Fire Frequency in Subalpine Forests of Yellowstone National Park[1]

William H. Romme[2]

Abstract.--Dead woody fuels were sampled in 16 upland forest stands representing a chronosequence of forest successional stages. Different fuel components show different temporal patterns, but adequate levels of all components necessary for an intense crown fire are not present simultaneously until stand age 300-400 yr. Therefore, the average interval between successive fires is estimated to be ≥300 yr.

INTRODUCTION

There are two different aspects of fire history that must be distinguished if fire regimes are to be compared in different ecosystems. The first can be called fire incidence, or the number of fires occurring within a study area during a period of time. The second is fire frequency, or the average interval between successive fires on a single site. I determined the incidence of fire on a 73-km^2 subalpine watershed in Yellowstone National Park using fire-scar analysis (Romme 1979). I found evidence of 15 fires since 1600, of which seven were major fires that covered >4 ha, destroyed the existing vegetation, and initiated secondary succession. The other eight fires apparently covered very small areas and caused little change in the vegetation. Two large fires in 1739 and 1795 each burned about 25% of the watershed, with the other fires together burning another 10%. These were destructive, stand-replacing burns. Less than 10% of the watershed appears to have burned more than once in the last 350 years, mainly along the boundaries between two burns where the second fire apparently burned a short distance into the area burned earlier before going out. This is indicated by the fact that most fire-scarred trees contain only one scar and are found mainly in clumps that appear to represent the margins of burns. In addition, most forest stands either are dominated by a single age class, representing post-fire establishment, or have an all-aged structure representing 350+ yr without fire.

Because so little of the watershed shows evidence of more than one fire, it was not possible to estimate fire frequency using fire scar analysis alone. Despain and Sellers (1977) hypothesized that fire frequency in this area is controlled by changes in the fuel complex during succession. To test this hypothesis, I sampled dead woody fuels in a chronosequence of stands ranging from early to late successional stages. I then combined these data with the fire incidence data to develop a model for fire frequency in the Yellowstone subalpine ecosystem.

STUDY AREA AND METHODS

The study was conducted on the Little Firehole River watershed located on the Madison Plateau, a large rhyolite lava flow in west-central Yellowstone National Park. Most of the watershed has relatively little topographic relief, with an average elevation of 2500 m. Forests cover 90% of the watershed, with early and middle successional stages dominated by lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). Lodgepole pine also dominates late successional stages on drier sites, but shares dominance with subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Englemann spruce (*Picea engelmannii* Parry), and whitebark pine (*Pinus albicaulis* Engelm.) on more mesic sites. Ground cover is generally low and often sparse, dominated by *Carex geyeri* Boott on dry sites and by *Vaccinium scoparium* Leiberg on more mesic sites.

I sampled dead woody fuels with the planar intersect method (Brown 1974) in 16 upland stands ranging from age 29 to 550+ years. All stands were located on similar soils and substrata, with most on flat or gently sloping terrain. I counted intersections along 20 transects in each stand,

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[1]Paper presented at the Fire History Workshop (Laboratory of Tree-Ring Research, University of Arizona, Tucson, October 20-24, 1980).

[2]William H. Romme is Assistant Professor of Natural Science, Eastern Kentucky University, Richmond, Ky. This work was done as part of a doctoral dissertation at the University of Wyoming, Laramie, and was supported by a grant from the University of Wyoming--National Park Service Research center.

resulting in percent errors (standard error divided by $\bar{x}$ times 100) of about 10-20 for duff and needle litter, 10-35 for small particles (up to 7.5 cm diameter), and 15-60 for large material (≥7.5 cm). I plotted each fuel component against stand age and looked for apparent temporal patterns. For time periods where an apparent change in a fuel component coincided with events in the development of a forest stand that could be expected to produce such a change, I applied linear regression to determine whether the pattern was statistically significant.

RESULTS

Figures 1-3 show temporal patterns in three different fuel categories, each of which has an important influence on fire behavior. Fire ignition and initial spread occur in the needle litter (undecomposed needles, twigs, cone scales, and other small particles on the ground) and 1-hour timelag fuels (1-HR-TL; dead woody pieces ≤0.635 cm diameter) (Brown 1974, Deeming et al. 1977). These small fuels are low in very young stands, but increase to a maximum after 150-200 yr due to litterfall, self-pruning, and suppression mortality in the maturing, even-aged lodgepole pine forest (fig. 1). Small fuels remain constant or decrease slightly in older stands as production of small materials declines and is balanced by decomposition. Even maximum accumulations of fine fuels are relatively low, and probably are not adequate to carry a fast-moving surface fire. With the assistance of the U.S. Forest Service, Northern Forest Fire Laboratory, I applied my fuels data from representative 350-yr-old and 450-yr-old stands to Rothermel's (1972) fire simulation model. Even under high wind and low moisture conditions, the model predicted maximum fire spread rates of 3.0-3.6 m/min and maximum fire intensities of 60-87 kcal/sec/m of fireline, values that are in the same range as those reported for controlled, prescribed fires (Romme 1979).

