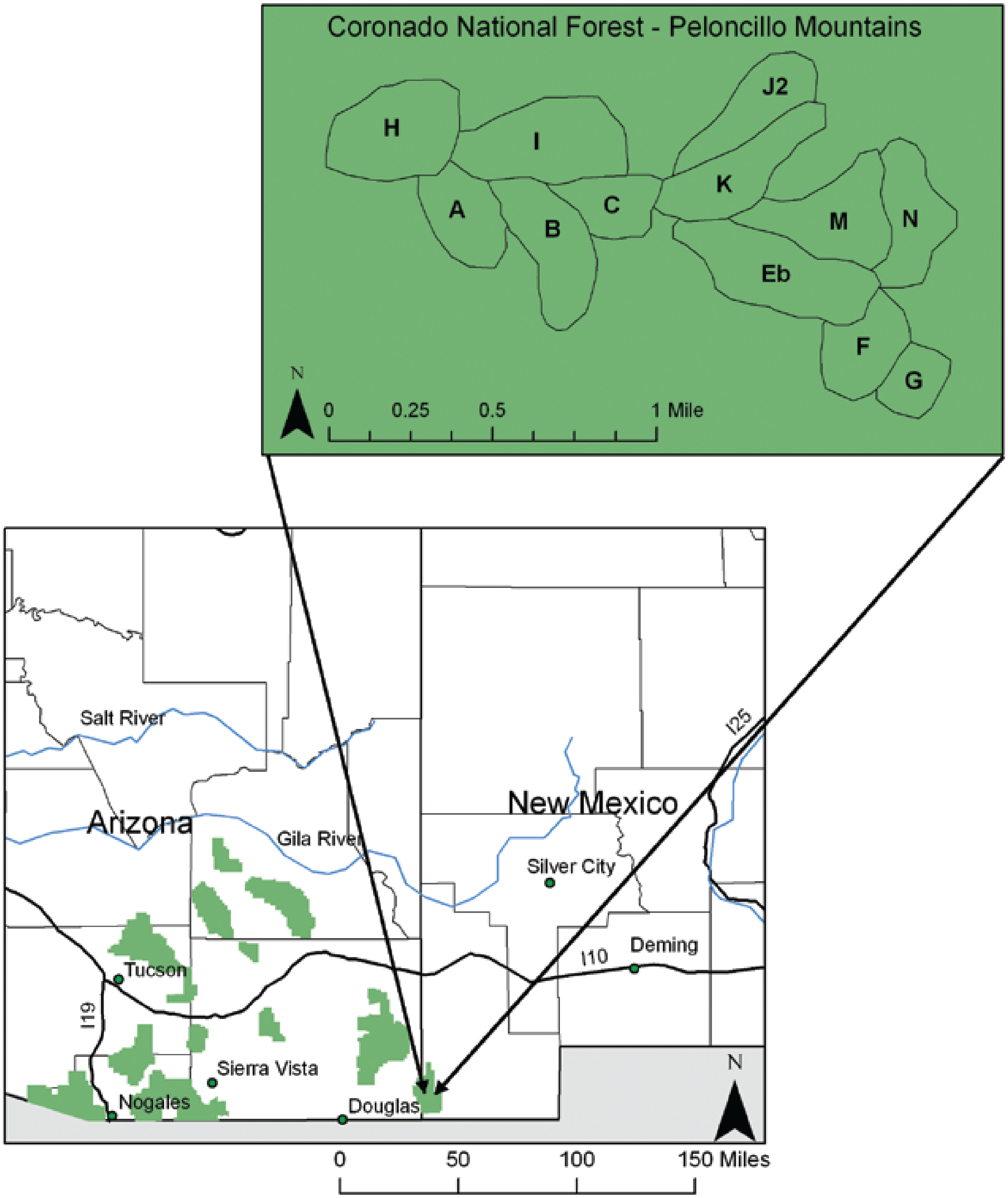


Figure 1. The Cascabel Watersheds (arrow) are located within the oak savannas of the Malpai Borderlands, an area of approximately 802,750 acres within the larger Southwestern Borderlands region.

Sites in the oak woodlands selected for comparison with the oak savannas on the Cascabel Watersheds are located on the southern slope of the Huachuca Mountains within the Coronado National Forest along the United States-Mexico border. Trees on these sites had not been harvested for wood products prior to this study. Elevations of the sites ranged from 5,650 to 5,875 ft. Annual precipitation in the Huachuca Mountains averages 21.4 inches, equally distributed between the summer and winter. Hendricks (1985) classified the moderately fine to fine textured and relatively deep soils on these sites in the Casto-Martinez-Canelo Association. Streamflow in the oak woodlands is largely intermittent.

Study Protocols

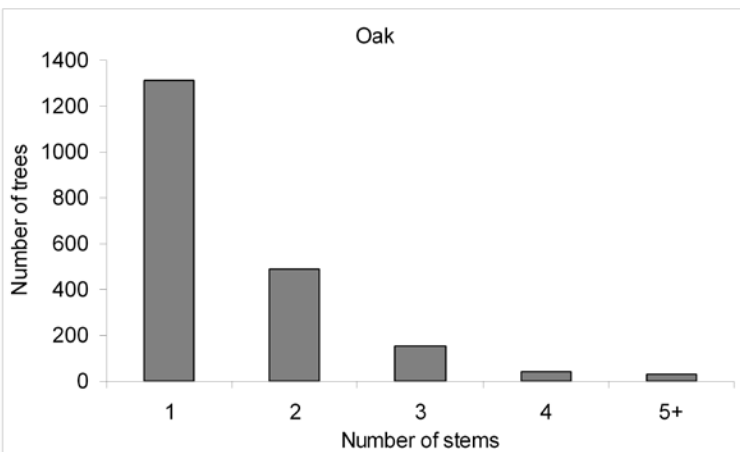
Sampling Basis

Each of the Cascabel Watersheds contains between 35 and 45 permanent sample plots that were established along transects located perpendicular to the main stream channels and situated from ridge to ridge. The intervals between the sample plots vary depending on the size and configuration (shape) of the watershed sampled. A total of 421 sample plots were established on the watersheds. We obtained measurements of tree overstory, herbaceous understory, flammable fuel loadings, and ground cover on varying-sized plots centered over these sample plot locations, with the configuration of the plot dependent on the resource sampled.

The sampling basis for sites in the oak woodlands was different than that on the Cascabel Watersheds. Depending on whether tree overstories, herbaceous understories, or fuel loadings were measured, the number, distribution, and location of the sample plots and the plot configurations varied (see the following).

Tree Overstory Measurements

We measured species compositions and densities (in number and volume) of tree overstories in the oak savannas on the Cascabel Watersheds on 1/4-acre circular plots established at the sample locations. Both single-stemmed and multiple-stemmed trees were sampled on the watersheds (fig. 2). Single-stemmed trees were measured in terms of their diameter



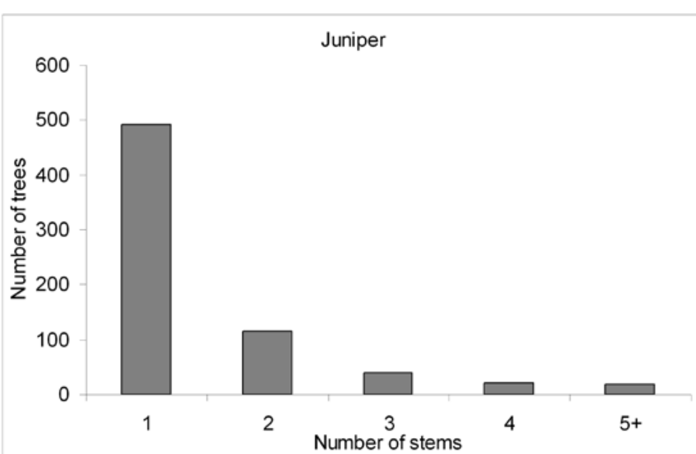


Figure 2. Numbers of single- and multiple-stemmed trees tallied on the Cascabel Watersheds. Oak and juniper trees are presented by representative species-groups. Tallies of Mexican pinyon and the tree-form of mesquite were too few to include in the figure.

root collar (drc) and multiple-stemmed trees by the equivalent diameter root collar (edrc) following the procedures outlined by Chojnacky (1988). Sampled trees were grouped into size-classes that were similar to those selected by O'Brien (2002) to describe resource characteristics of the "woodland types" in Arizona. Saplings were 1.0 to 4.9 inches drc (edrc), medium trees 5.0 to 8.9 inches drc (edrc), and large trees 9.0 inches drc (edrc) and larger. Total height measurements of the trees were also taken to provide a basis to calculate volume.

