Forest Ecology and Management, 14 (1986) 193—203
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

CHANGES IN UNDERSTORY PRODUCTION FOR THREE PRESCRIBED BURNS OF DIFFERENT AGES IN PONDEROSA PINE

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(Accepted 8 October 1985)

ABSTRACT

Andariese, S.W. and Covington, W.W., 1986. Changes in understory production for three prescribed burns of different ages in ponderosa pine. *For. Ecol. Manage.*, 14: 193—203.

The general lack of resource response information severely limits economic evaluation of prescribed burning in most forest types. This paper presents changes in understory production at three sites on basalt soils following prescribed burning in ponderosa pine (*Pinus ponderosa* Laws.) in Arizona. The sites were burned during the fall 2, 5, and 7 years before sampling in 1981. Regression equations were developed to predict production from plant basal area for four common grass species; production of remaining herbaceous vegetation was measured by harvesting. Based on the results of our study and other studies of fall prescribed burning on volcanic soils in Arizona ponderosa pine, understory production response appears to be variable for 1—2 years following burning. Herbage production exhibits no change or an increase; forage production exhibits no change or a decrease. Studies of understory response more than 2 years following both wildfire and prescribed burning in Arizona ponderosa pine, however, show a general trend toward increased production. Thus, prescribed burning in southwestern pine on basalt soils produces long-term benefits in increased understory production, particularly in pole stands, which dominate much of the region.

INTRODUCTION

Understory production in the ponderosa pine (*Pinus ponderosa* Laws.) region of the southwestern United States has declined since the advent of European settlement. Early explorers recorded the area as open and park-like with large, widely spaced trees and an abundant understory of grass and forbs (Beale, 1858; Dutton, 1881). Today's decreased understory production is attributed in part to the exclusion of periodic, naturally occurring surface fires and resultant increased tree density and heavy forest floor accumulation (Cooper, 1960; Biswell, 1972).

Fire is being reintroduced to some areas of the southwestern ponderosa pine region through prescribed burning. The original objective was to decrease wildfire hazard by fuel reduction (Kallander, 1969). More recently,

0378-1127/86/$03.50

however, prescribed burning has also been advanced as a treatment for a variety of resource yields (e.g., Biswell, 1972; Martin and Dell, 1978). Complete economic evaluation of prescribed burning should include both the benefits of wildfire hazard reduction, which have been the focus of most economic studies to date, and its effects on resource yields. Studies on the effect of prescribed burning on understory production in Arizona ponderosa pine, however, are few.

Gaines et al. (1958) reported reduced grass density for only 1 year following a low intensity burn. Grass density was reduced for 2 years, however, following a more intense burn. The authors cautioned that their results were not adequate for drawing final conclusions due to small sample sizes.

Ffolliott et al. (1977) recorded herbage production following prescribed burning on two sites. On one area, herbage production increased from 3 kg/ha before to 45 kg/ha 1 year after the fire and remained at that level 11 years after burning. On a second area, with a greater tree density and a more intense burn, herbage production was 6 kg/ha before burning with no change 1 year later; however, by 11 years after burning it had increased to 19 kg/ha.

Harris and Covington (1983) examined understory production on burned and control plots 1 year after a prescribed burn on basalt soils. They reported significantly greater production on burned plots for intermediate (dominated mainly by trees 7.6—28 cm dbh) and dense (dominated mainly by trees less than 7.6 cm dbh) overstory strata where overstory basal area reduction by the fire was minimal.

Oswald and Covington (1984) recorded understory production on burned and control plots 4 years after a prescribed burn on limestone soils. They reported an increase of 195 kg/ha on burned plots. A portion of this increase, however, was *Pteridium aquilinum* (L.) Kuhn., a relatively unpalatable species for livestock and wildlife, which increased in composition on the burned plots.

Due to this limited number of studies, the extent and duration of production changes can, for the most part, be only speculated. In this study we measured changes in both herbage and forage production at three sites, prescribe burned during the fall 2, 5, and 7 years ago on basalt soils in Arizona ponderosa pine. This information, coupled with similar studies, will aid in determining the change in value of understory production required for a more complete economic analysis of prescribed burning.

