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Prescribed Burning in an Aspen – Mixed Hardwood Forest

DONALD A. PERALA

North Central Forest Experiment Station, U.S.D.A. Forest Service, Northern Conifers Laboratory, Grand Rapids, Minnesota 55744

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The effects of prescribed burning and complete clearcutting on *Populus tremuloides* and associated hardwoods and shrubs were compared for 8 years after commercial harvest of a 60-year-old *P. tremuloides* stand. Because of the lack of suitable burning weather, *P. tremuloides* suckers were 2 years old before the burn could be made. All suckers were killed by fire and new suckers were more numerous but less vigorous, probably because of heat damage to shallow sucker-producing roots, loss of nitrogen, and reduced root carbohydrate reserves. Although prescribed fire can effectively control residual hardwood overstories detrimental to *P. tremuloides* sucker growth and survival, the long term effect of fire on sucker growth is unknown. Fire can be used to prepare sites for *P. tremuloides* regeneration when other methods are unavailable or impractical. Burning should be done during the first dormant season following logging. Effort should be made to distribute slash uniformly to provide even burning conditions. Burning prescription guidelines are given.

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Sur une période de huit ans suivant la récolte commerciale d'un peuplement de 60 ans de *Populus tremuloides*, on a comparé les effets du brûlage contrôlé et d'une coupe rase sur le développement de *P. tremuloides* et des feuillus et arbustes associés. Les drageons étaient âgés de 2 ans avant qu'on puisse procéder au brûlage, faute de conditions propices antérieures. Tous les drageons ont été tués par le feu, et les nouveaux drageons étaient plus nombreux et moins vigoureux, probablement en raison des dommages causés par la chaleur aux racines superficielles productrices de drageons, des pertes d'azote et de la réduction des réserves d'hydrates de carbone dans les racines. Bien que le brûlage contrôlé puisse éliminer efficacement les feuillus résiduels qui nuisent à la croissance et à la survie des drageons de *P. tremuloides*, l'effet à long terme du feu la croissance des drageons demeure inconnu. Le feu peut être utilisé pour préparer les stations en vue de la régénération de *P. tremuloides*, lorsque d'autres méthodes s'avèrent impraticables. Le brûlage devrait se faire au cours de la première saison d'arrêt de croissance qui suit la coupe. On devrait voir à une distribution homogène des déchets de coupe pour uniformiser les conditions de brûlage. L'article fournit des indications relatives aux prescriptions de brûlage.

[Traduit par le journal]

Trembling aspen (*Populus tremuloides* Michx.) stands on good sites in eastern North America commonly contain a mixed hardwood association. Through natural succession, this more tolerant and longer-lived hardwood component will eventually relegate aspen to a minor status in these stands. In many cases succession is desirable and even encouraged because of increased timber value, esthetic enhancement, or added recreational opportunity. But in many production forests, these hardwoods commonly are poor in quality while aspen will provide good yields of pulpwood, boltwood, and sawtimber. Aspen is understandably favored in management of these stands.

Aspen regenerates readily and vigorously by adventitious root sprouts (suckers) when two conditions are met. First, suckering is under auxin control and so until apical dominance is relieved by felling or killing the parent tree, little suckering can take place (Farmer 1962; Steneker 1972a). Second, the soil at parent root depth, usually less than 5 cm, must be warmed by solar radiation to 18 to 35 °C with about 24 °C being optimum (Maini and Horton 1966; Gifford 1967). The first condition is met when the aspen is harvested. However, the second condition may be more difficult to achieve when a residual unmerchantable overstory is left to shade and cool the forest floor.

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Usually warming is sufficient to produce initially good sucker stocking, but growth and survival will be seriously reduced because aspen is intolerant of shade and requires full sunlight to develop (Zehngraff 1947; Stoeckeler and Maccon 1956; Farmer 1963; Perala 1972).

Residual hardwoods can be controlled by felling, girdling, stem injection of chemicals, or aerially applied phenoxy herbicides (Perala 1972). As another alternative, Buckman (1965) proposed using prescribed fire to regenerate aspen. Burning in coniferous slash fuels has successfully reduced overstories and stimulated aspen suckering in harvested spruce-aspen stands (Tucker and Jarvis 1967; Kiil 1970). However, the silvicultural use of prescribed fire in aspen – mixed hardwood forest has not been reported previously. We now have 8-year results showing that burning aspen slash fuels can control residual hardwood overstories, but involves certain risks to future aspen productivity.