We obtained similar information on tree species compositions and densities in two separate inventories of the oak woodlands on the south slope of the Huachuca Mountains. The first inventory consisted of tallying trees on 80 1/10-acre circular plots (Touchan 1988), while trees were tallied on 23 1/4-acre circular plots in the second inventory (Ffolliott and Gottfried 2005, Gottfried and Ffolliott 2002). The plots were randomly located in both inventories. Inventory information was obtained in the same general area. Estimates of species compositions and tree overstory densities from the two inventories were summarized and combined to characterize the oak woodlands.

We estimated annual growth of the tree overstories in both the oak savannas and oak woodlands by using a growth and yield model developed by Fowler and Ffolliott (1995). This model is based on variable-density yield tables that facilitate the calculation of growth for specified time periods (Avery and Burkhart 2001, Husch and others 2002). Variable-density yield tables display relationships between the dependent variable of volume per acre and the three independent variables of stand age, a site quality value, and tree overstory density. Solutions of the basic growth equation in the model provided estimates of cubic-foot volume using stand age based on increment cores, site quality values obtained from Callison (1988), and tree overstory densities from inventory data as input variables. Current and future volumes (in 10 years) of the tree overstories were estimated by this growth equation, with the difference between the two estimates of volume representing the (net) growth for the tree overstory sampled.

Herbaceous Understory Measurements

We obtained species compositions and seasonal (spring and fall) estimates of the production (standing biomass) of grasses, forbs, and shrubs comprising the herbaceous understories on the Cascabel Watersheds from the spring of 2003 through the fall of 2007. The spring estimates represented the production of early-growing plants and the fall estimates reflected the production of the late-growing plants (McPherson 1992, 1997). The main factors favorable to early-growing plants are temperature and antecedent soil water derived largely from late fall and winter precipitation events, while plant species that are late growers are more responsive to the summer monsoonal rains.

We estimated herbage production by following the weight-estimate procedure originally outlined by Pechanec and Pickford (1937). Estimates of herbaceous plant green weights were obtained on 9.6-ft^2 circular plots at the sample locations. We then applied appropriate corrections factors to convert the estimates of green weight to actual oven-dry weight. The estimates of herbage production were expressed in lbs/acre.

Comparisons of herbage production in the oak savannas to herbage production in the oak woodlands are problematic unless the respective estimates are obtained at the same time (season) because of the large variability in the amount and distribution of seasonal precipitation in the region. Therefore, we compared an estimate of the production of late-growing plants obtained on the south slope of the Huachuca Mountains in the fall of 2005 (Ffolliott and Gottfried 2005) to the estimate of late-growing plants obtained on the Cascabel Watersheds at the same time.

We determined that utilization of forage species by herbivores by ocular estimation at the same time that herbage production was estimated in the two oak ecosystems. No differentiation was made of the herbivore involved.

Measurements of Flammable Fuel Loadings

Fuels in oak savannas that are available for burning consist largely of vegetative biomass. Oven-dry weight (tons) of these fuels per unit of surface area (acre) is a measure of the loadings of these fuels. Loadings of three fuel fractions were measured at the sample plots on the Cascabel Watersheds in earlier studies (Ffolliott and others 2006). These fractions were standing trees (alive and dead), downed woody materials (sound and decaying logs, branches, and twigs), and herbaceous biomass (grass, forbs, and shrubs). We converted cubic-foot volumes of standing trees to oven-dry weights by applying species-specific gravity (wood density) values for the tree species tallied on the Cascabel Watersheds to estimate the loading of this fuel fraction. The estimate of the downed woody materials loading was obtained by applying the planar-intersect procedure outlined by Brown and others (1982). This procedure consists of counting the intersections of downed woody materials with a vertical sampling plane that resembles a guillotine dropped through the accumulated fuels. The estimate of herbage production of late-growing plants in the fall of 2005, when compared with production of late-growing plants in the oak woodlands, represented the loading of herbaceous biomass. Estimates of the fuel fraction comprised of litter and duff were not available.

Comparable fuel fractions were estimated in oak woodlands on the south slope of the Huachuca Mountains by similar mensurational procedures. However, the sampling basis to obtain these estimates was different. An estimate of the standing tree fraction loading was obtained on the circular plots comprising the two inventories of tree overstories (Ffolliott and Gottfried 2005; Gottfried and Ffolliott 2002; Touchan 1988). We measured loading of downed woody materials on a randomly situated 2.5-acre grid of 25 systematically located plots established as equally spaced intervals (Ffolliott and others 2008). Errors of 20 percent or less—adequate levels of precision for most fuel inventories according to Brown and others (1982)—are generally obtained with this sampling design and the number of plots. The loading of the herbaceous fraction was represented by the estimated production of late-growing plants in the fall of 2005.

Measurements of Ground Cover Conditions

Percentages of plant material, litter, bare soil (including cobble, gravel, and stones), and bedrock on a landscape are often used to predict hillslope erosion rates (Renard and others 1997) and indicate the successional status of vegetative communities on a site (Bedell 1998). Furthermore, the current state of vegetation and soil protection of the site in relation to the "potential natural community" on the site can be estimated with knowledge of the percentages of bare soil and bedrock (Magurran 1988). Percentages of plant materials, litter, bare ground, and bedrock in a 12 by 18-inch rectangular frame were estimated at three equidistantly-spaced locations within 3 ft of the sample plots on the Cascabel Watersheds to obtain a "baseline" estimate of ground cover conditions in oak savannas. Ground cover conditions in oak woodlands on the south slope of the Huachuca Mountains were not available, and, as a consequence, a comparison of ground cover in the two oak ecosystems was not possible.

Analytical Procedures

We evaluated tests of significance to determine statistical differences in the data sets at a 0.10 level of significance. However, because the three tree size-classes (saplings, medium trees, and large trees) and the three herbaceous components (grasses, forbs, and shrubs) studied were nested within the overall tests of all size-classes in the tree overstories and all components in the herbaceous understories, the individual tests of the three tree size classes and tree herbaceous components were evaluated separately at a 0.30 level to maintain the overall 0.10 level of significance in accordance with a Bonferroni adjustment.

Results and Discussion

Tree Overstories

Species compositions

A larger number of tree species comprised the overstory of the oak savannas on the Cascabel Watersheds (seven) than in the overstory of the oak woodlands on the south slope of the Huachuca Mountains (four). The species tallied on the watersheds were 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), and 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) were tallied.

Emory oak (89.3 percent) dominated the overstories in the oak woodlands on the south slope of the Huachuca Mountains, with limited intermingling of Arizona white oak (8.7 percent), scattered alligator juniper (1.3 percent), and border pinyon (0.7 percent) trees. The composition of tree species on these sites was characteristic of the lower elevations of the oak woodlands in the region (Ffolliott 1999, 2002; McClaran and McPherson 1999; McPherson 1997). Tree species found at the higher elevations of the oak woodlands in the Huachuca Mountains often include a greater representation of Arizona white oak with scattered Mexican blue oak (*Q. oblongifolia*), silverleaf oak (*Q. hypoleucoides*), and gray oak (*Q. grisea*).

Intermingling alligator juniper and border pinyon also occur at the higher elevations.

Numbers of trees

Average numbers of trees per acre and 90 percent confidence intervals on the Cascabel Watersheds are presented by species (oak and juniper) and size-class in figure 3. The size-classes shown are those specified by O'Brien (2002). Oak dominated the numbers of trees in all size classes (as expected) followed by juniper. Border pinyon was a minor component and occurrences of the tree-form of mesquite were inconsequential.

Average numbers of all trees (all species) per acre and 90 percent confidence intervals of tree overstories in oak savannas on the Cascabel Watersheds and oak woodlands on the south slope of the Huachuca Mountains are illustrated in figure 4. The numbers of medium, large, and all trees in the oak savannas were significantly less than the corresponding numbers in the oak woodlands. However, the numbers of saplings were statistically similar. While reasons for the similar numbers of saplings are open to conjecture, one explanation might be attributed to the episodic cycles of obtaining (sexual) reproduction of trees in the oak ecosystems of the Southwestern Borderlands (Borelli and others 1994). Numerous seedlings blanket the landscapes of the two ecosystems when these episodic reproduction events occur, often obscuring the effects of site characteristics on the surviving number of plantlets. Such an event could have coincided with the approximate age of the numerous saplings sampled on the study areas.

