Aspen management options using fire or cutting

M.G. Weber

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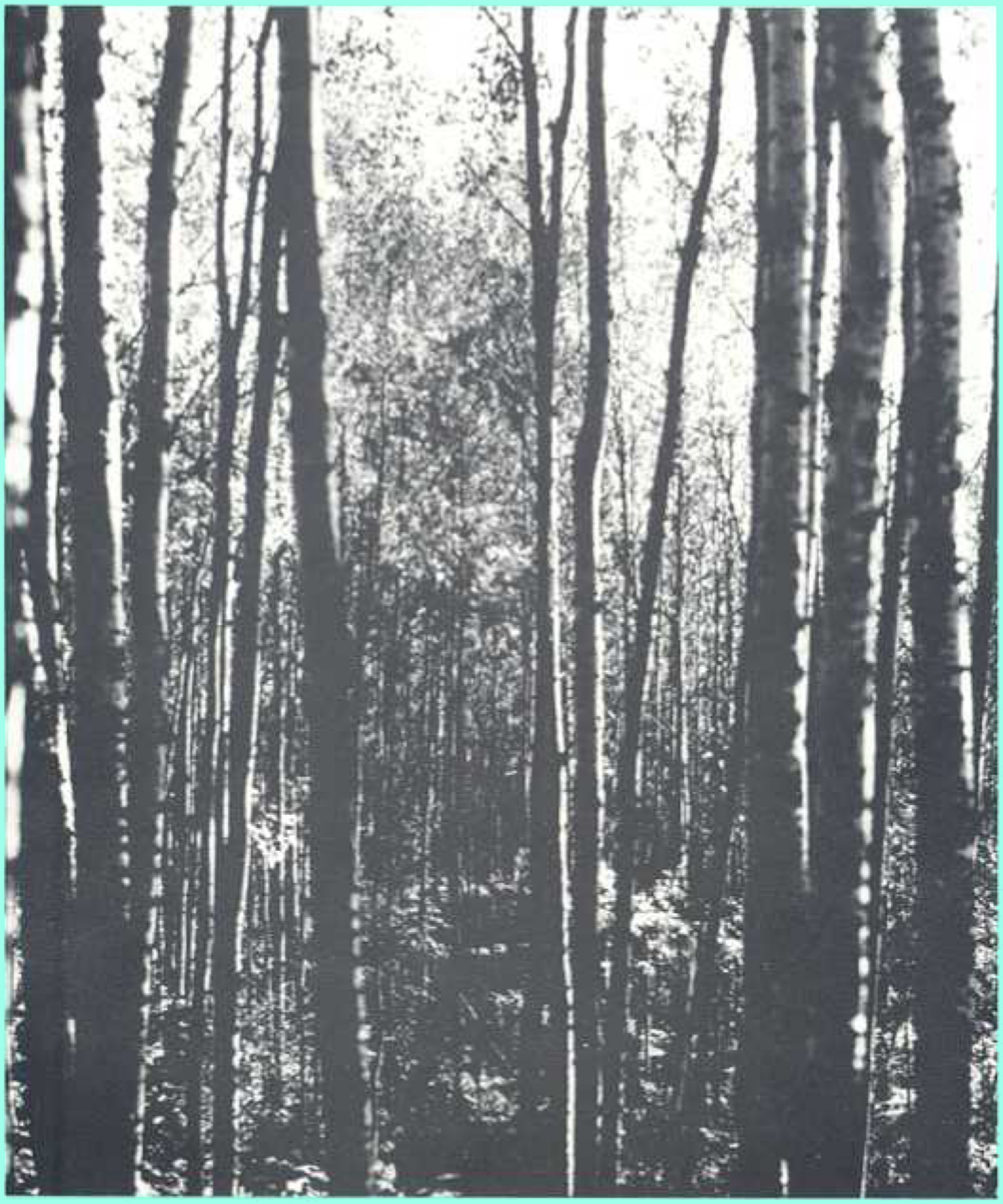

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ASPEN MANAGEMENT OPTIONS USING FIRE OR CUTTING

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ABSTRACT

Vegetative reproduction, leaf and stem biomass and nutrient pools, soil nutrient pools, soil respiration, litterfall, and winter forage (twig) production were monitored in eastern Ontario immature (20 yrs) aspen (*Populus tremuloides* Michx., *Populus grandidentata* Michx.) ecosystems which had been treated as follows: low intensity burning before, burning after, cutting before, and cutting after spring leaf flush. An untreated control was set aside for comparison.