METHODS

Study area

Temperatures recorded at the Fort Valley Experimental Forest are representative of the ponderosa pine areas of central Arizona (Schubert, 1974). High temperatures may reach 32°C in the summer and 20°C in the winter. Low temperatures can drop to −4°C in the summer and −34°C in the winter.

The mean monthly temperature is about 16°C in the summer and −2°C in the winter. The growing season is generally between 117 and 160 days (Clary, 1975). Annual precipitation averages about 50 cm, but may be greater than 64 cm in some areas and less than 43 cm in others (Schubert, 1974). The majority falls during two pronounced periods, winter and late summer (Clary, 1975).

To minimize intersite variation, sites were chosen with similar soil type (basaltic parent material), overstory (exclusively ponderosa pine), elevation (2210 to 2350 m), and season of burn (fall). Due to the need for understory production estimates, sites grazed by livestock during the current growing season were not considered. Only three sites were located which met the above selection criteria. Each site had been burned initially after decades of fire exclusion and all are on the Coconino National Forest in central Arizona.

Howard Seep, the 2-year burn site, was burned in November of 1979 using backfires. Portions of the burn and control areas were thinned in 1974 and 1975 (K. Porter, personal communication, 1981). Grazing by livestock was light in 1980 and excluded in 1981 (P. Boucher, personal communication, 1981).

Chimney Spring, the 5-year burn site was burned in November of 1976 using strip headfires. It is a part of the Interval Burning Study on the Fort Valley Experimental Forest (Sackett, 1980). Grazing by livestock has been excluded since the burn.

Hostetter, the 7-year burn site, was burned in October of 1974 using strip headfires. Portions of the burn and control areas were thinned in 1970. Grazing by livestock has been minimal since the burn (C. Gutierrez, personal communication, 1981).

Research design

Production data were obtained from the three study sites during the 1981 growing season. Sampling at each site was stratified by overstory type. Pole stands were defined as those dominated by trees 10—30 cm dbh; mature stands were defined as open, old growth areas dominated by trees greater than 30 cm dbh. Basal area was 40—55 m^2/ha in pole stands and greater than 70 m^2/ha in mature stands. (Stand area measurements were based on canopy dripline in mature stands.) Stands on slopes greater than 25% were not considered for sampling due to possible differences in understory response to burning on steep slopes.

Burned and nearby control stands were generally greater than 20 by 25 m in size. Due to limited availability, stands smaller than this were sampled in some instances. In fact, at the 5-year and 7-year burn sites some mature stands consisting of only one tree were sampled. Within a stand, areas with greater understory production are often associated with large gaps in the canopy. To reduce this source of variation, canopy openings not caused by the fire and greater than 5 m in diameter were excluded from sampling in both overstory types.

Dry weight of green material was used as a measure of annual production of above-ground standing crop; however, this can give a somewhat inaccurate estimate. The inclusion of a portion of last year's standing crop which remained green (P. Ogden, personal communication, 1981) could result in an overestimate and loss by death or grazing could result in an underestimate. In this paper, the terms production and weight are used interchangeably and are assumed to be estimates of annual production of aboveground standing crop.

Production was measured using allometric regression equations and with actual harvest data. Due to relatively greater sampling efficiency when compared with harvesting (Reese et al., 1980) vegetation allometric relationships are often used to predict weight (e.g., Payne, 1974; Brown and Marsden, 1976; Ohmann et al., 1981). Regression equations were developed to predict plant weight from basal area for four common grass species: squirreltail (*Sitanion longefolium* J.G. Smith), muttongrass (*Poa fendleriana* (Steud.) Vasey), Arizona fescue (*Festuca arizonica* Vasey), and mountain muhly (*Muhlenbergia montana* (Nutt.) Hitchc.). Production of remaining herbaceous vegetation was measured by actual harvesting.

Sampling for production data occurred from early September to mid-October which approximates the peak of understory standing crop accumulation. Within stands, plots were located systematically. For each stand, a baseline was established. Along this baseline, belt transects were randomly located and run through the stand perpendicular to the baseline. Each transect was 2 m wide and plot divisions were established every 5 m giving a plot size of 10 m^2.

