Forest Sciences

Prince Rupert Forest Region

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Effects of Broadcast Burning on Fuels and Soil Properties After Ten Years

Research Issue Groups:

- Forest Biology
- Forest Growth
- Soils
- Wildlife Habitat
- Silviculture
- Timber Harvesting
- Ecosystem Inventory and Classification
- Biodiversity
- Ecosystem Management
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Introduction

Prescribed fire is sometimes used in the Prince Rupert Forest Region for wildfire hazard abatement and site preparation following clearcut logging. In the early 1980's, concerns were raised about the short- and long-term impacts of broadcast burning on organic matter and soil nutrients. Burning was suspected of causing losses in soil fertility, especially through nitrogen volatilization and nutrient leaching.

Burning effects on forest soils have been studied in many parts of the world, and soil impacts are often tied to site factors such as climate, soil mineralogy, and burn severity. Little information was available for interior sites of northwestern British Columbia, so the B.C. Forest Service established a monitoring program of operational broadcast burns. Monitored plots were established across a range of forest zonal types to examine trends and consistent burning effects on average site conditions. This note summarizes broadcast burning effects from seven sites on fuels (logging slash and forest floors) as well as changes in forest floor and mineral soil nutrients from pretreatment through to post-burn years 1, 5 and 10. In addition, tree response to broadcast burning is examined through growth rates and foliar nutrient concentrations of lodgepole pine.

Site selection

Sites were selected from three major Prince Rupert Forest Region biogeoclimatic zones: the mid-elevation interior forests of the Sub-boreal Spruce Zone (SBS); the high-elevation, subalpine forests of the Engelmann Spruce-Subalpine Fir Zone (ESSF); and the transitional coastal/interior forests of the Interior Cedar-Hemlock Zone (ICH). All sites had predominantly medium moisture and nutrient regimes, and had typical vegetation and surficial materials for the given biogeoclimatic unit. Soils were typically glacial tills with sandy loam to loam texture and moderate coarse fragment content. Seven sites were established between 1982 and 1985: two sites in the SBSmc2, three in the ESSFmc, and two in the

ICHmc1. One unburned site was also established in the ICHmc1.

Slash and forest floor consumption

On average, broadcast burning resulted in a 29% reduction in forest floor mass and 55% reduction in total slash (Table 1). This translates to 71.7 tonnes/ha of organic matter consumed by the burning treatment (41% of pre-burn organic matter levels). Most of the fine slash (< 3 cm) and intermediate slash (3-7 cm) was consumed (91% and 72% respectively). The average fuel consumption compares to burning impacts of low to moderate fire severity from previous research.

Table 1. Slash and forest floor consumption.

Slash dia. class	pre-burn	post-burn	consumed	% loss
	(tonnes/ha)			
Forest floor	90.7	64.3	26.4	29
< 3 cm	13.2	1.2	12.0	91
3 - 7 cm	13.7	3.9	9.8	72
> 7 cm	55.8	32.3	23.5	42
Total slash	82.7	37.4	45.3	55

Changes to forest floor chemistry

Combustion of slash and forest floor led to increases in exchangeable Ca, exchangeable Mg and available P in the forest floor one year after burning (Table 2). The inputs of exchangeable cations increased soil pH (reduced soil acidity) by 1.3 units to 5.2, on average. Exchangeable potassium decreased by 35% in year 1, likely through rapid leaching of released potassium in the ash.

Volatilization of organic nitrogen resulted in losses in forest floor nitrogen that matched losses in forest floor mass (30%). Nitrogen volatilization can be quite variable, depending on fire temperatures and duration, and losses from 110 to almost 1000 kg/ha have been reported. The nitrogen loss from these operational burns (average 288 kg/ha) indicates again a low to medium fire severity. The changes in forest floor chemical properties are consistent with trends reported in fire-related literature. Increases in soil pH and the availability of such nutrients as phosphorus, calcium and magnesium, and decreases in total amounts of some elements, notably nitrogen, have been widely documented.