Three years after treatment the greatest numbers of stems per ha were produced through suckering on the pre-flush cutting plots (12 000) followed in decreasing order by post-flush cut (9000), post-flush burn (4000), and pre-flush burn (2000). No suckering was observed on control plots. Aboveground biomass and nutrient pools, winter browse production, and litterfall patterns consistently reflected sucker stem density trends on the cuts and stand break-up on the burning treatments. The burning treatments reduced aspen to a minor component of the site, particularly on the pre-flush burn. The pre-flush cutting treatment, on the other hand, is representative of the most desirable outcome if vigorous aspen reproduction is the management objective.

Substrate nutrient and soil respiration measurements indicated that rates of key ecosystem processes returned rapidly to pre-disturbance levels. This supports our understanding of aspen as a resilient forest ecosystem in the presence of periodic human or natural intervention.

RÉSUMÉ

On a surveillé la multiplication végétative, la biomasse ainsi que la teneur en éléments nutritifs (y compris en oligo-éléments) du feuillage et des tiges de même que la teneur en éléments nutritifs du sol, la respiration de ce dernier, le dépôt de la litière et la production de broutilles pour l'hiver dans des écosystèmes à jeunes peupliers de 20 ans (*Populus tremuloides* Michx., *Populus grandidentata* Michx.) de l'est de l'Ontario, qui avaient été traités comme suit : brûlage à faible intensité avant le débourrement, brûlage après ce dernier, coupe avant et après le débourrement. Un écosystème non traité a servi de témoin.

Trois ans après le traitement, on a observé le nombre maximal de drageons à l'hectare (12 000) dans les parcelles coupées avant le débourrement, puis, dans l'ordre décroissant, dans les parcelles coupées après (9 000), les parcelles brûlées après (4 000) et les parcelles brûlées avant (2 000). Il n'y a pas eu de drageonnement dans les parcelles témoins. La biomasse aérienne et les éléments nutritifs, la production de broutilles pour l'hiver et le dépôt de la litière ont constamment reflété l'évolution de la densité des drageons sur les parcelles coupées et la dégradation des peuplements traités par le feu. Le brûlage, particulièrement avant le débourrement, a réduit le peuplier à une proportion mineure de la station. D'autre part, la coupe avant le débourrement donne les résultats les plus satisfaisants si la reproduction vigoureuse du peuplier reste l'objectif de l'aménagement.

Les mesures des éléments nutritifs ainsi que de la respiration du sol ont montré que les processus déterminants des écosystèmes sont rapidement revenus à leur intensité d'avant le traitement. Ainsi se trouve confirmée notre perception de la résilience des peupleraies aux interventions humaines ou aux phénomènes naturels périodiques.

INTRODUCTION

This report is intended for the land manager concerned with the management of aspen (*Populus tremuloides* Michx.). Aspen has been traditionally managed to provide one or several resource needs. The most obvious is the strategy to ensure continued occupation by the species of the site. Another might be the creation of one or more age classes for the purpose of wildlife management, and yet another could be concerned with site conversion, in which case the objective would be to eliminate the species from the site. Regardless of management objective, aspen autecology and physiology has to be considered if any management activity is to be successful. One of the key physiological characteristics of aspen that can be effectively manipulated is its ability to reproduce vegetatively from root suckers. In the present study, use is made of what is already known of aspen physiology and of applying this knowledge to the management of the aspen resource (DeByle and Winokur 1985). The forest manager can then select the treatment or treatments which most closely match the operational guidelines along which the forest is managed.

The approach taken here is based on the timing of cutting vs. burning in relation to spring leaf flush. Timing the disturbance in this way makes use of our understanding of the physiological state of aspen before and after green-up in the spring (Schier 1976, Schier and Smith 1979). That is, before leaf flush, or any time during the dormant season, nutrient and energy reserves will be sequestered in the root system. After leaf flush, on the other hand, resources are transported out of the roots to support photosynthetic tissue. In this state the trees' recuperative powers to disturbance can be expected to be diminished.