Volume of trees

A local volume table based on volumes calculated by Chojnacky (1988) was the basis for converting the average numbers of trees per acre to corresponding estimates of average cubic-foot volume per acre. Average cubic-foot volume of all trees per acre and 90 percent confidence intervals on the Cascabel Watersheds are presented by species (oak and juniper) and size-classes in figure 5. Most of the volume was contained in large oak trees followed by large juniper trees, resembling the pattern for numbers of trees. The volume of border pinyon trees was insignificant, while the volume of the tree-form of mesquite was only a trace.

Average ft^3/acre volume of all trees (all species) and 90 percent confidence intervals of tree overstories in the oak savannas on the Cascabel Watersheds and oak woodlands on the south slope of the Huachuca Mountains are shown in figure 6. Tree volumes were grouped by the size-class categories specified by O'Brien (2002) for presentation. The volumes of medium, large, and all trees in the oak savannas were significantly less than the corresponding volumes of trees in the oak woodlands. The volumes of saplings were statistically similar but contributed comparatively little to the total volume of the trees in either of the ecosystems.

The smaller cubic-foot volumes of trees in the medium, large, and all tree size-classes in the oak savannas was attributed largely to two reasons—the total numbers of all trees and the relative proportion of oak in the tree overstory were both less in the oak savannas than the oak woodlands. There were significantly fewer numbers of trees in these size classes in the oak savannas (fig. 4), and, as a consequence, one would expect generally smaller volumes of trees in this ecosystem. Contributing to this finding is the fact that the relative proportion of oak in the species composition of the tree overstory in the oak savannas was less than that in the oak woodlands. One might also expect less volume in the oak savannas than in the oak woodlands because tree species other than the oak tallied in the two ecosystems contained less volume for a specified drc (edrc) and for height measurements than oak (Chojnacky 1988).

Annual growth rates

Trees in the oak ecosystems of the Southwestern Borderlands grow slowly, rarely exceeding a fraction of a ft^3/acre each year (Ffolliott 1999, 2002; McClaran and McPherson 1999; McPherson 1992, 1997). This value is equivalent to a growth rate that is less than one percent of the volume of the trees. It was not surprising, therefore, that the estimated annual growth rate of the tree overstory in the oak savannas on the Cascabel Watersheds was only 0.069 ± 0.023 of a ft^3/acre, while that in the oak woodlands on the south slope of the Huachuca Mountains was 0.11 ± 0.016 of a ft^3/acre. While a difference in growth rates is suggested by these two estimates, the confidence intervals for the respective estimates can not be accurately calculated because the errors embedded in the development of the growth and yield model forming the basis for obtaining these estimates are unknown (Fowler and Ffolliott 1995).

An analysis of increment cores collected from a total of 42 trees in the oak savannas and oak woodlands indicated that the annual growth rates of oak trees sampled in both ecosystems were relatively "fast" in the early and middle stages of their development. However, these annual growth rates declined to the point where the (net) annual growth rates became negligible as the trees became older.

Figure 3. Average numbers of trees per acre and 90 percent confidence intervals in the oak savannas on the Cascabel Watersheds by species (oak and juniper) and size-classes. Mexican pinyon and the tree-form of mesquite were too few to include in the figure.

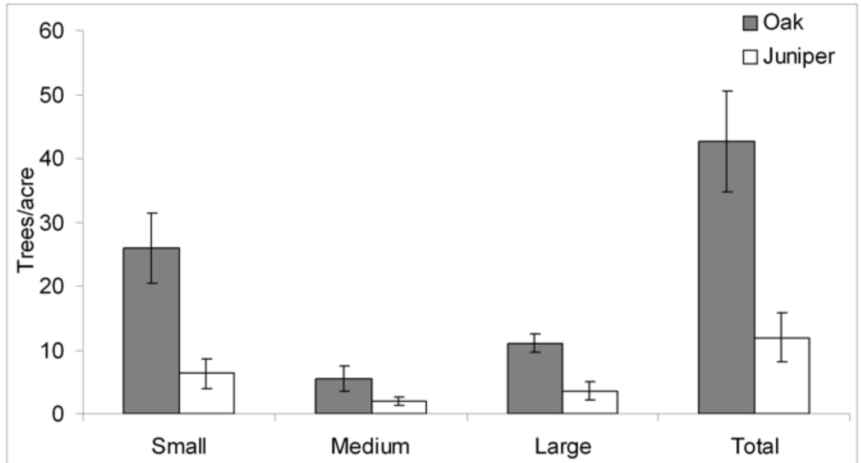


Figure 4. Average numbers of trees per acre and 90 percent confidence intervals of all trees in the respective overstories of the oak savannas on the Cascabel Watersheds and oak woodlands on the south slope of the Huachuca Mountains.

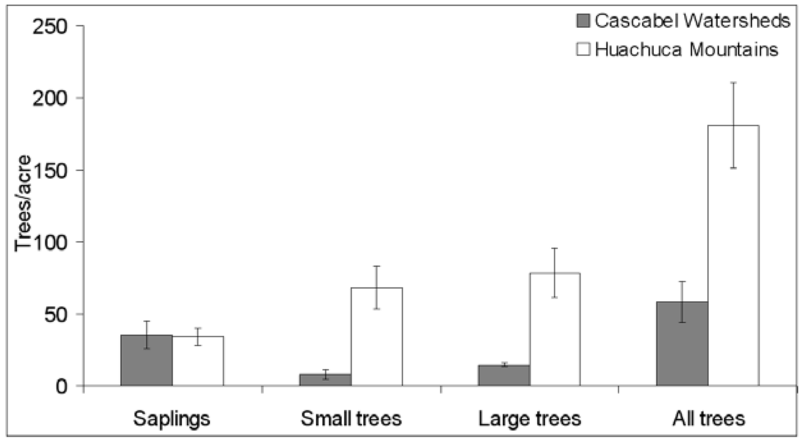


Figure 5. Average cubic-foot volume of trees per acre and 90 percent confidence intervals in the oak savannas on the Cascabel Watersheds by species (oak and juniper) and size-classes. Mexican pinyon and the tree-form of mesquite were too few to include in the figure.

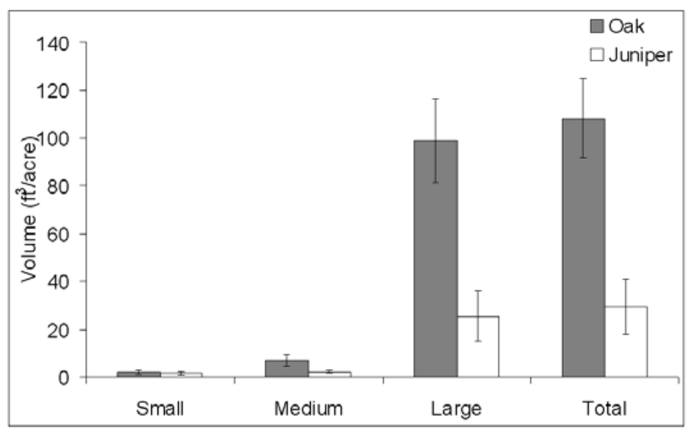
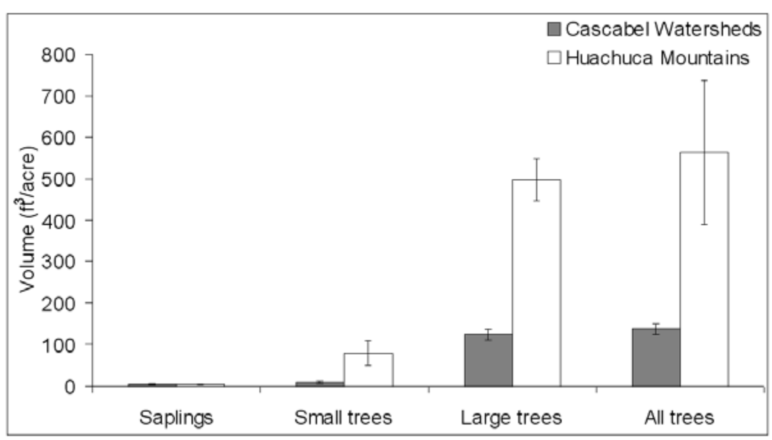


Figure 6. Average cubic-foot volume of trees per acre and 90 percent confidence intervals of all trees in the respective overstories of the oak savannas on the Cascabel Watersheds and oak woodlands on the south slope of the Huachuca Mountains.