After burning, forest floor N and C continued to decrease from year 1 to year 10 by almost 25%. This decrease results from decomposition, which probably was accelerated compared to unburned sites by the increased heat absorption of the black, burnt surface. The C:N ratio did not decrease over time, which was unexpected, since nitrogen is usually immobilized by microorganisms until C:N ratios reach approximately 25. The reason for the lack of nitrogen immobilization might be related to the change in carbon quality over time. With only low amounts of fresh litter inputs in clearcuts, carbon substrates of the forest floor decline

Table 2. Changes in forest floor chemistry (n=76).

Chemical property	Pre-burn (kg/ha)	Post-burn (kg/ha) year 1	Year 5	year 10	year p<F	interaction p<F
Total carbon	42684a*	28261b	23729bc	19161c	*0.0001*	*0.4917*
Total nitrogen	948a	660b	592bc	482c	*0.0001*	*0.4916*
C:N	45	45	41	43	*0.2098*	
Phosphorus	9.8b	15.2a	6.1c	2.9c	*0.0001*	*0.6479*
Calcium	406bc	642a	537b	64b	*0.0001*	*0.6545*
Magnesium	50a	61a	37b	32b	*0.0001*	*0.4114*
Potassium	97a	62b	24b	16b	*0.0001*	*0.0005*
pH ($CaCl_2$)	3.90d	5.21a	4.74b	4.35c	*0.0001*	*0.0462*

** values significantly different between columns are distinguished by different letters (p<0.05)* in quality as decomposition proceeds, leaving only the most recalcitrant carbon types such as lignin and humus. Microbial biomass declines, because fewer microorganisms can use these poorer carbon sources. As the microbial biomass declines, the amount of immobilized nitrogen also decreases, since the microbial biomass holds much of the nitrogen in the forest floor. This results in nitrogen being mineralized at higher C:N ratios than expected, allowing either plant uptake of N or perhaps leaching of N through the rooting zone.

Another possible reason for the high C:N ratios is nitrogen translocation from forest floors to woody debris by fungi. The competition for nitrogen between saprophytes removes nitrogen from the forest floor, keeping the C:N ratio higher than expected. In this case nitrogen could be redistributed from the forest floor to woody debris without net losses to the site. Losses of forest floor N have also been found in hardwood forests after clearcutting (800 kg/ha after 20 years), so relatively large changes to forest floor N mass are perhaps unavoidable after disturbance, whether burning occurs or not.

Available P and exchangeable Ca, Mg and K changed significantly over the ten-year period, likely leaching from the forest floor; values of these cations were usually lower at year 10 than pre-treatment levels (with the exception of Ca). The decrease in K was variable across sites at year 1, which could be related to the amount of slash consumed and leaching rates from the forest floor. The changes in pH were also not completely consistent, which could also be related to the variability of cation inputs and leaching rates across sites.

Changes to surface mineral soil chemistry (0-15 cm)

The upper mineral soil horizons had comparably larger pools of nutrients and less exposure to extreme fire temperatures, so fewer nutrients changed significantly over time compared to forest floors. Exchangeable cations and phosphorus tended to increase over time, probably due to leaching from the forest floor, but K and Ca mass showed the only statistically significant changes (Table 3). Enough basic cations entered the mineral soil over 10 years to cause a small increase in soil pH. The trends in chemical properties of mineral soils were more variable between sites (significant site interactions) than were the trends in forest floors. Changes in K were again inconsistent, perhaps because of factors such as rainfall and soil texture which influenced leaching and weathering rates. The organic matter dynamics (carbon, nitrogen and C:N ratio) were sometimes significant but much too variable from site to site to treat as an overall trend.

Table 3. Changes in 0-15 cm mineral soil chemistry (n=76).