On each plot, individual plant basal diameter measurements were recorded for the four regression species. Since defining an individual of a bunch grass is difficult, an individual plant was defined in this study as green plant material with horizontal discontinuities no greater than 2.54 cm. For each plant, the longest basal diameter and the widest basal diameter perpendicular to this were recorded to the nearest 0.25 cm. The product of the two diameters was defined as plant basal area.

Remaining herbaceous vegetation on each plot was clipped at ground level and classified as (1) miscellaneous grass (including *Carex* spp.), (2) palatable forb, or (3) unpalatable forb. Palatable forbs were defined as those listed as decreasers by the USDA Forest Service (Anonymous, 1981) and on our sites consisted mainly of deer-vetch (*Lotus wrightii* (Gray) Green) and vetch (*Vicia* spp.). Due to insufficient numbers for inclusion in the regression equation, Arizona fescue was clipped and classified as a miscellaneous grass in pole stands at the 7-year burn site. Clipped samples were returned to the lab and sorted. Green material was dried at 80°C to constant weight and weighed to the nearest 0.01 g.

Regression equations for each species were then applied to plot basal area measurements to predict weight. Analysis of production data was based on regression estimated weight for these species and actual weight for the remaining plant classifications.

Due to the violation of the normality assumption associated with parametric tests, data were analyzed with the nonparametric Mann and Whitney Rank Sum Test. For each overstory type, significant difference ($P < 0.05$) of means between burn and control was tested for herbage and forage production. Only differences which were significant are reported. Herbage production was defined as the sum of all plant classifications (four regression species and three harvested classifications); forage production was defined as the sum of all plant classifications except unpalatable forbs. A two-tailed test was used due to the possibility of either an increase or a decrease in production.

Since results of Pearson (1967) indicate that in the Arizona ponderosa pine region maximum flower stalk height is coincident with maximum dry matter production for Arizona fescue and mountain muhly, allometric regression data for each species were obtained after seed head production was complete. Muttongrass was sampled in late June and early July, Arizona fescue in mid-August, squirreltail in late August, and mountain muhly in early September.

At each site, approximately 20 plants per treatment (burn and control) were sampled in pole stands and 15 plants per treatment were sampled in yellow pine stands for each species. Two basal diameter measurements were recorded for each plant in the manner previously discussed. The plant was then clipped at ground level. Samples were returned to the laboratory and sorted. Green material was dried at 80°C to constant weight and weighed to the nearest 0.01 g.

A predictive equation for each species was developed with 80% of the data. Plant weight was the dependent variable and plant basal area (the product of the two basal diameters) was the independent variable. To obtain linearity and a constant variance (Gholz et al., 1979), the linearized form of the allometric equation

$$\ln Y = \ln A + B(\ln X) \tag{1}$$

was used in this study. To account for variations due to differences in site, overstory type, and treatment, dummy variables representing these factors and their interaction with basal area were entered into each equation using a stepwise procedure (Nie et al., 1975). Only dummy variables with significant F values ($P < 0.05$) were used in the final prediction equations.

Final prediction equations for squirreltail, muttongrass, Arizona fescue, and mountain muhly all exhibited F ratios significant at the 0.05 probability level. Adjusted R^2 values ranged from 0.81 for muttongrass to 0.87 for Arizona fescue. The standard error of the estimate ranged from 0.436 for Arizona fescue to 0.515 for muttongrass.

Equations were validated with the remaining 20% of the data. The regression equations were applied to this data to predict ln of dry weight for each species. The mean squared difference between predicted and observed ln of dry weight was in close agreement with the residual mean square of the equation in all instances (Table 1), indicating that the equations make accurate predictions of independent data (see Snee, 1977).

When regression equations were applied to inventory data, direct antilog conversion of the predicted ln of plant weight to arithmetic units would have given an underestimate of plant weight (Baskerville, 1972). To correct for this, predicted weight in arithmetic units (Y) was calculated with the equation

$$\hat{Y} = \exp(\hat{\mu} + \hat{\sigma}^2/2) \qquad (2)$$

where $\hat{\mu}$ is the predicted ln of plant weight and $\hat{\sigma}^2$ is the sample variance of the logarithmic equation (Brownlee, 1967; Baskerville, 1972).