Spatial distributions of trees

Spatial distributions of trees in the overstory of the oak savannas on the Cascabel Watersheds were more variable than the spatial distributions of trees in the oak woodlands on the south slope of the Huachuca Mountains. This difference in relative variability, measured by the respective coefficients of variation (Ffolliott and Gottfried 2005), suggests more heterogeneous stocking conditions in the oak savannas than in the oak woodlands (fig. 7). However, acceptance of this difference as a fact must be "conditioned" by remembering that different sampling procedures were followed in the inventories of tree overstories in the two ecosystems. Nevertheless, the openings of varying sizes, shapes, and orientations that are interspersed within the scattered tree overstory in the oak savannas are less common in the more homogeneous stocking conditions of oak woodlands.

Herbaceous Understories

Species compositions

Plant species in the herbaceous understories of the oak savannas on the Cascabel Watersheds and the oak woodlands on the south slope of the Huachuca Mountains were mostly similar. Included among perennial grasses were 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*). Forbs including species of mariposa lily (*Calochortus* spp.), verbena (*Verbena* spp.), and lupine (*Lupinus* spp.) were a comparatively minor component of the herbaceous understories of both ecosystems. Beargrass or sacahuista (*Nolina microcarpa*), fairyduster (*Calliandra eriophylla*), common sotol (*Dasylirion wheeleri*), pointleaf

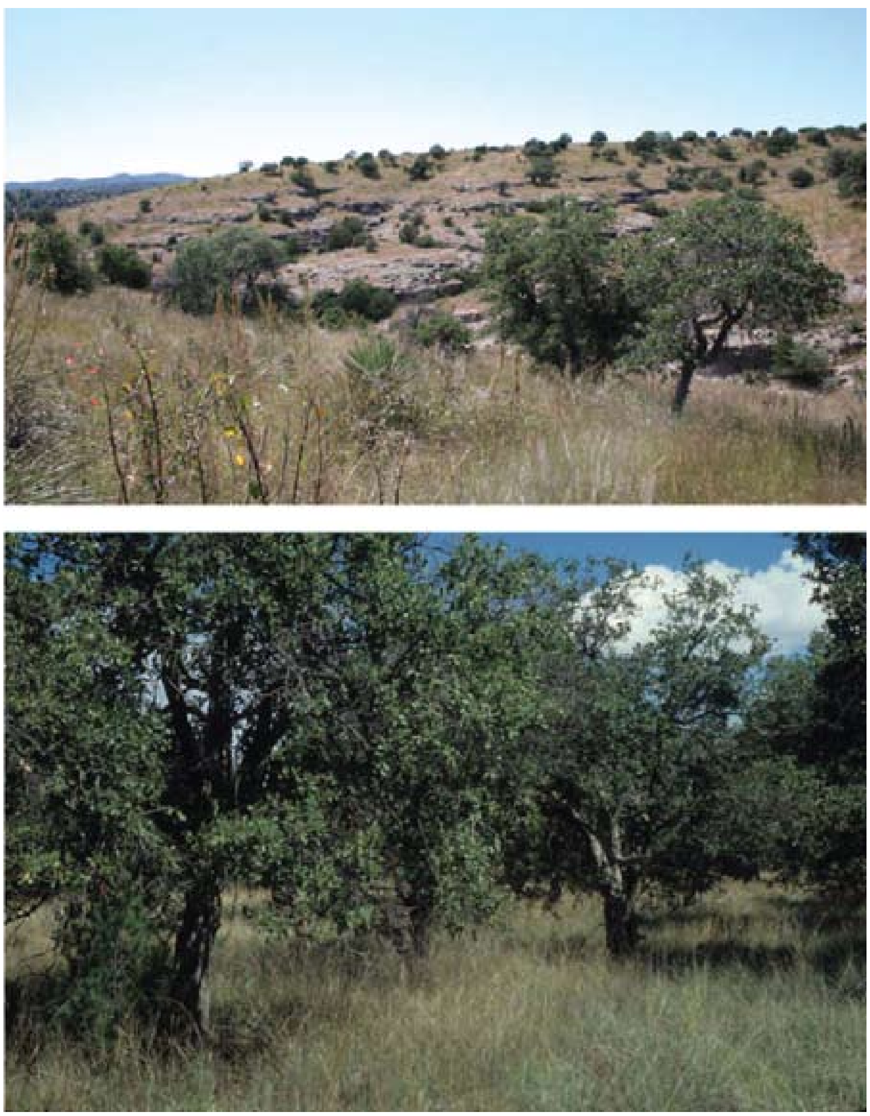


Figure 7. Oak savannas on Cascabel Watersheds (top) are more open and variable in the spatial distributions of trees in the overstory than in the denser oak woodlands on the south slope of the Huachuca Mountains (bottom).

manzanita (*Arctostaphylos pungens*), Fendler's ceanothus (*Ceanothus fendleri*), and Mexican cliffrose (*Purshia mexicana*) were among the scattered half-shrubs and shrubs in the ecosystems. Palmer's century plant (*Agave palmeri*) and banana yucca (*Yucca baccata*) were also found on well-drained rocky slopes. Shrub-forms of oak species and mesquite were present. Annual plants were largely absent in both ecosystems when the baseline data for this paper were obtained.

Production of early- and late-growing herbaceous plants

Averages and 90 percent confidence intervals for the estimated production of early- and late-growing herbaceous plants (grasses, forbs, and shrubs combined) in the oak savannas on the Cascabel Watersheds from 2003 to 2007 are presented in figure 8. The production of early-growing plants averaged 139.7 ± 5.4 (mean ± [$t_{0.10}$ x standard error]) lbs/acre for the study period, while the average production of late-growing plants was significantly greater at 306.7 ± 9.4 lbs/acre. Many of the herbaceous species in the understories of oak savannas germinate and grow during or shortly following the summer monsoonal rains (Gottfried and others 2007b) and, therefore, are late-growing plants. It should be kept in mind, however, that estimates of seasonal herbage production in this study were obtained in a period of prolonged drought in the region.

Seasonal precipitation amounts considered "favorable" to the production of early-growing and late-growing plants are also shown in figure 8. The correlation coefficient between the production of early-growing plants and precipitation between October 15 to April 14, and the correlation coefficient between the production of late-growing plants and precipitation between April 15 and October 14, were statistically significant, similar in magnitude and, therefore, combined. The resulting (combined) correlation coefficient (+0.658) indicated that 43 percent of the variation in seasonal herbage production could be attributed to the precipitation amounts affecting the herbage production for that season. Relationships between the production of early- and late-growing plants and seasonal temperature or seasonal relative humidity were insignificant.

The estimated production of late-growing plants in the oak savannas on the Cascabel Watersheds in 2005 was 265.0 ± 12.1 lbs/acre. This value was significantly greater than the corresponding production estimate of 155.9 ± 23.6 lbs/acre for late-growing plants in the oak woodlands on the south slope of the Huachuca Mountains obtained at the same time. This comparison, therefore, suggests that a higher level of herbage production might be expected in the more open oak savannas than in the denser oak woodlands. However, simultaneous estimates of production for both early- and later-growing herbaceous plants should continue until a sufficient number of years (seasons) have been sampled to encompass the inherent variability of precipitation in the region before final conclusions on these comparisons are made.