The purpose of this report is to provide realistic options to the forest manager who has to administer multiple uses of the aspen resource under a sustainable development scenario. The mix of uses and resources considered here include wood supply, wildlife habitat maintenance, aesthetics, and conversion of aspen to other cover types without compromising longterm site quality as reflected in key ecosystem processes.

LOCATION

The study area is located within the Petawawa Research Forest (PRF), classified by Rowe (1972) as part of the Middle Ottawa Forest Section (L.4c) of the Great Lakes St. Lawrence Forest Region. The field sites are underlain by Precambrian granite and gneiss of the Canadian Shield. Surficial deposits, climate, and soils were previously described by Pollard (1971, 1972), Weber (1985), and Weber et al. (1987). Briefly, surficial deposits are made up of uniformly fine-grained sand that originated as deltaic or valley-fill sediments deposited in the Ottawa Valley by glacial and postglacial streams. The depth of these deposits ranges from 10 to 30 m (Gadd 1962) and soil profile development is poor.

The climate, continental in character, is moist-humid locally (Hills 1959). Total annual precipitation is 822 mm of which 612 mm falls as rain, the remainder being snow (Anonymous 1982). During a growing season of ca. 180 days there are 112 frostfree days (Hills 1959), with freezing temperatures regularly recorded during all months except July.

Within this general region a topographically uniform area was selected, supporting even-aged trembling aspen with a minor component of largetooth aspen (*Populus grandidentata* Michx.). The aspen stand was created by a high intensity wildfire (I=17 000 Kw/m^2) in the spring of 1964 (Van Wagner 1965, Weber 1987). At the time the experiment was initiated in 1984 the site supported ca. 5000 aspen stems per ha with a mean height of 8 m (range 4 to 16 m) and dbh of 8 cm (range 3 to 13 cm). Dominant understorey vegetation consisted of *Pteridium aqualinum* (L.) Kuhn, *Gaultheria procumbens* L., *Vaccinium angustifolium* Ait., *Kalmia angustifolia* L., *Oryzopsis asperilolia* Michx., and *Rhus radicans* L.

MATERIALS AND METHODS

Detailed descriptions of field as well as laboratory methods can be found in Weber (1990a, 1990b). However, sufficient information will be presented below to allow for operational duplication of the treatments prescribed: in early spring of 1984 five stands were randomly selected. One stand was set aside as an untreated control, and the remaining four were treated as follows: 1) clear-cutting before leaf flushing; 2) clear-cutting after leaf flushing; 3) prescribed surface fire before leaf flushing; and 4) prescribed surface fire after leaf flushing. Plot size was 50 x 50 m. The burning conditions and fire behaviour parameters (Table 1) resulted in flame heights of between 50 and 100 cm. Low flame heights and slow spread rates, in conjunction with fire guards (2 m wide), bulldozed around the burning plots, assured that control activities could be reduced to patrolling the perimeter of the burned area without any significant mop-up effort.

Pre- and post-disturbance ecosystem attributes on the cutting and burning treatments measured in the field or sampled and processed further in the lab included: forest floor consumption (combined L,F, and H layers) after fire; forest floor and mineral soil (top 10 cm) nutrient changes after disturbance; sucker stem heights, basal diameters, numbers per ha, biomass and nutrient content; winter twig (ungulate browse) production and nutrient content; annual litter fall; and soil respiration. In addition precipitation, soil surface temperature, and surface soil (upper 10 cm) moisture content were monitored for three growing seasons after treatment application. Sampling, replication, and randomization schemes as well as statistical analyses are described by Weber (1990a, 1990b).

RESULTS AND DISCUSSION

Impact on soils

The fires resulted in a 13% and 19% reduction of forest floor organic layer mass on pre- and post-flush burns, respectively. Greater forest floor reduction on the post-flush burn was due to the more severe fire weather under which the burn was carried out compared to the other burning treatment (Table 1). Post-fire forest floor nutrient pools (N, P, K, Ca, Mg, NH_4) one month after burning reflected the mass loss on the two treatments, i.e., more nutrients were lost on the post-flush burn than on the pre-flush burn except in the case of ammonium (NH_4) where significant increases were recorded after fire on all treatments. The increases were over 100% on the pre-flush burn and 50% on the post-flush burn in both forest floor and underlying mineral soil. This is of particular importance because available nitrogen in this form is in limited supply on these deep outwash sands. The fires thus had a beneficial effect on the substrate ammonium status on this particular site indicating improved environmental conditions for nitrogen mineralization by the microbial population. A positive short-term effect of fire on substrate nitrogen status has been reported elsewhere (eg. Christensen 1973, Kovacic et al. 1986), but should not be taken as a universal response of all ecosystems to fire (Wells 1979). Response of the nutrient budget to fire can be positive or negative depending on such diverse parameters as fire behaviour characteristics and local conditions like organic matter quality and quantity, microenvironment, latitude, altitude, and decomposer population characteristics among others (Perala and Alban 1982).