TABLE 1

Mean squared difference between predicted and observed ln of dry weight for 20% of the data not used in predictive equations and residual mean square for each regression equation

	Mean square difference predicted vs observed	Residual mean square regression equation
Squirreltail (*Sitanion longefolium*)	0.259	0.245
Muttongrass (*Poa fendleriana*)	0.507	0.265
Arizona fescue (*Festuca arizonica*)	0.265	0.190
Mountain muhly (*Muhlenbergia montana*)	0.250	0.208

RESULTS AND DISCUSSION

Herbage and forage production at each site are presented in Table 2 for pole stands and Table 3 for mature stands. At Howard Seep, the 2-year burn site, only forage production in mature stands showed a significant difference. Control plots produced 30.2 kg/ha more forage than burn plots. Greater fuel accumulations in mature than in pole stands may have resulted in a more severe fire and therefore more heat-related stress and mortality of understory plants. This decrease in forage production appears to have been offset by an increase in unpalatable forbs (burn plots 24.1 kg/ha greater than control plots), resulting in no change in herbage production. In pole stands either the effect of burning had not yet resulted in production changes or beneficial and detrimental effects were balanced.

At Chimney Spring, the 5-year burn site, only herbage production in mature stands failed to exhibit a significant difference between burn and control plots. Forage production in mature stands was greater on control plots, but the difference (6.6 kg/ha) was less than the difference in mature stands on the 2-year study site. This suggests a partial recovery of forage

TABLE 2

Total herbage and forage production[a] (kg/ha) on burn and control plots in pole stands

Treatment	Study site		
	Howard Seep (2-year burn)	Chimney Spring (5-year burn)	Hostetter (7-year burn)
Herbage production			
Burn	19.5 (2.1)	13.6 (2.1)	26.2 (3.9)
Control	14.8 (1.5)	6.8 (1.4)	6.3 (0.8)
Difference[b]	—	6.8	19.9
Forage production			
Burn	16.9 (2.1)	9.6 (1.6)	22.5 (3.4)
Control	14.7 (1.5)	5.7 (1.2)	4.9 (0.7)
Difference[b]	—	3.9	17.6

[a]Herbage is the sum of all understory plant classifications; forage is the sum of all plant classifications except unpalatable forbs. Data are mean (standard error); $N = 40$.
[b]Burn minus control — reported only if burn and control are significantly different ($P < 0.05$).

TABLE 3

Total herbage and forage production[a] (kg/ha) on burn and control plots in mature stands

Treatment	Study site		
	Howard Seep (2-year burn)	Chimney Spring (5-year burn)	Hostetter (7-year burn)
Herbage production			
Burn	73.0 (10.5)	41.6 (7.3)	43.6 (9.1)
Control	79.1 (12.9)	29.1 (4.6)	15.2 (2.6)
Difference[b]	—	—	28.4
Forage production			
Burn	24.4 (3.9)	11.8 (4.0)	24.1 (4.4)
Control	54.6 (8.9)	18.4 (3.7)	10.1 (1.9)
Difference[b]	–30.2	– 6.6	14.0

[a]Herbage is the sum of all understory plant classifications; forage is the sum of all plant classifications except unpalatable forbs. Data are mean (standard error); $N = 28$ for Howard Seep and $N = 30$ for Chimney Spring and Hostetter study sites.
[b] Burn minus control — reported only if burn and control are significantly different ($P < 0.05$).

species by 5 years following prescribed burning. In pole stands, herbage and forage production were greater on burn plots. It appears that by 5 years after burning in pole stands, beneficial effects on the understory outweigh detrimental effects and are reflected in increased understory production.

At Hostetter, the 7-year burn site, herbage and forage production on burned plots were significantly greater than control plots in both overstory types. By 7 years after prescribed burning in pole and mature stands, herbage and forage production appear to have benefited from the effects of burning.