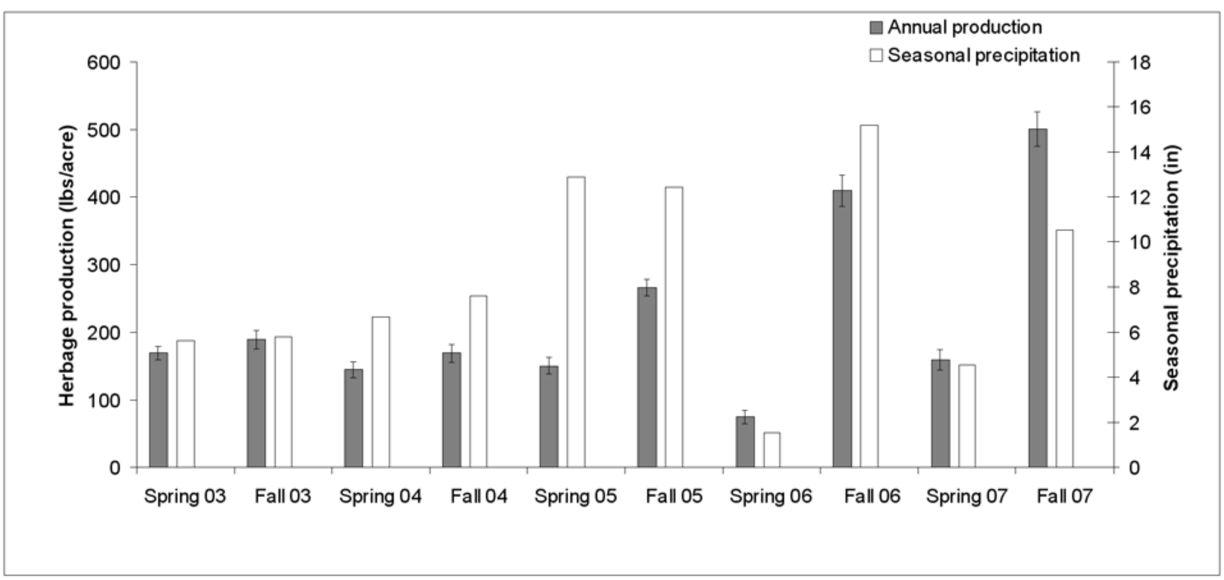


Figure 8. Annual production of early- and late-growing plants in the oak savannas and seasonal precipitation on the Cascabel Watersheds from 2003 to 2007. Estimates of average herbage production and 90 percent confidence intervals are shown. It was assumed that precipitation "favorable" to early-growing plants occurs from October 15 to April 14, while precipitation affecting late-growing plants falls from April 15 to October 14.

Production of early- and late-growing grasses, forbs, and shrubs

Averages and 90 percent confidence intervals for the estimated production of early- and late-growing grasses, forbs, and shrubs (considered individually) are shown in figure 9. Because the contribution of half-shrubs to total herbage production was small, it was combined with the production of shrubs. The production of early growing grasses averaged 84.8 ± 3.7 lbs/acre, early-growing forbs 25.7 ± 2.4 lbs/acre, and early-growing shrubs 28.9 ± 3.8 lbs/acre for the study, while production of late-growing grasses, forbs, and shrubs averaged 218.7 ± 7.2 lbs/acre, 57.1 ± 4.2 lbs/acre, and 32.4 ± 4.2 lbs/acre, respectively. The production of late-growing grasses and forbs, therefore, was greater than the production of the early-growing component. However, the production of early- and late-growing shrubs was not significantly different. The seasonal production of these respective herbaceous components was largely parallel to the pattern of seasonal production of total herbage.

Seasonal precipitation associated with estimates of the production of early- and late-growing grasses, forbs, and shrubs are also presented in figure 9. The correlation coefficients between the production of early-growing grasses and early-growing forbs and precipitation amounts for October 15 to April 14, and the correlation coefficients for the production of late-growing grasses and late-growing forbs and precipitation between April 15 and October 14, were significant, similar, and combined for each of the herbaceous components. The resulting correlation coefficients (+0.717 and +0.615, respectively) signified that approximately 51 and 38 percent of the variation in seasonal grass and forb production was attributed to the precipitation amounts influencing the production of the herbaceous components for that season.

Seasonal production of shrubs and seasonal precipitation affecting the production of this herbaceous component was not significant. Shrubs typically have deeper rooting systems than grasses and forbs, and, therefore, often have access to a "greater reservoir" of soil water. As a result, rainfall might be less likely to limit their growth. Relationships of the production of early- and late-growing grasses, forbs, and shrubs with seasonal temperature or seasonal relative humidity were not significant.

Utilization of forage plants

Utilization of forage species by herbivores averaged less than 5 percent for the 2003 through 2007 seasons of observation. However, the rancher had removed the cattle from the Cascabel Watersheds in the summer of 2004 because of the prevailing drought conditions (Gottfried and others 2007b), while the population of deer in the vicinity of the watersheds had been comparatively low in recent years. The low level of utilization, therefore, was not a surprise. Comparable levels of forage utilization also occurred in the oak woodlands on the south slope of the Huachuca Mountains throughout the study period.

Overstory–Understory Relationships

Analyses of the frequently reported relationships of increasing herbage production with decreasing densities of a tree overstory (Bartlett and Betters 1983, Ffolliott and Clary 1982) indicated no significant correlations between the production of either early- or late-growing herbaceous plants and the densities of tree overstories in either of the oak ecosystems. While tree overstory densities in the oak savannas were significantly less than in the oak woodlands, relationships between herbage production and tree overstory densities were not (statistically) significant for the range of tree overstory densities sampled in the two ecosystems.

Similar results showing a lack of statistical correlation between herbage production and densities of tree overstories have also been reported in earlier studies in the oak ecosystems of the Southwestern Borderlands (Ffolliott and Gottfried 2005, Gottfried and Ffolliott 2002). It seems likely, therefore, that tree overstory density (by itself) might not be a significant factor in "controlling" the production of herbaceous plants in these ecosystems. This hypothesis is further strengthened by the finding that the correlation between herbage production and tree densities in the Gambel oak (*Q. gambelii*) stands that intermingle with the ponderosa pine (*Pinus ponderosa*) forests in northern Arizona was also not statistically significant (Reynolds and others 1970).

While overstory tree densities might not be related to herbage production in the oak ecosystems, herbage may influence tree regeneration. McClaran and McPherson (1999) reported that a dense cover of perennial grasses can limit successful Emory oak regeneration on ungrazed sites in the Southwestern Borderlands region. However, further study is required to verify the extent of this situation.