Study Area

A 60-year-old trembling aspen stand (site index 21 m at 50 years) was studied on the Chippewa National Forest, Minnesota (47°20' N, 94°30' W). Basal area averaged 30 m² ha⁻¹; 22 m² of aspen and the rest basswood (*Tilia americana* L.), white birch (*Betula papyrifera* Marsh.), sugar maple (*Acer saccharum* Marsh.), and other hardwoods with occasional balsam fir (*Abies balsamea* (L.) Mill.), white spruce (*Picea glauca* (Moench) Voss), and white pine (*Pinus strobus* L.). The soil was a Warba very fine sandy loam with clay-loam subsoil, considered good site for aspen. The elevation is 400 m and topography is level. The climate is continental with a mean annual precipitation of 61 cm and mean July temperature of 20 °C. The successional trend is toward a sugar maple – basswood climax (Kittredge 1934).

Methods

The stand was commercially harvested by a short-wood operation in June and July, 1965. About 74 t ha⁻¹ (184 m³) of aspen averaging 19 cm d.b.h. were removed with utilization to a 12.7-cm minimum top diameter. Most of the conifers were utilized but only a few associated hardwoods were merchantable. Those remaining averaged 14 cm d.b.h.

Twelve 1-ha blocks provided three replicates where all remaining overstory trees were felled (complete clearcut) and nine replicates that were prescribed burned. In each replicate, the original overstory was systematically sampled on four 400 m² plots (48 total). Slash fuel and woody regeneration were subsampled on 16 8-m² plots (192 total). Slash depth was measured and visually estimated for percentage of ground covered. Slash fuel oven-dry weight was

estimated by solving the aspen stand equations of Schlaegel (1974) for total tree and merchantable bole to 7.6 and 12.7 cm top diameters. The differences were equivalent to total fuel and fuel less than 7.6 cm diameter.

The regeneration plots were measured annually in the fall; stems were recorded by species, total height to the nearest 30 cm, and diameter to 0.25 cm at 30 cm above the ground. This was summarized as $\Sigma (d^2h)$, and converted to total dry weight per hectare of stemwood, bark, and branches. An equation, $TW = 0.082 \Sigma (d^2h)$, was derived from Buckman (1966) and used to estimate shrub dry weight. An aspen dry weight equation, $TW = \exp(-3.264 + 0.941 \log_e \Sigma (d^2h) + 0.38 \text{ Age}^{-1})$ (Perala 1973) was used for both aspen and associated hardwoods.

Suitable burning conditions did not occur until May 1967, 2 years after logging. The burn was done then in 15- to 30-m-wide strip head fires after back-firing the downwind sides. Hardwoods on the unburned treatment and those few not killed by the fire were also felled at this time, 2 years after logging.

Before the burn, black painted 1-l cans with a 1 cm vent hole in the lid and containing 300 ml water were set out on each regeneration plot. The amount of water lost provided a measure of fire energy (FE) variability. While these analogs do not directly measure total heat or heat rate, they do estimate net heat absorbed which is more important in evaluating fire effects on vegetation (Beaufait 1966), a main point in this study.

The soil organic layer (L, F, and H horizons) was sampled just outside each regeneration plot with a core cutter in the spring of 1965 before logging and in spring 1969, 2 years after the burn.