Two factors complicate the interpretation of these results as a time-sequence. (1) Pole stands on the 2- and 7-year study sites were thinned prior to prescribed burning. Clary and Ffolliott (1966) reported no significant difference ($P < 0.10$) in herbage production between thinned and unthinned stands with equal basal area at basal areas greater than 16 m^2/ha. Since residual basal areas of pole stands in our study were greater than this, the effect of thinning on understory production is probably minimal; however, the interaction between thinning and burning is not known. (2) Despite our attempt to minimize intersite variation, understory production on control plots was variable between sites. (We do not feel that treatment differences reported here are simply a result of the general pattern of variability, as intersite distances — minimum of 14 km — were far greater than intrasite distances between burn and control stands — maximum of 0.5 km.) Because of this variability between sites development of a time-sequence depicting actual production changes is difficult. Using our results and those of other researchers, however, general trends of changes in understory production following prescribed burning can be discerned.

Results of our study and other studies of fall prescribed burns on volcanic soils in Arizona ponderosa pine show either no change or an increase in herbage production 1 to 2 years following burning. In our study, herbage production displayed no change in either pole or mature stands 2 years after burning. Harris and Covington (1983), however, reported an increase in herbage production (19 kg/ha) 1 year after prescribed burning in pole stands, but no change in open areas with old growth trees. Ffolliott et al. (1977) reported no change and an increase of 42 kg/ha in herbage production 1 year following prescribed burning on two separate areas. This variation in herbage response 1—2 years after prescribed burning is probably due to intersite variation as well as differences in the severity of the burn and the extent of overstory reduction resulting from the burn.

Studies of understory response more than 2 years following prescribed burning in Arizona ponderosa pine show a general trend of increased herbage production similar to that illustrated in our study. Ffolliott et al. (1977) reported herbage production increases of 13 and 42 kg/ha 11 years after a fall prescribed burning on two separate areas with volcanic soils. Oswald and Covington (1984) reported significantly greater ($P < 0.05$) herbage production on burned versus control plots for a 4-year old prescribed burn on limestone soils. Their observed increase of 195 kg/ha was substantially larger than any increase reported in our study, suggesting the importance of soil type and other factors in determining understory response to burning.

In contrast to herbage production, which shows no change or an increase, forage production can initially decrease following prescribed burning. In a 2-year study Gaines et al. (1958) reported reduced grass density for 1 and 2 years after two separate prescribed burns on volcanic soils. In our study, forage production had decreased in mature stands and showed no change in pole stands by 2 years following burning. After a possible decrease initially, however, results of our study indicate that forage production also exhibits a trend toward increased production following prescribed burning.

Although the response of understory production following wildfire generally differs in magnitude from that of prescribed burning, the trend reported in two long-term wildfire studies in Arizona ponderosa pine is similar to the general trend of increased production beyond year 2 after prescribed burning illustrated in our study. Oswald and Covington (1983) reported increased herbage production 3 and 9 years following wildfire on limestone soils. Changes in grass basal area following wildfire on basalt soils reported by Lowe et al. (1978) exhibit a trend similar to that of forage production in yellow pine stands presented in our study. They reported an initial decrease 1 year after wildfire, which was followed by a trend of increased grass basal area that peaked at year 7. Despite differences in season and severity of burn between wildfire and prescribed burning, as well as the fact that these wildfire burns were seeded with understory species, the trend toward sustained increases in understory production past year 2 after wildfire is similar to our study and other prescribed burning studies.

CONCLUSIONS

Information presented here is suggestive of the long range effect of prescribed burning on herbage and forage production on basalt soils in northern Arizona ponderosa pine. In pole stands, the major component of the region, long-term benefits in increased understory production appear evident. In mature stands, initial costs (decreases in production) may be offset by a trend toward increased production benefits after 2 years following burning. Further study is warranted; ideally, various burning conditions should be examined at replicated sites with appropriate controls. These sites should be studied prior to burning and then annually following burning. Such studies would provide the more detailed information necessary to determine the change in value of forage and herbage production following prescribed burning in Arizona ponderosa pine.

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