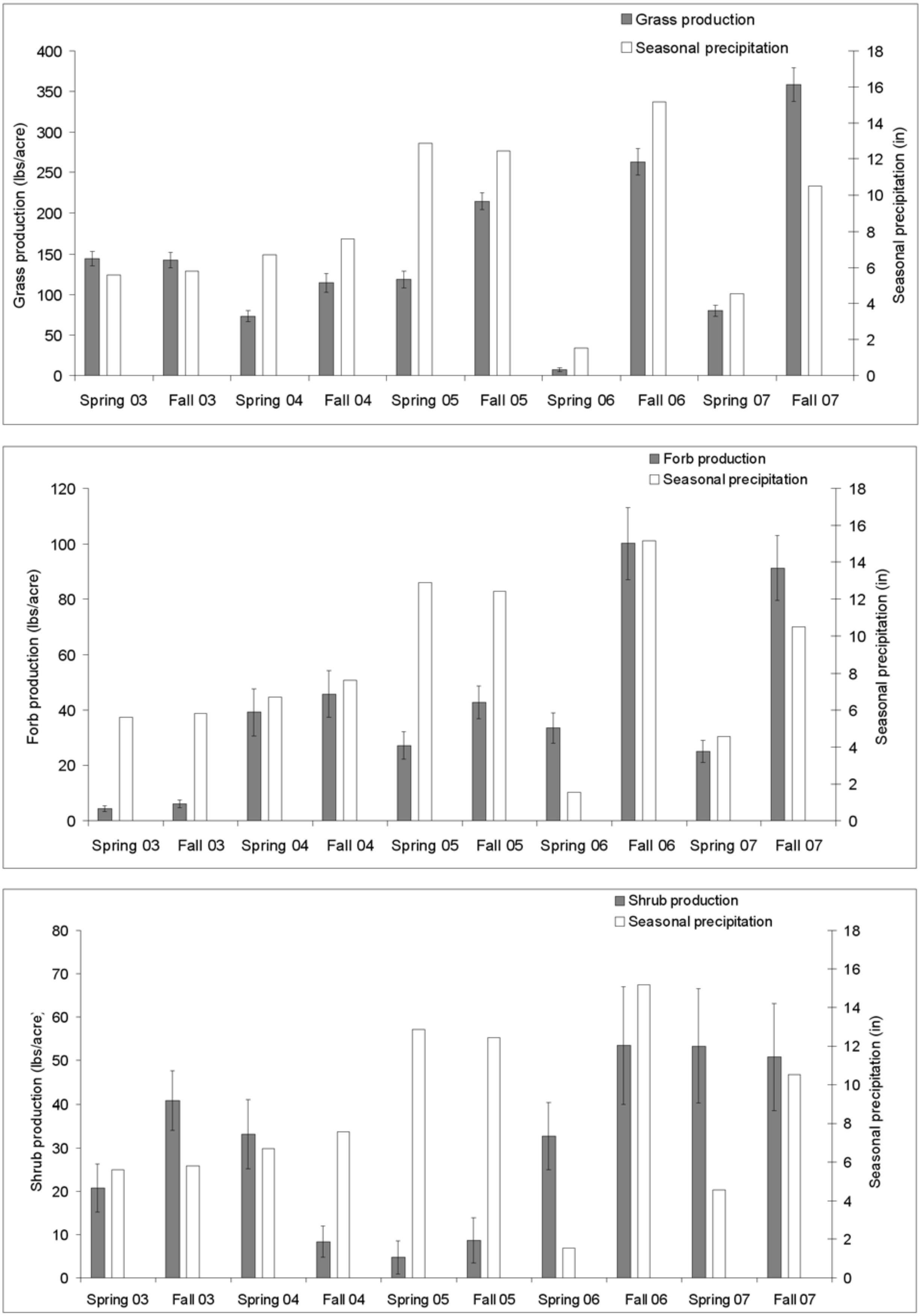


Figure 9. Annual production of early and late-growing grasses (top), forbs (middle), and shrubs (bottom) and seasonal precipitation in the oak savannas for the 2003 through 2007 seasons. Production of half-shrubs and shrubs has been combined in this figure. Estimates of average production and 90 percent confidence intervals are shown. The scale on the Y-axis is unique for each graph.

Flammable Fuel Loadings

Average loadings of flammable fuels (including standing trees, downed woody materials, and herbaceous biomass fractions) in the oak savannas on the Cascabel Watersheds and 90 percent confidence intervals are shown in figure 10. The total loadings value in the oak savannas averaged 2.98 ± 1.89 tons/acre. However, accumulations of these fuels on the watersheds were scattered and discontinuous across the landscape. Standing trees represented the largest fuel fraction (by far), followed by the accumulations of downed woody materials and then the herbaceous biomass. Loading of the fraction represented by the standing trees has been underestimated, however, because the volume table used to estimate cubic-foot volume of the trees (Chojnacky 1988) excludes branches and twigs smaller than 1.5 inches in diameter. Over 95 percent of the standing trees were alive when tallied, reducing (somewhat) their value as a fuel because of the relatively high moisture contents of their stems, branches, twigs, and foliage. Accumulations of the fuels in the fraction represented by downed woody materials were mostly sound (as opposed to rotten) stems, branches, and twigs that were less than 0.5 inches in diameter and 2 ft in length. The comparatively small herbaceous fraction was comprised of the grasses, forbs, and shrubs on the watersheds.

Loadings of flammable fuels in the oak woodlands of the south slope of the Huachuca Mountains are also presented in figure 10. The average loadings of these fuels was 6.28 ± 1.24 tons/acre, a value almost twice the estimated fuel loadings in the oak savannas. The larger number of trees in the oak woodlands (fig. 4) and the greater proportion of oak trees (with higher specific gravity [wood density] values) than the other species inhabiting the oak woodlands were the major factors attributing to this difference. Accumulations of downed woody materials were also significantly greater in the oak woodlands than in the oak savannas. Herbaceous biomass was a minor component of the fuels in both oak ecosystems.

Ground Cover Conditions

Average percentages and 90 percent confidence intervals of plant material, litter, bare soil, and bedrock in the oak savannas on the Cascabel Watersheds are illustrated in figure 11. Plant material, litter, and bedrock were the largest components of ground cover, with the percent of bare soil significantly less than these three components. Ground cover has been defined specifically by Bedell (1998) to represent the (cumulative) percentages other than plant material covering a landscape. This value was nearly 75 percent on the Cascabel Watersheds. It is suggested that the percentages shown in figure 11 could be one basis for evaluating the ecological effects of future management actions in the oak savannas (such as changes in livestock grazing practices or prescribed burning treatments) in a broader perspective by including changes in ground cover conditions.

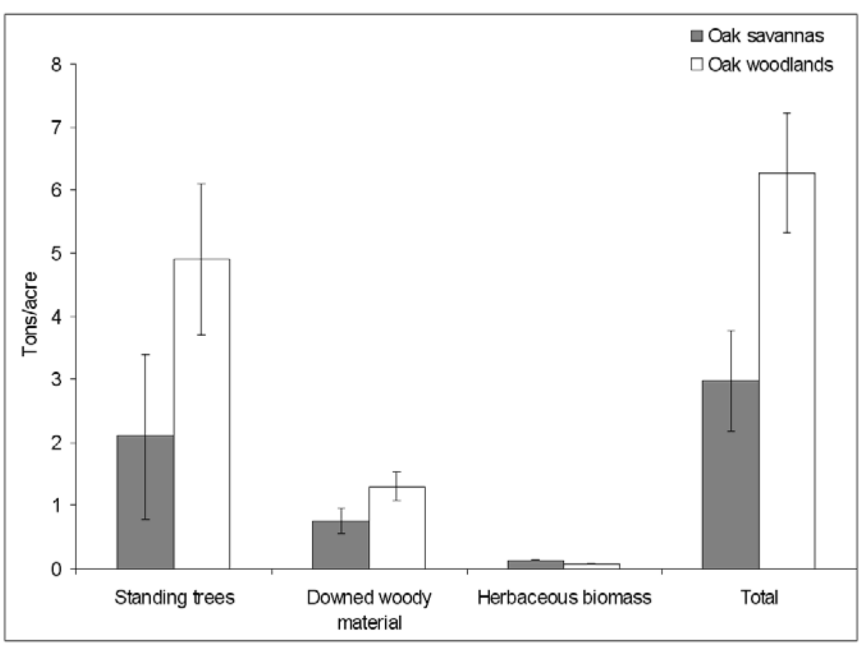


Figure 10. Average loadings of flammable fuel fractions and 90 percent confidence intervals in the oak savannas on the Cascabel Watersheds and the oak woodlands on the south slope of the Huachuca Mountains.

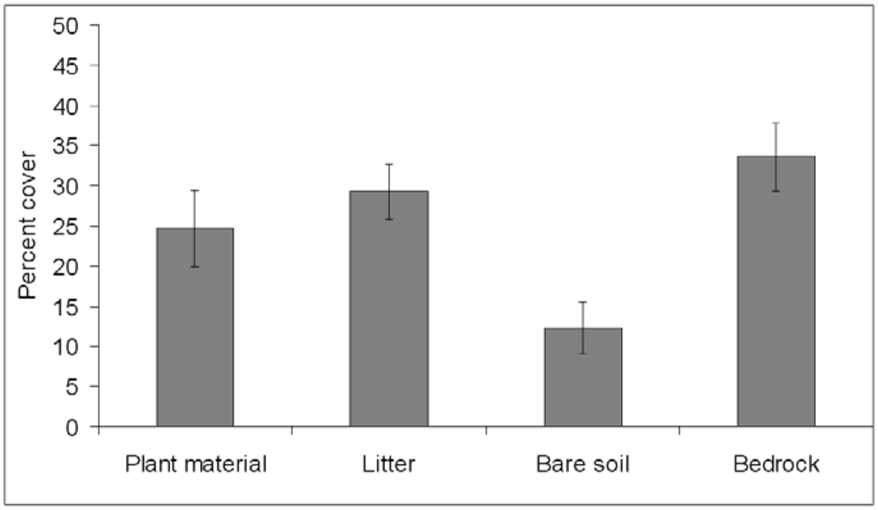


Figure 11. Average percentages and 90 percent confidence intervals of plant material, litter, bare soil, and bedrock in the oak savannas on the Cascabel Watersheds.

Ecological Diversity

There is a growing interest in the concept of "ecological diversity" because this characteristic has often become a central theme of ecology. Measures of ecological diversity can also serve as indicators of the "well being" of an ecosystem (Magurran 2004). No matter how it is measured, however, ecological diversity embodies two fundamental indices—species richness (the number of species) and species evenness (how equally abundant the species are). High species evenness, that is, when the species inhabiting an area are virtually equal in abundance, is equated with high diversity. The concept of ecological diversity can be illustrated by considering (1) the number of species (species richness) in the tree overstories and herbaceous understories of the oak savannas on the Cascabel Watersheds and in the oak woodlands on the south slope of the Huachuca Mountains and (2) the species evenness (their relative abundance) in these two ecosystems.