Results and Discussion

Fire Weather

Burning conditions were nearly ideal. The month of May was drier than normal and 6 days had elapsed since the last rain (8 mm). Relative humidities were generally low during the 2 weeks preceding the burn and dropped to 29% at 1300 h C.S.T. on the burning day. Air temperature was 20.6 °C under skies having only scattered clouds. Fine fuels less than 6 mm diameter contained 5% moisture, and fuels up to 7.6 cm had 6–10% moisture content. Wind speed was 5 m s⁻¹, which was ideal for fire spread but increased the difficulty of control. Suppression was required of some fire which spotted into aspen slash outside the intended burn area. Table 1 summarizes fire weather and fire indices calculated according to the National Fire-Danger Rating System (Deeming *et al.* 1972). The indices require considerable explanation and computation which are best understood by referring to the

TABLE 1. Fire weather summary for May 17, 1967. Components and indices are computed according to Deeming *et al.* (1972) assuming their Fuel Model D as the hardwood slash model. These computed values have no units of measure but are relative on a scale from 0 to 100. The maximum values for Fuel Model D are indicated in parenthesis

Item	Value	Comment
Air temperature (°C)		
Dry bulb	20.6	
Wet bulb	11.1	
Dew point	1.1	
Relative humidity (%)	29	
Wind speed (m s^{-1})	5	
1-h time lag (TL) fuel moisture (%)	5	Moisture content of dead fuels less than 0.6 cm diameter
10-h TL fuel moisture (%)	6	Moisture content of dead fuels 0.6- to 2.5-cm diameter
100-h TL fuel moisture (%)	10	Moisture content of dead fuels 2.5- to 7.6-cm diameter
Herbaceous vegetation condition	10	Percentage fine fuels alive
Fine fuel moisture (%)	6	1-h TL fuel moisture adjusted for live fine fuels
Ignition component	48	Probability (100 = max.) that a spreading fire will result if a fire brand encounters fine fuel
Spread component	5	Rate of fire spread (33 = max.)
Energy release component	16	Rate of heat release (31 = max.)
Burning index	17	Effort needed to contain fire (51 = max.)

System. However, a brief description of each index is included in Table 1.

Fuels and Fire Characteristics

Slash fuels covered 47% of the area at a mean depth of 27 cm with a few accumulations up to 1.5 m. Total oven-dry weight of slash averaged 32 t ha^{-1} . Virtually all fuels less than 7.6 cm (18 t ha^{-1}) were completely consumed while little of the coarser fuels (14 t) burned. These fuel parameters were adjusted for percentage of area actually covered by slash:

Fuel	Weight (g cm^{-2})	Bulk density (g cm^{-3})
Available (<7.6 cm)	0.38	0.14
Total	0.68	0.26

About 25 minutes were required to burn each 1-ha replicate and rate of fire advance averaged 4.2 cm s^{-1} . Assuming 3600 cal g^{-1} as the heat yield of aspen slash at 10% moisture content (Byram 1959, Fig. 3.1), estimated mean energy output rate in slash was $5790 \text{ cal s}^{-1} \text{ cm}^{-1}$. This was computed from Byram's 1959 formula: ($I = H w R$; where: I is fire intensity per unit of fire front, $\text{cal s}^{-1} \text{ cm}^{-1}$; H is

heat yield; w is fuel weight consumed, g cm^{-2} ; and R is rate of advance, cm s^{-1} . Fire intensity in litter fuels between slash accumulations was not estimated but obviously was minor in comparison. However, litter fuels were important in carrying fire between slash accumulations and burn coverage was virtually complete.

FE absorbed by the analogs averaged from 33 to 68 kg-cal for the nine burn replications with an overall average of 46 kg-cal. As expected, individual cans varied from as little as 5 ml to complete water loss, 26 to 186 kg-cal, due to variation in the amount of available fuels.

Soil Organic Changes

The burn had no significant effect on the organic horizon characteristics compared to the complete clearcut. Removal of the overstory by either means accelerated organic layer decomposition and incorporation with mineral soil. Preharvest organic layer depth averaged 61 mm; after complete clearcutting, 57 mm; and after burning, 56 mm.

Fire Effects on Vegetation

The burn killed all woody regeneration to the ground line and 76% of the hardwood over-

FIG. 1. Left. Typical fuels and nonmerchantable overstory hardwoods after aspen harvest. Right. A prescribed burn killed 76% of the hardwood basal area, preparing the stand for aspen sucker regeneration. Thirty-four kilogram-calories of fire energy were recorded here.

story. Of an average of $6.9 \text{ m}^2 \text{ ha}^{-1}$ basal area of overstory hardwoods, only 1.7 m^2 were alive after the burn (Fig. 1). All hardwood stems were killed within 2 m of *FE* analogs that recorded 35 kg-cal or more, roughly three-fourths of the study average. This suggests that killing overstory hardwoods with prescribed fire depends more on uniform distribution than on the amount of cured fuels. Hardwood resprouting was not suppressed by fire except in a few extremely heavy slash accumulations.

