## SHORT COMMUNICATION

# A 43-YEAR EVALUATION OF A PRESCRIBED FIRE: AN ARIZONA CASE STUDY

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## ABSTRACT

We evaluated the effects of a prescribed fire in a ponderosa pine (*Pinus ponderosa*) forest intermittently over 43 years. Changing climatic (precipitation) conditions spanned this evaluation with a sequential pattern of annual precipitation regimes above average, average, and below average (drought conditions) encompassed. The original objective of the fire to consume three-fourths of the litter and duff layers to reduce the water-holding capacities of these layers was initially met. Although nearly 50 % of the basal area of the pre-fire tree overstory was lost in the burn, basal area was approaching 90 % of the pre-fire level 43 yr following the fire. We attributed the lack of ponderosa pine reproduction after 43 yr to the litter and duff layers returning to pre-fire conditions. Annual herbage production increased for a while following the fire but then decreased with the increasing tree overstory and litter and duff layers following the burn. Within the context of the changing climatic (precipitation) conditions encountered, the results of this evaluation indicate that prescribed burning at intervals less than the 43 yr evaluation period are required to sustain the effects of this prescribed fire.

*Keywords*: Arizona, ecosystem resources, impacts, ponderosa pine forest, prescribed fire

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## INTRODUCTION

Potential benefits of applying prescribed fire in Arizona ponderosa pine (*Pinus ponderosa*) forests include reducing fuel loads, thinning overstocked tree overstories, preparing more receptive seedbeds for ponderosa pine, increasing herbage production, and changing hydrologic processes (Ffolliott *et al.* 1996). Because the values that people place on these benefits often change with time and place, we believe that long-term evaluations of the effects of prescribed fire help to place the role of this managerial tool into a context of these changing values. Such evaluations can also assist in the planning of fire-management interventions when the uncertainties of changing climatic conditions are faced (Ryan 2000).

We evaluated a prescribed fire ignited in October 1964 to consume three-fourths of the litter and duff layers in a ponderosa pine forest 32 km south of Flagstaff, Arizona, in relation to its lasting effectiveness in meeting the original objective of reducing the water-holding capacities of these layers (Davis *et al.* 1968) and, as a result, making more water available for plant growth and increasing overland flow (Clary and Ffolliott 1969). The prescribed fire was also evaluated in a framework of its broader objectives of reducing the density of the overstocked tree overstory, creating a seedbed for reproduction of ponderosa pine, increasing the production of herbaceous plants, and enhancing aesthetic values of the site. An initial evaluation of the effectiveness of the prescribed fire in meeting its original objective of consuming litter and duff layers was made one month after the burn (Davis *et al.* 1968). Subsequent evaluations on the broader array of effects were then made 1 yr, 2 yr, 11 yr, and 24 yr after the prescribed fire (Davis *et al.* 1968; Ffolliott *et al.* 1976, 1977; Ffolliott and Guertin 1990). Here we report on a 43 yr evaluation of this prescribed fire.

## METHODS

We selected a 0.10 ha site to evaluate the impacts of the prescribed burn. While the site was small, the burning prescription (Table 1) and ignition procedure were deemed appropriate (at the time) for larger areas (Davis *et al.* 1968). Burning strips spaced at 3 m to 6 m intervals were ignited to attempt to hold the flame heights to the 0.5 m limit prescribed. Surface fuels on the level terrain burned easily and carried the fire well. However, the fireline intensity was nearly 173 kW $m^{-1}$.

We systematically established 16 sample locations in a grid at 8 m by 8 m intervals to evaluate the effects of the prescribed fire. Depth of the combined litter and duff layers was measured at these locations before the prescribed fire and at the time intervals indicated after the burn. Mortality of fire-damaged trees tallied by point sampling (Avery and Burkhart 2002) with a five-factor angle gage was monitored to characterize the changing post-fire densities of the tree overstory. We also monitored the stocking of ponderosa pine reproduction on 4 $m^2$ plots at the sample locations. A plot was considered to be stocked if at least one plantlet was tallied; otherwise, the plot was not stocked. Annual herbage production was estimated (Pechanec and Pickford 1937) before the burn and at the post-fire intervals.