Based on data collected for this paper, the tree overstory of the oak savannas is more diverse than the oak woodlands in terms of species richness. Seven tree species were tallied on the Cascabel Watersheds, while only four were tallied on the south slope of the Huachuca Mountains. However, one species (Emory oak) was especially abundant in both oak ecosystems, while the remaining tree species were significantly less common in their occurrences. Therefore, the unevenness (the unequal abundance) of these tree species indicates that both of the oak ecosystems have a relatively low diversity in terms of this measure. Reconciling the differences between these two indices of ecological diversity for these tree overstories lies in the relative weighting that people place on the indices of species richness and evenness.

The numbers of herbaceous species tallied in the oak savannas and oak woodlands were essentially the same. As a result, the two oak ecosystems can be considered similar in terms of species richness. Unfortunately, the relative frequencies of occurrences of these species were not determined in this study, and, therefore, a "direct measurement" of species evenness (how equally abundant the species occur in the two ecosystems) was not possible. However, the production of the herbaceous plants has been estimated. Assuming that these estimates of production can serve as a "proxy" for the frequencies of occurrences of the species, the ecological diversities of the oak savannas and oak woodlands also appear to be similar by this measure of diversity.

Ecological diversities of the oak ecosystems in the Southwestern Borderlands at this time reflect past and present land-use activities and fire regimes. Harvesting of trees for firewood and fenceposts, large-scale livestock production, and mining operations that spread across the region in the late 1880s caused profound changes in the nature of the landscapes of the ecosystems in this settlement period (Bahre 1991, 1995; Bahre and Shelton 1996; Sayre 1999). There has also been a reduction in recurring and often widespread wildfires that were commonplace at the turn of the last century (Swetnam and Baisan 1996a, b). Fire suppression policies and practices of land management agencies after the 1900s contributed to the reduction of fires. A frequent buildup of fuels resulting from fire suppression has often caused the fires that currently occur to become damaging crown fires rather than the earlier less-damaging surface fires. Ecologists, land managers, and local ranchers are increasingly interested in reintroducing the "more natural" regime of low-severity surface fires into the region to help restore the pre-settlement features of the oak ecosystems. The Cascabel Watersheds considered in this research paper (Gottfried and others 2007b) were established primarily to assist in these efforts.

Management Implications

Sustainable ecosystems are the goal of most land management activities; however, management should be based on the best information available. The oak woodlands and savannas of the southwestern borderlands have often been considered as one vegetation type. Recent research in the savannas at Cascabel in southwestern New Mexico and the woodlands on the south side of the Huachuca Mountains in Arizona suggests that the two oak ecosystems in the Southwestern Borderlands—both of which are located in the Upper Encinal Type (Turner and others 2003) and classified in the *Quercus emoryi*/*Bouteloua curtipendula* (Emory oak/sideoats grama) habitat type by the U.S. Forest Service (1987)—should not necessarily be considered as "homogeneous management units." Such a differentiation has been occasionally made in the extensive oak ecosystems in California (Pillsbury and others 1997; Standiford 1991, 2002; and others).

Our findings indicate that tree overstories in the oak savannas on the Cascabel Watersheds are less dense and stocking conditions are more heterogeneous than in the oak woodlands on the south slope of the Huachuca Mountains. A higher level of production of late-growing herbaceous plants was observed beneath the more open tree overstories in the oak savannas than in oak woodlands. However, further estimates of herbage production will be necessary before arriving at defendable conclusions on the comparative levels of herbage production in the two oak ecosystems. Flammable fuel loadings are less in the oak savannas than those observed in the oak woodlands, largely because of fewer standing trees, the largest fuel fraction on the landscape of the woodlands. The ground cover conditions estimated in this study represent a "baseline" for the oak savannas of the region.

Managers should consider these differences between oak savannas and woodlands when planning or implementing practices to alter the respective tree overstories, herbaceous understories, or other natural resources that are closely related to these vegetative characteristics (such as the capacity for livestock production, quality of wildlife habitats for food and cover, or water-related resources).

Acknowledgments

This research and the 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 Agricultural Experiment Station, University of Arizona, Tucson, Arizona.

References

Avery, T. E.; Burkhart, H. E. 2001. Forest measurements. New York, NY: McGraw-Hill Book Company. 480 p.

Bahre, C. J. 1991. A legacy of change: historic human impact on vegetation of the Arizona borderlands. Tucson, AZ: University of Arizona Press. 231 p.

Bahre, C. J. 1995. Human disturbance and vegetation in Arizona's Chiricahua Mountains in 1902. Desert Plants. 11(4):39-45.

Bahre, C. J.; Shelton, M. L. 1990. Rangeland destruction: cattle and drought in southeastern Arizona at the turn of the century. Journal of the Southwest. 38:1-22.

Bartlett, E. T.; Betters, D. R., eds. 1983. Overstory-understory relationships in western forests. West. Reg. Res. Pub. 1. Fort Collins, CO: Colorado State University Experiment Station. 37 p.

Bedell, T. E. 1998. Glossary of terms used in range management. Denver, CO: Society for Range Management. 32 p.

Borelli, S.; Ffolliott, P. F.; Gottfried, G. J. 1994. Natural regeneration in encinal woodlands of southeastern Arizona. The Southwestern Naturalist. 39:179-183.

Brown, J. K.; Oberheu, R. D.; Johnston, C. M. 1982. Handbook for inventorying surface fuels and biomass in the Interior West. Gen. Tech. Rep. INT-129. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 48 p.

Callison, J. C. 1988. Site quality indices in oak woodlands. Tucson, AZ: PhD Dissertation, University of Arizona. 38 p.

Chojnacky, D. C. 1988. Juniper, pinyon, oak, and mesquite volume equations for Arizona. Res. Pap. INT-391. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 11 p.

DeBano, L. F.; Ffolliott, P. F.; Gottfried, G. J.; Hamre, R. H.; Edminster, C. B., tech. coords. 1995. Biodiversity and management of the Madrean Archipelago: the sky islands of southwestern United States and northern Mexico. Gen. Tech. Rep. RM-264. Fort Collins CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 699 p.

Ffolliott, P. F. 1999. Encinal woodlands in the southwestern United States. In: Ffolliott, P. F.; Ortega-Rubio, A., eds. Ecology and management of forests, woodlands, and shrublands in the dryland regions of the United States and Mexico: perspectives for the 21st century. La Paz, Baja California Sur, Mexico: Centro de Investigaciones Biologicas del Noroeste: 69-81.

Ffolliott, P. F. 2002. Ecology and management of evergreen oak woodlands in Arizona and New Mexico. In: McShea, W. J.; Healy, W. M., eds. Oak forest ecosystems: ecology and management for wildlife. Baltimore, MD: The Johns Hopkins University Press: 304-316.

Ffolliott, P. F.; Clary, W. P. 1982. Understory-overstory vegetation relationships: an annotated bibliography. Gen. Tech. Rep. INT-136, Logan, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 39 p.

Ffolliott, P. F.; Gottfried, G. J. 2005. Vegetative characteristics of oak savannas in the southwestern United States: a comparative analysis with the oak woodlands in the region. In: Gottfried, G. J.; Gebow, B. S.; Eskew, L. G.; Edminster, C. B., compilers. Connecting mountain land and desert seas: biodiversity and management of the Madrean Archipelago II. Proceedings. RMRS-P-36. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 399-402.

Ffolliott, P. F.; Gottfried, G. J.; DeBano, L. F. 2008. Fuel loadings in forests, woodlands, and savannas of the Madrean Province. In: Narog, M. G., tech. coord. Proceedings of the 2002 conference on managing fire and fuels in the remaining wildlands and open spaces of the southwestern United States. Gen. Tech. Rep. PSW-189. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Ffolliott, P. F.; Gottfried, G. J.; Goldenetz, J. A. 2006. Fuel loadings in the oak savannas of the Southwestern Borderlands region. In: Borders, boundaries, and time scales: proceedings of the sixth conference on research and resource management in the southwestern deserts. Tucson, AZ: Southwest Biological Science Center: 29-31.