Chemical property	Pre-burn (kg/ha)	Post-burn (kg/ha) year 1	Year 5	year 10	year p<F	interaction p<F
Total carbon	29806a*	27374ab	29891a	24415b	*0.0087*	*0.0001*
Total nitrogen	1148	1090	1160	1221	*0.0973*	*0.0039*
C:N	25.8ab	26.4a	24.4b	19.6c	*0.0001*	*0.0001*
Phosphorus	120	139	132	148	*0.2641*	
Calcium	964	946	1189	1156	*0.0351*	*0.8097*
Magnesium	119	129	132	141	*0.3202*	
Potassium	109b	134b	163a	131b	*0.0001*	*0.0024*
pH ($CaCl_2$)	4.23b	4.27ab	4.25b	4.36a	*0.0069*	*0.0001*

** values significantly different between columns are distinguished by different letters (p<0.05)*

Pre-burn and 10th year site nutrient capital

Logging slash, forest floors and surface mineral soils (0-15 cm)

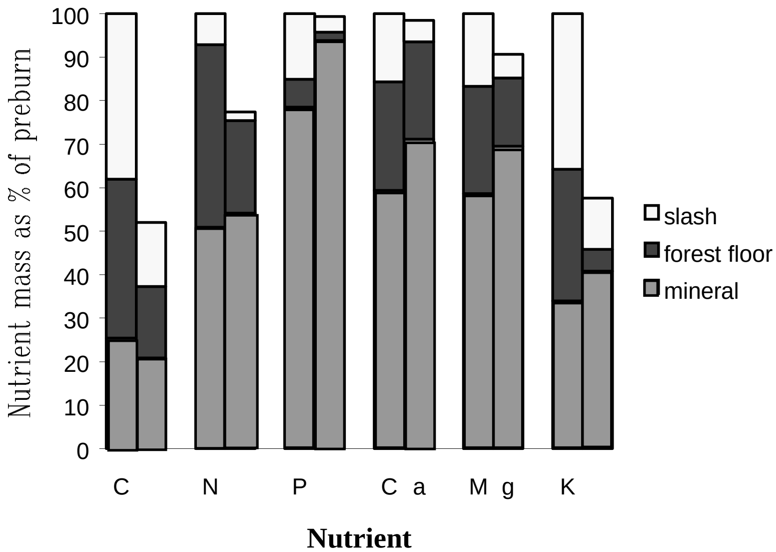

Figure 1. Comparison of pre-burn (first column) and 10th year (second column) distribution of nutrient mass between logging slash, forest floor and mineral soil (0-15 cm). Note that total cations were determined for slash while exchangeable cations are shown for forest floor and mineral soil.

represent much of the site nutrient capital which can be affected by broadcast burning. Figure 1 shows the relative changes in nutrients after 10 years across the sites. The site nutrient budget is not exact because total cations and phosphorus were determined for logging slash while exchangeable cations and available phosphorus were determined for soils. Despite the difference in methods, it is apparent that mineral soils hold the bulk of the site nutrients, and that burning led to a redistribution of some nutrients from logging slash and forest floors to mineral soil, with little change in overall totals for P, Ca and Mg. Net losses occurred with C and N, likely through volatilization and decomposition, and K, likely through leaching.

Changes in nutrient mass of complete soil profile

Where the deeper soil profile was monitored (on a subset of 11 plots across the seven sites) the changes in soil nutrient mass were generally statistically insignificant (Table 4). Carbon was the only element to be significantly reduced, although some interaction between sites affects the strength of this conclusion. The net changes in exchangeable cations and available P were not significant over the ten-year period. Total N decreased by approximately 10%, but this was not a large enough loss for a significant treatment effect.