In the underlying mineral soil, nutrient changes after fire reflected post-burn conditions at the surface. Namely, the post-flush burn, where more of the forest floor had been ashed, released more cations to the mineral soil below than the pre-flush burn. As well, the post-flush burning treatment showed a 137% increase in mineral soil ammonium levels compared to pre-fire conditions. On the pre-flush burn a loss of 17% from pre-fire levels was recorded (Weber 1990a). The difference in the mineral soil response to fire on the two burning treatments can probably be ascribed to more favourable conditions for microbial activities on the post-flush burn resulting in greater ammonium production rates. The improved conditions consisted of temporarily elevated soil nutrient levels from leached ash, as well as ameliorated temperature and moisture regimes. Furthermore, on the post-flush burn fire killed some of the trees outright by scorching emergent leaves. In contrast, gentle burning before flushing does not cause immediate mortality because leaves are still protected as buds. Consequently, on the post-flush burn there is a short-term cessation or reduction in nutrient uptake by killed vegetation. This uptake decreases temporarily increases in the mineral soil nutrient pool, at least in the case of ammonium, a condition also observed in ponderosa pine (*Pinus ponderosa* Dougl.) ecosystems in Arizona (Covington and Sackett 1986) and aspen woodland in southern Ontario (Smith and James 1978).

Three years after cutting and burning, forest floor and mineral soil nutrient pools were again largely comparable to those found in the undisturbed control. Statistically significant differences between treatments, where they showed up, were so small as to have little biological implication (Weber 1990a), especially when considering the great amount of variation associated with physical and chemical characteristics of the soil profile (Carter and Lowe 1986, Quesnel and Lavkulich 1980, Riha et al. 1986).

The quick recovery of soil nutrient pools to pre-disturbance levels indicates system resilience and has been observed for other disturbance-adapted ecosystems (Boerner 1983, Covington and Sackett 1986, Stock and Lewis 1986, Vance et al. 1983, Weber 1987).

Impact on soil respiration

Forest soil respiration, in relation to the treatments applied, is the subject of a separate technical paper addressing issues and principles beyond the scope of this report (Weber 1990b). What is of relevance to the present discussion is the usefulness of forest soil respiration measurements as a diagnostic tool assessing the effects of ecosystem manipulation on site productivity (Gordon et al. 1987, Schlentner and Van Cleve 1985, Weber 1985). Soil respiration measured in the field is a reflection of CO_2 evolved by microbial, microfaunal, rhizospheral, and root respiration. As such it reveals the general state of metabolic vigour of the substrate and serves as a robust comparative index against various disturbance regimes such as cutting and burning.

Results from this aspect of the study confirmed the above-made observation that the aspen ecosystem is well adapted to periodic disturbance. One of the key criteria for evaluating ecosystem stability is the speed of return of ecosystem processes to rates commensurate with pre-disturbance levels (Holling 1973). Table 2 shows soil respiration (CO_2 evolution) rates on the treatments for three growing seasons. The critical observation to be made here is that the respiration rates on all treatments were depressed below control levels for only two growing seasons and then recovered fully.

Table 1. Burning conditions and selected fire behavior parameters on the days of treatment application.

Parameter	Fire	
	Before flushing	After flushing
Date	April 27	June 4
FFMC[a]	89	92
DMC	15	21
DC	32	52
ISI	10	14
BUI	15	21
FWI	13	19
Relative humidity (%)	28	28
Ambient temperature (°C)	22	28
Wind speed ($km \cdot h^{-1}$)	19	18
Litter layer moisture content (%)	10	11
Fuel consumption ($kg \cdot m^{-2}$)	0.4	0.6
Fire rate of spread ($m \cdot min^{-1}$)	2.4	3.0
Frontal fire intensity ($kW \cdot m^{-2}$)	300	500

[a] Codes and indices of the Canadian Forest Fire Weather Index System (Canadian Forestry Service 1984).
FFMC – fine fuel moisture code; DMC – duff moisture code; DC – drought code; ISI – initial spread index; BUI – buildup index; FWI – fire weather index.