Fowler, W. P.; Ffolliott, P. F. 1995. A growth and yield model of Emory oak: applications on watershed lands in the southwestern United States. In: DeBano, L. F.; Ffolliott, P. F.; Gottfried, G. J.; Hamre, R. H.; Edminster, C. B., tech. coords. Biodiversity and management of the Madrean Archipelago: the sky islands of southwestern United States and northern Mexico. Gen. Tech. Rep. RM-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 347-350.

Gottfried, G. J.; Ffolliott, P. F. 2002. Notes on herbage resources in encinal woodlands. In: Halvorson, W. L.; Gebow, B. S., eds. Meeting resource management information needs: fourth Conference on Research and Resource Management in the Southwestern Deserts. Tucson, AZ: U.S. Geological Survey, Western Ecological Center, Sonoran Desert Field Station: 53-55.

Gottfried, G. J.; Ffolliott, P. F.; Neary, D. G. 2007a. Hydrology of southwestern encinal oak ecosystems: a review and more. Hydrology and Water Resources in Arizona and the Southwest. 37:19-30.

Gottfried, G. J.; Neary, D. G.; Ffolliott, P. F. 2007b. An ecosystem approach to determining the effects of prescribed fire on Southwestern Borderlands oak savannas: a baseline study. In: Fire in grassland and shrubland ecosystems: proceedings of the 23rd Tall Timbers Fire ecology conference. Tallahassee, FL: Tall Timbers Research Station: 140-146.

Gottfried, G. J.; Neary, D. G.; Bemis, R. J. 2000.Watershed characteristics of oak savannas in the southwestern borderlands. Hydrology and Water Resources in Arizona and the Southwest. 30:21-28.

Gottfried, G. J.; Gebow, B. S.; Eskew, L. G.; Edminister, C. B., compilers. 2005. Connecting mountain islands and desert seas: biodiversity and management of the Madrean Archipelago II. Proc. RMRS-P-38. Fort Collins CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 631 p.

Gottfried, G. J.; Neary, D. G.; Ffolliott, P. F.; Decker, D. D. 2006. Impacts of a high-intensity summer rainstorm on two oak savannas watersheds in the Southwestern Borderlands. Hydrology and Water Resources in Arizona and the Southwest. 36:67-73.

Hendricks, D. M. 1985. Arizona soils. Tucson AZ: College of Agriculture, University of Arizona. 244 p.

Husch, B.; Beers, T. W.; Kershaw, J. A., Jr. 2002. Forest mensuration. New York NY: John Wiley & Sons, Inc. 456 p.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton, NJ: Princeton University Press. 179 p.

Magurran, A. E. 2004. Measuring biological diversity. Malden, MA: Blackwell Publishing. 256 p.

McClaran, M. P.; McPherson, G. R. 1999. Oak savannas in the American Southwest. In: Anderson, R. C.; Fralish, J. S.; Baskin, J. M., eds. Savannas, barrens, and rock outcrop plant communities of North America. New York NY: Cambridge Press: 275-287.

McPherson, G. R. 1992. Ecology of oak woodlands in Arizona. In: Ffolliott, P. F.; Gottfried, G. J.; Bennett, D. A.; Hernandez C., V. M.; Ortega-Rubio, A.; Hamre, R. H., tech. coords. Ecology and management of oak and associated woodlands. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 24-33.

McPherson, G. R. 1997. Ecology and management of North American Savannas. Tucson AZ: University of Arizona Press. 208 p.

Neary, D. G.; Gottfried, G. J. 2004. Geomorphology of small watersheds in an oak encinal in the Peloncillo Mountains. Hydrology and Water Resources in Arizona and the Southwest. 34:65-71.

Niering, W. A.; Lowe, C. H. 1984. Vegetation of the Santa Catalina Mountains: community types and dynamics. Vegetatio. 58:3-28.

O'Brien, R. A. 2002. Arizona's forest resources, 1999. Res. Bul. RMRS-RB-2. Logan UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 116 p.

Osterkamp, W. R. 1999. Runoff and sediment yield derived from proxy records: Upper Animas Valley, New Mexico. In: Gottfried, G. J.; Eskew, L. G.; Curtin, C. G.; Edminster, C. B., compilers. Toward integrated research, land management and ecosystem protection in the Malpai Borderlands: conference summary. Proc. RMRS-P-10. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 22-24.

Pechanec, J. F.; Pickford, G. D. 1937. A weight estimate method for determination of range or pasture production. Journal of the American Society of Agronomy. 29:894-904.

Pillsbury, N. H.; Verner, J.; Tietje, W. D., tech. coords. 1997. Oak woodlands: ecology, management, and urban interface issues. Gen. Tech. Rep. PSW-160. Berkeley CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 738 p.

Renard, K. G.; Foster, G. R.; Weesies, G. A.; McCool, D. K.; Yoder, D. C. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agr. Handb. 704. Washington, DC: U.S. Department of Agriculture. 404 p.

Reynolds, H. G.; Clary, W. P.; Ffolliott, P. F. 1970. Gambel oak for southwestern wildlife. Journal of Forestry. 68:45-547.

Robertson, G.; Damrel, D.; Hurja, J.; Leahy, S. 2002. Terrestrial ecosystem survey of the Peloncillo watershed study area. Draft Rep. Albuquerque, NM: U.S. Department of Agriculture, Forest Service.

Sayre, N. 1999. The cattle boom in southern Arizona: towards a critical political ecology. Journal of the Southwest. 41:239-271.

Standiford, R. B., tech. coord. 1991. Proceedings of the symposium on oak woodlands and hardwood rangeland management. Gen. Tech. Rep. PSW-126. Berkeley CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 376 p.

Standiford, R. B. 2002. California's oak woodlands. In: McShea, W. J.; Healy, W. M., eds. Oak forest ecosystems: ecology and management for wildlife. Baltimore, MD: The Johns Hopkins University Press: 280-303.

Swetnam, T. W.; Baisan, C. H. 1996a. Fire histories of mountain forests. In: Ffolliott, P. F.; DeBano, L. F.; Baker, M. B., Jr.; Gottfried, G. J.; Solis-Garza, G.; Edminster, C. B.; Neary, D. G.; Allen, L. S.; Hamre, R. H., tech. coords. Effects of fire on Madrean Province ecosystems. Gen. Tech. Rep. RM-GTR-289. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 15-36.

Swetnam, T. W.; Baisan, C. H. 1996b. Historical fire regime patterns in the Southwestern United States since AD 1700. In: Allen, C. D., tech. ed. Fire effects in southwestern forests: proceedings of the 2nd La Mesa fire symposium. Gen. Tech. Rep. RM-GTR-286. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 11-32.

Touchan, R. 1988. Growth and yield of Emory oak. In: Ffolliott, P. F.; Hasbrouck, J. D., eds. Oak woodland management: proceedings of the workshop. Tucson, AZ: University of Arizona, School of Renewable Natural Resources: 11-18.

Turner, R. M.; Webb, J. W.; Bowers, J. E.; Hastings, J. R. 2003. The changing mile revisited. Tucson, AZ: University of Arizona Press. 334 p.

U.S. Forest Service. 1987. Forest and woodland habitat types (plant associations) of Arizona south of the Mogollon and southwestern New Mexico. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region. np.

Vincent, K. R. 1998. Tectonics and earthquake hazards of the southern Animas Valley, Hidalgo County, New Mexico. Open-File Rep. OF-429. Santa Fe, NM: State of New Mexico, Bureau of Mines and Mineral Resources. 59 p.

Youberg, A.; Ferguson, C. A. 2001. Geology and geomorphology of 12 small watersheds in the Peloncillo Mountains, central portion of the Malpai Borderlands project area, Hidalgo County, New Mexico. Open-File Rep. 01-05. Tucson, AZ: Arizona Geological Survey. 22 p.

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of the National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals. Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

Station Headquarters
Rocky Mountain Research Station
240 W Prospect Road
Fort Collins, CO 80526
(970) 498-1100

Research Locations

Flagstaff, Arizona
Fort Collins, Colorado
Boise, Idaho
Moscow, Idaho
Bozeman, Montana
Missoula, Montana
Reno, Nevada
Albuquerque, New Mexico
Rapid City, South Dakota
Logan, Utah
Ogden, Utah
Provo, Utah

Federal Recycling Program Printed on Recycled Paper