Data sets obtained in the 43 yr evaluation of this prescribed fire are archived in paper and electronic forms at the School of Natural Resources, University of Arizona. Contact the senior author of this paper for further information. Copies of the publications reporting the

**Table 1.** Conditions selected for igniting the prescribed fire and average burning conditions when the fire was ignited. Fuel moisture conditions specified for the L and F layers (combined) were separated from the H layer in the original fire prescription (from Davis *et al.* 1968).

| Conditions | Prescribed fire | Burning conditions |
|---|---|---|
| Fuel moisture: | | |
| L and F layers | 6 % to 12 % | 8.6 % |
| H layer | 15% or more | 17.6 % |
| Fuel temperature | 26.6 ºC average | 30.0 ºC in sunlight<br>23.8 ºC in shade |
| Air temperature | 23.8 ºC or higher | 23.8 ºC |
| Wind velocity in flame zone (0.6 m above surface) | 3.2 km $hr^{-1}$ to 8.1 km $hr^{-1}$ | 1.6 km $hr^{-1}$ to 6.4 km $hr^{-1}$ |
| Weather | Clear | Clear |

earlier effects of the prescribed fire are also available from the senior author.

## RESULTS

Depth of the combined litter and duff layers, residual basal areas, stocking of ponderosa pine reproduction, and herbage production for the evaluation intervals are presented in Table 2. These summaries represent the averages obtained at the 16 sample locations for the evaluation periods.

### *Litter and Duff Layers*

The prescribed fire consumed 71 % of the pre-fire depth of the litter and duff layers. We concluded, therefore, that the original objective of the fire was accomplished (Davis *et al.* 1968). The depth of the litter and duff layers increased steadily following the fire, however, almost reaching 50 % of the pre-fire depth 11 years following the fire (Table 2). Accumulation of needles falling from the surviving overstory trees was the primary factor contributing to this increase (Ffolliott *et al.* 1976, 1977). Depth of the combined layers 24 yr after burning was two-thirds of the pre-fire depth (Ffolliott and Guertin 1990), with little significant change in these depths 43 yr following the fire.

### *Tree Overstory*

Trees killed outright by the fire were mostly smaller trees less than 10 cm in diameter breast height (dbh) that had been overtopped (Davis *et al.* 1968). Almost 75 % of the trees with more than two-thirds of their crowns scorched or consumed by the fire died within 2 yr of the burn (Table 2). Most of these trees were less than 20 cm in dbh. No tree mortality was observed since that time. One effect of the prescribed fire, therefore, was a thinning of the tree overstory from below. Nearly 50 % of the pre-fire basal area density was initially lost to the fire, again, largely in the smaller trees. A residual basal area of 20 $m^2$ $ha^{-1}$ remained 2 yr following the burn (Davis *et al.* 1968). Basal area then increased by 40 % 11 yr after the fire (Ffolliott *et al.* 1976, 1977) and by another 10 % 24 yr after the fire (Ffolliott and Guertin 1990). We determined that the basal area 43 yr after the burn approached 90 % of the pre-fire level.

### *Ponderosa Pine Reproduction*

More post-fire ponderosa pine seedlings had germinated on the burned area than on adjacent unburned areas 1 yr after the fire (Davis *et al.* 1968). Newly started seedlings were found on nearly 90 % of the 4 $m^2$ plots 1 yr

**Table 2.** Litter and duff layers, residual basal areas, stocking of ponderosa pine reproduction, and herbage production at the selected time intervals following the prescribed fire.

| **Interval** | **Litter and duff** (cm) | **Basal area** ($m^2$ $ha^{-1}$) | **Stocking** (% of plots) | **Herbage** (kg $ha^{-1}$) |
|---|---|---|---|---|
| Pre-fire | 4.3 | 39.0 | 19 | 3.36 |
| Post-fire | | | | |
| 1 month | 1.3 | - | - | - |
| 1 year | 1.3 | 9.2 | 88 | 44.8 |
| 2 years | 1.5 | 20.7 | 62 | 45.9 |
| 11 years | 2.0 | 27.6 | 25 | 44.8 |
| 24 years | 2.8 | 29.2 | 25 | 14.6 |
| 43 years | 2.3 | 35.1 | 0 | 19.0 |

after the burn (Table 2). However, the stocking of seedlings dropped to 62 % 2 yr after the fire and 25 % 11 yr after the fire (Ffolliott *et al.* 1976, 1977) and remained at this level 24 yr following the burn (Ffolliott and Guertin 1990). We observed no stocking of ponderosa pine seedlings 43 yr after the fire.