One year after the burn, aspen suckers, shrubs, and associated hardwoods numbered 85, 75, and 31% more, respectively, compared with those in the complete clearcut (Fig. 2). The hardwood difference was much less because regeneration by root collar sprouting was initiated the same year in both treatments. Five years later, both treatments had the same number of hardwood stems. However, the difference in shrub and aspen numbers between the burned and complete clearcut treatments was still large after 6 years.

Dry weight of all woody vegetation accumulated exponentially (Fig. 3) and due to its superior regenerative capacity and rapid early growth, aspen comprised about 86% of the total woody dry weight after clearcutting (Table 2). After burning, however, new suckers grew 28% slower ($950 \text{ versus } 1315 \text{ kg ha}^{-1} \text{ year}^{-1}$), while associated hardwood and shrub growth was unaltered. The proportion of total stand dry weight in aspen thus declined more rapidly after burning than without burning.

In order to assess the impact of burning on aspen, we regressed aspen sucker growth on fire energy and all other available variables using multivariate analysis. Stepwise fitting eliminated four variables at the 0.05 level and produced this final equation:

$$TW_1 = \exp[0.836 + 0.880 \log_e TW_0 + 0.572 A_L^{-1} - 0.027 \log_e (FE + 1)];$$

$$n = 108, r^2 = 0.97$$

TW_0 and TW_1 are aspen sucker dry weights (stem, bark, and branches) at the beginning and end of the annual growth period and A_L^{-1} is the inverse of years since logging. Variations in aspen or associated hardwood basal area in the original stand, aspen site index, and sucker age did not significantly affect growth. However growth was affected by dry weight and years since logging. This means that suckers initiated after burning grew at the same rate per unit dry weight as suckers 2 years older in the clearcut. The first year's vigorous growth observed after logging was not equalled after burning. Since sucker production and vigor are strongly associated with levels of stored root carbohydrates (Stoekeler 1947; Tew 1970; Schier and Johnston 1971; Steneker 1972b), it is likely the sucker-producing roots had not fully replenished their carbohydrate reserves expended in the first production of suckers 2 years earlier. The role of auxins and other biochemicals on aspen suckering may also be important but are yet only poorly understood.

The equation also shows that sucker growth

FIG. 2. Regeneration and survival of aspen, associated hardwoods, and shrubs after complete clearcutting or prescribed burning. * represents 105 suckers per hectare prior to harvest.

diminished with increasing fire energy. The underlying cause is difficult to isolate without further study and likely is a combination of factors. Volatilization of nitrogen or other chemical or physical changes in the soil may have reduced growth (Van Cleve 1973), or heat released from burning slash may have damaged the shallow sucker-producing parent roots. Horton and Hopkins (1965) also observed that fire in slash 60- to 90-cm deep reduced first year sucker height growth more than one-third. Considering the great insulating effect of soil, largetooth aspen (*P. grandidentata* Michx.) suckers, which originate about 5 cm deeper than trembling aspen, should suffer less heat damage.

FIG. 3. Accumulated dry weight (stemwood, bark, and branches) of aspen, associated hardwoods, and shrubs after complete clearcutting or prescribed burning.

TABLE 2. Composition of woody vegetation by percentage of total oven-dry weight of stemwood, bark, and branches

	Six years after		
	Before burning	Complete clearcut	Prescribed burn
Shrubs	5.9	6.0	5.5
Hardwoods	8.3	12.3	18.6
Aspen	85.8	81.7	75.9

Species composition of associated hardwoods and shrubs by percentage of dry weight varied somewhat between the burned and complete clearcut treatments (Fig. 4). Root collar sprouts accounted for perhaps 80–90% of all hardwood dry weight. Sugar maple was the slowest growing hardwood and comprised a decreasing share of total dry weight with time. Basswood, white birch, and the oaks (*Quercus*