Table 2. Mean seasonal CO_2 evolution on five treatments for three growing seasons.

Treatments	CO_2 evolved ($mg/m^2/d \pm SE$)		
	1984[1]	1985	1986
Burned before flushing	4234 ± 151 a	5115 ± 199 a	4952 ± 233 a
Burned after flushing	4426 ± 198 ab	4886 ± 154 ab	5033 ± 213 a
Cut before flushing	4517 ± 159 ab	4458 ± 152 b	4738 ± 217 a
Cut after flushing	4589 ± 196 ab	4539 ± 147 b	4889 ± 231 a
Control	4802 ± 182 b	5335 ± 252 a	4924 ± 261 a

Note: Data in vertical columns followed by the same letter are not significantly different ($P < 0.05$).
[1] measurements started after treatments were applied.

Response of aspen

The response of aspen to the treatments applied was quite dramatic (Fig. 1). The two cutting treatments produced more stems per ha, with greater basal diameters and height growth, than was observed on the burns. Cutting before leaf flush (or any time during the dormant season) represents the optimal treatment if promotion of suckering is the prime management objective (Fig. 2). Low intensity burning before leaf flush, on the other hand, will reduce the presence of aspen to a minor component of the site. Recall that stem density on control areas was around 5000 stems per ha. Pre-flush burning reduced this number to less than 2000 of sucker stems three years after treatment, with additional mortality to be expected over the years. The other two treatments represent intermediate situations, post-flush cutting producing significantly more suckers than burning at the same time. Control areas showed complete lack of suckering. After three growing seasons leaf and stem biomass on the treatments clearly mirror sucker growth trends (Fig. 3) as do stem and leaf nutrient pools (Table 3). The ranking of treatments in terms of resource production thus remains: pre-flush cut>post-flush cut>post-flush burn>pre-flush burn. For the purpose of vigorous aspen regeneration as well as summer browse production for wildlife, the pre-flush cutting treatment therefore represents the most desirable option.

These differences in vegetative reproduction and site occupation are entirely consistent with what is known about the physiology of the species. Thus, complete lack of suckering on the control treatment indi-