Potential fire intensity (heat release) and flame height are functions of the total fuel mass (Byram 1959). This is high immediately after a fire, consisting mainly of large, fire-killed stems (fig. 2). The developing even-aged pine forest subsequently contributes primarily small fuels, and decomposition of large fire-killed material results in a net decline in total fuels to a minimum between 70-200 yr. Extensive mortality usually begins to occur in the even-aged pine canopy after 250-300 yr, resulting in an increase in total dead fuels which reaches a peak at ca. 350 yr. In recent uncontrolled fires in Yellowstone Park, D. G. Despain (personal communication) has observed that usually only the partially decomposed ("rotten") wood and the sound material up to about 7.5 cm diameter are actually combusted. However, the larger sound material (1000-HR TL sound fuels) constitutes a major portion of the total fuel mass in stands ≥200 yr old. Therefore, I also examined changes

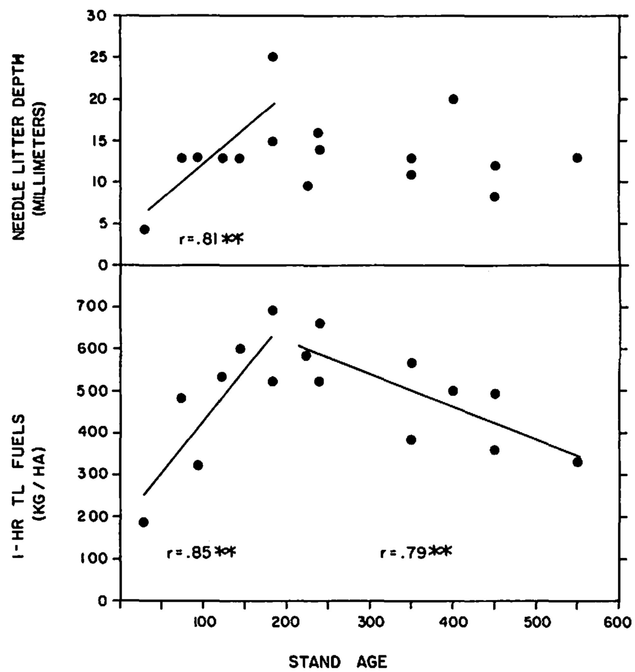

Figure 1.--Temporal changes in small fuels capable of supporting ignition and initial fire spread. The regression line and correlation coefficient are shown for intervals where the slope is significantly non-zero (** = 95% significance level).

in total fuels excluding the 1000-HR TL sound fuels (i.e., including all rotten material plus sound pieces ≤7.5 cm diameter), observing the same general pattern except that maximum fuel accumulations occur later, around 450 yr (fig. 2).

An important factor controlling initiation of a crown fire is the vertical continuity between a surface fire and the canopy (Van Wagner 1977). The patterns shown in figure 3 are based on qualitative observations. Vertical continuity is high in very young stands where the small trees have living branches close to the ground. Subsequent self-pruning by maturing lodgepole pine eventually creates a gap between the lowermost branches and the ground. In a 200-yr old pine forest this space may be 3 m or more, and filled only by relatively non-flammable large tree trunks. Around stand age 250-300 yr a well-developed understory usually begins to appear and vertical continuity increases. However, at this time the even-aged pine canopy is usually breaking up, and horizontal continuity appears inadequate for a fire to move through the canopy (although individual crowns may ignite). With maturation of the understory (ca. 400 yr), both vertical and horizontal canopy continuity appear adequate to support a crown fire (fig. 3).

DISCUSSION

The fuels data support Despain and Sellers' (1977) hypothesis that fire frequency in this area is controlled by the slow development during succession of a fuel complex capable of supporting an intense crown fire. Less intense surface fires do occur, but because even the maximum accumulations of fine fuels are comparatively low and because the small needles tend to form a relatively compact litter layer, light surface fires generally spread slowly and cover only small areas. Thus they have a minor impact on overall vegetation structure and dynamics.

The very small quantity of easily ignited fine fuels in early successional stages (fig. 1) makes a second fire unlikely during the first several decades following a destructive crown fire. By stand age 150-200 yr fine fuels have accumulated to maximum levels, but total fuel mass and canopy continuity are by this time very low (figs. 2 and 3). This means that a surface fire is unlikely to generate sufficient heat to ignite the tree