FIG. 4. Changes over time in cumulative percentage species composition by dry weight of burned and unburned hardwoods (top) and shrubs (bottom). Codes and species: AE *Ulmus americana* L.; AS *Fraxinus nigra* Marsh., *F. pennsylvanica* Marsh.; AW *Viburnum rafinesquianum* Schultes; BO *Quercus macrocarpa* Michx.; BW *Tilia americana* L.; CY *Prunus virginiana* L., *P. pensylvanica* L., *Amelanchier laevis* Wieg.; DW *Cornus alternifolia* L., *C. stolonifera* Michx.; HZ *Corylus americana* Walt., *C. cornuta* Marsh.; IW *Ostrya virginiana* (Mill.) K. Koch; LW *Dirca palustris* L.; MM *Acer spicatum* Lam.; PB *Betula papyrifera* Marsh., *B. alleghaniensis* Britton; RM *Acer rubrum* L.; RO *Q. rubra* L.; SM *Acer saccharum* Marsh.; WW *Salix* spp.

macrocarpa Michx., *Q. rubra* L.) increased in proportion while the others were stable or declined. Mountain maple (*Acer spicatum* Lam.) was the only shrub which declined, especially when burned although not as dramatically as reported by Post (1965). Hazel (*Corylus americana* Walt., *C. cornuta* Marsh.) increased

in both treatments by sprouting from underground stems (Buckman 1964). Willow (*Salix* spp.) also increased on the burn, presumably by seeding (Lutz 1956). The cherry-juneberry (*Prunus virginiana* L., *P. pensylvanica* L., *Amelanchier laevis* Wieg.) group increased more rapidly without burning while dogwood (*Cornus alternifolia* L., *C. stolonifera* Michx.) was encouraged by burning.

Species frequency distribution over time was determined by presence on the regeneration plots. Shrubs were relatively constant in frequency in either treatment except willow and cherry-juneberry increased greatly in frequency on the burn compared to the complete clearcut. The hardwoods generally increased slightly in frequency. Conifers (white pine, white spruce, and balsam fir) steadily increased up to 12% frequency on both treatments, and aspen occurred on all sample plots.

Conclusions

Suitable conditions for prescribed burning following harvest in aspen – mixed hardwoods require an even distribution of cured fuels and proper burning weather. Slash accumulations will burn too hot and retard aspen sucker growth. Areas without slash can reduce burn coverage and more residual overstory hardwoods will survive. Fine slash and herbaceous fuels help to spread the fire, but, like incompletely burned coarse fuels, are unlikely to release enough energy in burning to kill hardwood overstories. Fuels less than 7 cm, because of their readily released energy, are the most important fuel component.

Based on our experience, burning weather for aspen slash should approach this prescription:

Months for burning	Dormant season (all but June, July, and August)
Fuel model ¹	D
Air temperature	> 18 °C
Relative humidity	< 35%
Ignition component ¹	40–50
Energy release component ¹	14–17
Spread component ¹	4–7
Burning index ¹	13–21
Wind	2.5–5 m s ⁻¹
Number of days with less than 2.5 mm rain	> 5

¹See Deeming *et al.* 1972.

These conditions are not easily met, however. In northern Minnesota, an energy release

component of 14–17 would occur on an average of only 2.8 days per year during the dormant season (Sando 1969). Other considerations may reduce the number of available days even further. In this study two attempts to burn 11 and 17 months after harvest were unsuccessful because of high humidity, low wind speed, or low temperature.

Aspen stands should be burned during the first dormant season following harvest and preferably before substantial suckering takes place to minimize growth loss attributed to reinitiation of suckering. Assuming good drying weather, aspen slash from summer harvesting can be ready to burn in the fall of that year or the following spring. Also relatively little suckering will occur and sucker regrowth after burning would be least affected.

The long term effect of prescribed burning on aspen productivity has not yet been determined, and a complete clearcut without burning is still the best silviculture for aspen stands. But in cases where complete clearcutting or other means of overstory removal are not possible, control of hardwood overstories with fire will result in a much better stand of aspen than with no cultural treatment at all. Shrubs and associated hardwoods of sprout origin will be important understory components of new aspen stands whether burned or unburned.

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