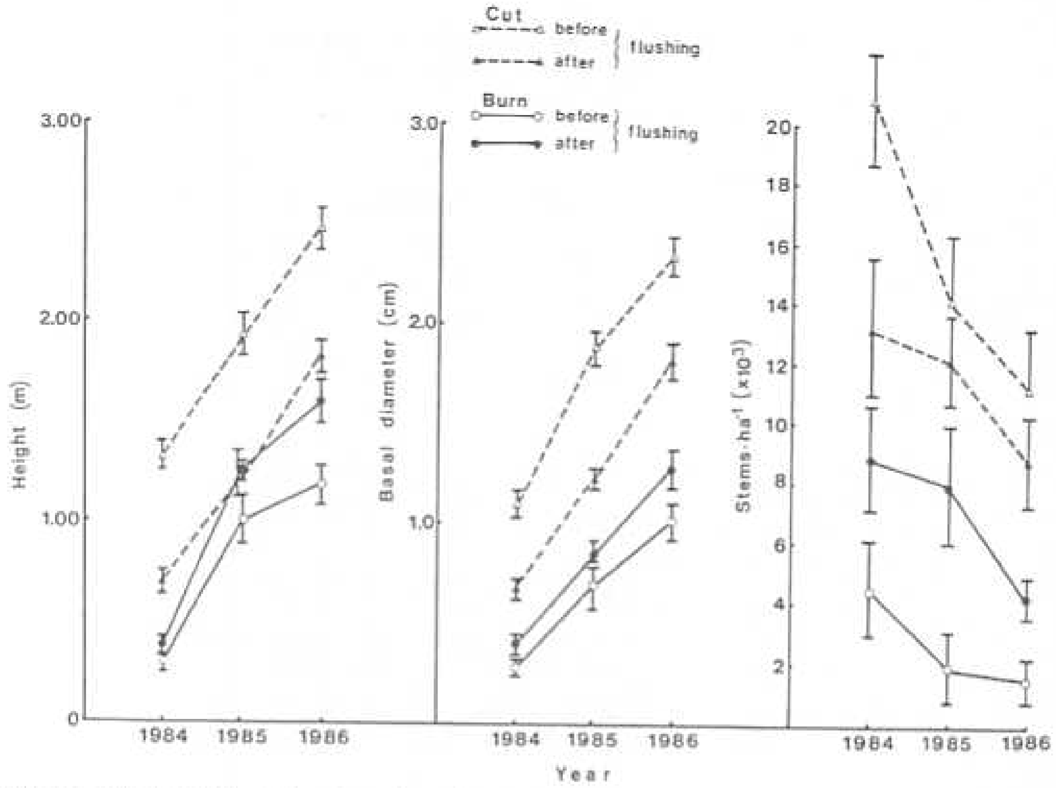

Figure 1. Aspen sucker height, basal diameter, and numbers on two cutting and two burning treatments. Note complete lack of suckering on control areas (after Weber 1990a).

Figure 2. Aspen sucker development on the cutting treatments during the first growing season. Vegetative reproduction is more vigorous on the pre-flush cut (to the left of centre) than on the post-flush cut (right of centre).

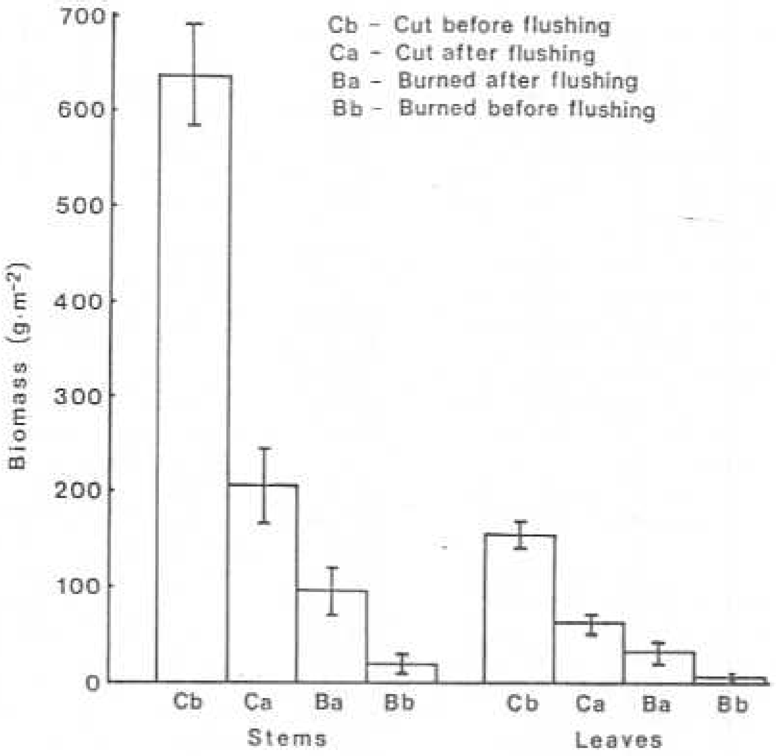

Figure 3. Aspen sucker stem and leaf biomass after three growing seasons on the cutting and burning treatments (after Weber 1990).

Table 3. Aspen sucker stem and leaf nutrient pools after three growing seasons on cutting and burning treatments.

Treatment	Nutrient mass (kg/ha^{-1} ± SE)					
	N	P	K	Ca	Mg	Fe
			Leaves			
Burned before flushing	1.1±0.0^a	0.2±0.0^a	0.7±0.2^a	0.7±0.1^a	0.1±0.0^a	t^{1a}
Burned after flushing	6.9±0.3^b	1.1±0.1^b	3.3±0.2^b	4.8±0.4^b	0.6±0.1^b	0.02±0.001^b
Cut before flushing	35.2±0.1^c	3.8±0.1^c	15.8±0.5^c	15.1±0.5^c	3.0±0.1^c	0.06±0.02^c
Cut after flushing	13.2±0.5^d	1.8±0.2^d	5.4±0.4^d	9.3±0.6^d	1.2±0.1^d	0.03±0.001^d
			Stems			
Burned before flushing	1.8±0.5^a	0.3±0.1^a	1.0±0.3^a	1.7±0.4^a	0.2±0.0^a	t^a
Burned after flushing	6.1±0.3^b	1.1±0.1^b	3.1±0.1^a	6.0±0.2^b	0.8±0.0^b	0.01±0.001^b
Cut before flushing	29.9±1.0^c	4.7±0.2^c	22.3±1.1^b	30.9±1.1^c	4.3±0.1^c	0.08±0.002^c
Cut after flushing	12.9±0.8^d	2.1±0.1^d	6.5±0.5^c	13.9±0.9^d	1.5±0.1^d	0.03±0.001^d