### *Herbage Production*

Annual herbage production increased 1 yr after the burn to a level 11 times that of the pre-fire production (Table 1). Most of this increase was attributed to mullein (*Verbascum thapsis*), an invasive species (Davis *et al.* 1968). Annual herbage production 11 yr after burning was approximately the same as that 1 yr after the fire (Ffolliott *et al.* 1976, 1977). However, mullein had been replaced by native herbaceous species including squirreltail (*Elymus elymoides*), muttongrass (*Poa fendleriana*), showy goldeneye (*Heliomeris multiflora*), and Fendler's ceanothus (*Ceanothus fendleri*). By 24 yr after the fire, annual herbage production had decreased to about one-third of the production estimated 1 yr after the fire (Ffolliott and Guertin 1990), remaining at this approximate level 43 yr following ignition of the burn.

## DISCUSSION

The original objective of the prescribed fire to consume three-fourths of the litter and duff layers was accomplished. However, we found that these layers were returning to their pre-fire conditions 43 yr following the burn and, furthermore, were approaching the depths of litter and duff generally found in ponderosa pine forests (Ffolliott *et al.* 1968, Sackett 1979). Repeated prescribed burning is probably necessary if this objective continues to be relevant to resource managers.

Similar levels of tree mortality as those observed in the initial years after the prescribed fire evaluated in this short communication have been found in other fire-damaged southwestern ponderosa pine forests (Herman 1950, Dieterich 1979, McHugh and Kolb 2003, Sieg *et al.* 2006). However, these latter studies monitored tree mortality for much shorter post-fire periods. Even 43 yr following the prescribed fire studied, however, we found that the density of the tree overstory on the site was still too high for optimal timber production (Schubert 1974, Oliver and Edminster 1988), highly-valued scenic beauty (Brown and Daniel 1986), or the pre-settlement conditions often targeted in restoring forest health (Covington *et al.* 1997). We attributed the lack of post-fire ponderosa pine seedlings after 43 yr to the litter and duff layers returning to pre-fire conditions.

Annual herbage production increased following the prescribed fire and then decreased in relation to the increase in the competing tree overstory and litter and duff layers following the burn. Earlier studies in ponderosa pine forests have shown that herbage production increases as tree overstories decrease in density (Clary 1975, Bojorquez-Tapia *et al.* 1990) and the depths of the litter and duff layers decrease (Clary *et al.* 1968), both of which occurred initially as a result of the prescribed burn. However, the level of herbage production has remained inadequate for livestock grazing throughout the 43 yr of evaluation.

The results presented in this short communication should be interpreted within the framework of the changing climatic (precipitation) conditions encountered in this evaluation of the prescribed fire. More specifically, annual precipitation amounts significantly above the long-term average of 635 mm for the vicinity of the burned area characterized the initial 10 yr to 15 yr of the 43 yr evaluation period. With only small annual variations, average precipitation regimes occurred in the following 15 yr. The prolonged drought impacting the southwest beginning about 1995 also impacted the site burned by the prescribed fire. Average precipitation during this period was about two-thirds of the long-term average amount.

Although it is difficult to adequately isolate the effects of the changing precipitation regimes on the resources evaluated, we nevertheless concluded that prescribed burning treatments at intervals less than 43 yr are required to sustain many of the effects of the prescribed fire evaluated in this short communication. Intervals approaching 10 yr, or less if sufficient fuels have accumulated, are likely more appropriate (Dieterich 1980, Swetnam and Baisan 1996). However, once again, the impact of the prolonged drought prevailing in the region at the conclusion of the 43 yr evaluation of this prescribed fire must also be considered in selecting the interval for a site. These impacts are likely to increase as climates change in the future.

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