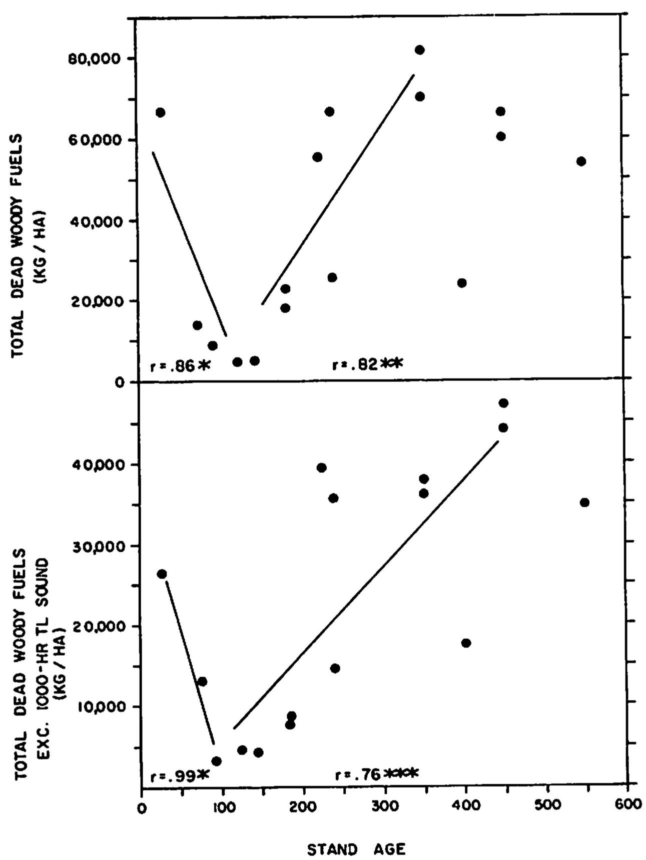

Figure 2.--Temporal changes in total dead woody fuels and in total fuels excluding 1000-HR TL sound fuels. The regression line and correlation coefficient are shown for intervals where the slope is significantly non-zero (*=90% significance level; **=95%; ***=99%).

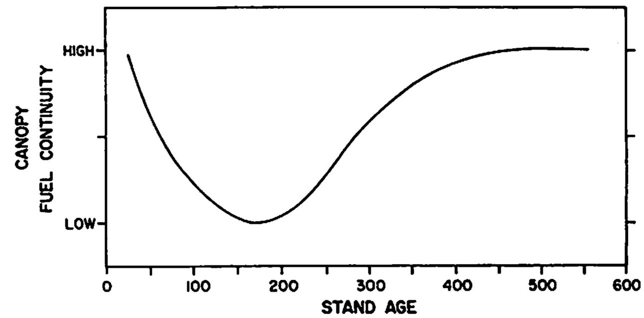

Figure 3.--Qualitative temporal changes in canopy fuel continuity.

crowns, and will probably go out before it burns a large area. Observations of recent uncontrolled fires in Yellowstone Park support this prediction. An intense crown fire burning rapidly through an old-growth spruce-fir forest (≥350 yr old) stopped when it reached a 97-yr old lodgepole pine forest, despite the fact that wind, temperature, and humidity all remained favorable and the pine forest was showered with fire brands (Despain and Sellers 1977).

Total fuel mass and canopy continuity reach high levels around stand age 250-300 yr and 350-400 yr, respectively (figs. 2 and 3). Fine fuels remain high (fig. 1), having by this time become more heterogeneously distributed with locally large accumulations (Romme 1979). Duff and partially decomposed wood in which a fire can persist during periods of humid or rainy weather (Despain and Sellers 1977) also have reached near maximum levels by this time (Romme 1979). Thus all of the fuel conditions necessary for an intense crown fire are not present simultaneously until stand age 300-400 yr. Once the fuel complex has developed, the actual occurrence of fire is probabilistic, depending on when an ignition source and hot, dry, windy weather occur together (Despain and Sellers 1977). Therefore, I concluded that the usual fire frequency or interval between successive destructive fires on a single site in subalpine forests of Yellowstone Park must be a minimum of 300-400 yr, and it may be much longer.

Fire history studies in subalpine forests of Montana and Alberta have reported fire frequencies (mean fire-return intervals) ranging from 63-153 yr (Arno 1980). These are strikingly different from my estimate of 300-400 yr for fire frequency in subalpine forests of Yellowstone Park. The difference probably results from two factors, the first being the high elevation (2500 m) and comparatively poor growing conditions (average site index 50-60) of my study area. On more productive sites at lower elevations in the Northern Rockies, tree growth and fuel accumulation probably occur more rapidly between fires, making more frequent fires possible (Arno 1980). The mountain pine beetle, which hastens fuel accumulation, is also generally more abundant at lower elevations. Bevins et al. (1977), using data from a large area in southwestern Montana, found patterns of fuel accumulation in relation to stand age that are very similar to the patterns in figures 1-3, except that major changes in fuel quantities generally occur 50-100 yr earlier in Montana. The second factor is related to the types of fires being considered. My estimate for Yellowstone applies only to the frequency of destructive, stand-replacing burns; whereas the estimates from the Northern Rockies include a range of fires from low intensity, non-stand-replacing burns through high intensity, stand-replacing burns. Apparently the low intensity fires are more common and cover larger areas in the Northern Rockies, where they consume a portion of the accumulated fuel and delay the occurrence of high intensity, destructive fires (Arno 1980).

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