Note: Data in vertical columns followed by the same letter are not significantly different ($P<0.05$).
[1] trace

cates that apical dominance, through downward movement of auxins from tree crowns to roots, completely suppressed vegetative reproduction (Farmer 1962, Schier 1975, Steneker 1974). One of the necessary requirements for suckering is, therefore, the elimination of apical dominance. In conjunction with this, cytokinins, another group of plant hormones, synthesized in root tips, have to accumulate in roots if sucker initiation is to occur. Cutting of trees, or killing them with high-intensity fire, eliminate apical dominance and assure high cytokinin to auxin ratios in roots, the essential prerequisite for vigorous suckering (Winton 1968, Wolter 1968). If cutting is carried out after spring leaf flush, nutrient and energy reserves stored over winter in roots have been transported upward for leaf production. Therefore, post-flush cutting produced less vigorous suckering than pre-flush cutting when stored root reserves were fully available for sucker growth support.

The burning treatments, where surface fires killed the cambium at the base of the trees (Fig. 4), in effect simulated mechanical girdling which has been shown to be the most effective method for eliminating aspen from the site other than herbicides (Schier 1981, Schier and Smith 1979). There are several reasons why girdling fails to stimulate aspen regeneration: 1. high cytokinin to auxin ratios do not develop in the root system because, although downward auxin movement in the phloem is stopped, cytokinins continue to move out of the roots and up the stem via the xylem (Schier 1976); 2. trees on the burning treatments survived for two more growing seasons before finally succumbing. This causes root dieback due to lack of replenishment of roots by photosynthates while roots are being exhausted of reserves; 3. strong sucker growth performance after sucker initiation is a function of adequate light intensity, a condition not provided as long as shade is cast by girdled trees (Schier et al. 1985, Steneker 1974). Slightly better suckering on the post-flush burning treatment compared to pre-flush burning is probably due to leaf scorch and outright, immediate mortality on some of the trees, resulting in conditions conducive to suckering.

Litterfall

Litterfall patterns provide another measure of response of aspen to the treatments applied. Growth performance on the cutting treatments on the one hand and stand deterioration on the burning treatments on the other is quite apparent from Table 4. The two burning treatments showed littermass production rates comparable to control levels for two more growing seasons after fire. During the third season, however, tree mortality had increased from 50% the previous year to 100%, and stand breakup (Fig. 5a,b) is reflected in greatly increased littermass input on the burns compared to the control. Variations in year to year amounts of litterfall, as seen on the control plots, indicate that natural phenomena such as annual climatic fluctuations, random events (eg. storms), changes in vegetative composition, and phenology are superimposed over treatment effects (Fyles et al. 1986, Lousier and Parkinson 1976). On the cutting treatments 3-year litter input totals are an order of magnitude smaller than on the burns. Litterfall here was made up almost exclusively of the annual crop of sucker leaves, being significantly greater on the pre-flush cut than on the post-flush cut.

Wildlife considerations

One observation made during the first winter after treatment application was that, at least on the cutting treatments, aspen suckers were subject to browsing by moose and/or deer. In order to quantify the amount and quality of winter browse available to these ungulates, burning and cutting treatments were intensively sampled during the third winter after disturbance (Weber 1990c). Table 5 shows winter twig nutrient concentrations and nutrient mass for twigs no greater than 4mm in diameter. The 1 - 4mm range in twig diameter represents the preferred size class for ungulate browse (D. Keppi, Univ. of New Brunswick, pers. comm.). The pre-flush burning treatment is not shown as a category in Table 5 because of the virtual absence of aspen suckers on these plots, which precluded animal visits for the purpose of browsing. Winter twig nutrient quality, expressed in terms of nutrient concentration, did not vary significantly with treatment. Nutrient mass available for browsers, however, was affected by treatment (Table 5) and showed the same trends as leaf biomass production in the summer. That is, total twig biomass on the three treatments was 395.1, 125.9, and 96.0 kg/ha for pre-flush cut, post-flush cut, and post-flush burn, respectively. The pre-flush cuts therefore should be the treatment of choice if winter browse production is an important management consideration.

Reduced suckering on the burned plots does not necessarily mean that this treatment is lost to wildlife use. Opening up of the stand due to overstorey mortality may be desirable if forb and grass production is to be encouraged as an ungulate summer food source (DeByle 1985). As pointed out earlier, high intensity fire, either prescribed or wild, can be expected to produce the same results as clear-cutting aspen, i.e. profuse suckering.

Aspen is the forest cover type most frequently manipulated to favour large game species in North America (Basile 1979, Berg and Watt 1986;). When using fire for wildlife habitat maintenance it is imperative that burning frequency be incorporated into the planning process because the beneficial effects of fire, in terms of increased forage, are transitory (DeByle et al 1989). This makes periodic re-burning mandatory. The management strategy chosen will, therefore, have to reconcile forage requirements of wildlife populations with the capacity of the vegetation to provide food through the use of repeated prescribed burning. Quinitilio et al. (1989), for example, reported that re-burning aspen

Figure 4. Blackened stem cambium (arrow) on one of the burning plots, evident during the first growing season after fire, and indicative of the impending death of the tree. Overstorey foliage appeared healthy at this time.

Table 4. Litterfall trends for three years after treatment applications.

Treatment	Total litterfall mass (kg/ha^{-1})			
	1985	1986	1987	3 yr total
Burned before flushing	3094	4176	14 123	21 393
Burned after flushing	2845	3831	22 794	29 470
Cut before* flushing*	1282	848	892	3022
Cut after flushing	299	847	616	1762
Control	3470	4191	2521	10 182

*Litterfall made up almost exclusively of sucker leaves.

Figure 5a. At the end of the second growing season stand breakup on the burning treatments is well underway. Most of the dead material has not yet quite reched ground level.

Figure 5b. At the end of the thrid growing season all remaining overstorey has come down and rests at ground level. Suckering is virtually absent.

Table 5. Winter twig nutrient concentrations and mass on three treatments.

Nutrient	Concentration (% ± SE)			Nutrient mass (kg/ha ± SE)[1]		
	Pre-flush cut	Post-flush cut	Post-flush[2] burn	Pre-flush cut	Post-flush cut	Post-flush[2] burn
N	1.20±0.08	1.45±0.15	1.35	4.8±1.1	1.5±0.6	1.3
P	0.17±0.01	0.22±0.02	0.21	0.7±0.2	0.2±0.1	0.2
K	0.63±0.01	0.56±0.02	0.51	2.5±0.6	0.7±0.4	0.5
Ca	0.83±0.01	0.98±0.08	0.90	3.3±0.8	1.3±0.6	0.9
Mg	0.15±0.01	0.17±0.01	0.16	0.6±0.1	0.2±0.1	0.2
Fe	26.8±1.65[3]	32.0±4.49[3]	27.0[3]	0.8±0.3	0.3±0.1	0.3

[1] twigs not exceeding 4 mm in diameter.
[2] insufficient sample for SE calculation.
[3] ppm.

within 6 years of a previous fire essentially eliminated aspen from the site. The desirability of this particular outcome has to be determined by the land manager within the context of the prevailing operational guidelines. Ideally, a range of age classes and tree densities of sufficient areal extent should be present to provide the mix of resources required on a year-round basis.

SUMMARY

In the study reported here I took advantage of our present understanding of aspen ecology and physiology and applied this knowledge to show experimentally how several land management goals can be achieved through timing of the intervention. Using common forest management practices, such as cutting and burning, in relation to spring leaf flush, diametrically opposed objectives can be accomplished. Thus, the land manager can satisfy client requirements spanning a range of operational needs from vigorous aspen regeneration to elimination of the species from the site. Given the universal physiological response of the species to various disturbances, the results reported here are probably applicable throughout the geographic range of aspen.

Ecosystem processes examined indicate that aspen forests are remarkably resilient in terms of the rate of recovery of key processes to pre-disturbance levels. Aspen ecosystems are presumably amenable to periodic prescribed disturbances if properly spaced in time.

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