Although the total N content of the soil profile was not greatly affected by burning, it is difficult to say whether the loss of forest floor N could significantly alter nitrogen availability for trees. In mature forests at least, higher concentrations of mineralizable nitrogen in the forest floor compared to mineral soils suggest greater biotic activity and consequently a more readily available source of nitrogen in the forest floor. On the other hand, it is interesting to speculate whether unburned sites would have

Table 4. Changes in soil profile (forest floor + 0-30 cm (n=44)

Chemical property	Pre-burn (kg/ha)	Post-burn (kg/ha) year 1	Year 5	year 10	year p<F	interaction p<F
Total carbon	90744a*	74293b	74162b	65717b	*0.0008*	*0.0917*
Total nitrogen	3039	2668	2609	2786	*0.1441*	*0.2388*
Phosphorus	279	356	294	361	*0.8407*	
Calcium	3008	2975	3421	3134	*0.4344*	
Magnesium	366	367	361	357	*0.9407*	
Potassium	330	357	353	305	*0.2472*	

** values significantly different between columns are distinguished by different letters (p<0.05)*

Table 5. Foliar nutrient concentrations for lodgepole pine at year ten (% and ppm).

	N	P	S	Ca	Mg	K	B	Cu	Fe	Mn	Zn	NW[†]
			(%)						(ppm)			(g)
Echo	1.19	0.15	0.08	0.14	0.07	0.65	10.9	2.6	22.4	184	41.1	2.53
McKendrick	1.20	0.14	0.08	0.17	0.08	0.65	11.9	3.0	69.4	266	41.9	2.68
Herron	1.27	0.14	0.11	0.17	0.08	0.63	13.1	2.8	38.3	181	38.0	1.93
Helene	1.22	0.15	0.10	0.14	0.07	0.63	9.3	2.3	23.1	169	41.4	2.11
Walcott	1.18	0.14	0.09	0.15	0.08	0.64	12.6	2.4	24.6	208	43.1	2.28
Kinskuch A	1.22	0.13	0.09	0.19	0.10	0.61	14.2	3.4	40.5	349	32.5	1.63
Kinskuch B	1.23	0.12	0.08	0.19	0.09	0.66	15.1	3.5	40.0	414	27.8	1.66
Kinskuch C	1.23	0.12	0.08	0.18	0.09	0.56	13.8	3.5	34.4	466	27.0	1.55
deficient*	**1.20**	**0.12**	**0.12**	**0.06**	**0.07**	**0.40**	**10.0**	**2.0**	**25**	**15**	**10**	

**values below which foliar nutrients are considered severely deficient for lodgepole pine (Ballard and Carter 1986)*
[†]average weight of 100 needles

undergone similar patterns of nutrient redistribution as did the burned sites. Without nitrogen immobilization in the forest floor, similar losses of forest floor N and cation transfer to mineral soils might have also occurred on unburned sites, through slow release by decomposition over longer periods of time rather than through the more immediate impact of broadcast burning.

Tree response after 10 years

Foliar nutrient concentrations of 10-year-old lodgepole pine from the monitored sites indicate probable deficiencies in nitrogen and sulphur (Table 5). Sulphur is also susceptible to losses from burning, but unfortunately was not monitored in these trials (sulphur was not part of standard soil analysis when monitoring began). Nitrogen and sulphur deficiencies have been documented in forest ecosystems in much of western North America, and could occur regardless of the most recent burning event. For example, on the unburned site Kinskuch C, the foliar nitrogen and sulphur concentrations were as low as on the burned ICH sites. Other nutrient deficiencies were less consistent, such as low levels of Fe, Mg and B found on a few sites. These deficiencies could be due to inherent differences in soils rather than the impacts of broadcast burning.

Tree growth data from across the sites show reasonable heights for lodgepole pine after 10 years, compared to regional averages (Table 6). On the unburned site Kinskuch C, tree height and diameter were lower than on the burned ICH plots. At Regan Creek (see Extension Note 28), we also found better growth of lodgepole pine on burned plots compared to unburned plots after 5 years. Good rates of tree growth on burned sites could be attributed to an 'assart' effect, which is the immediate but short-lived increase in nutrient availability that occurs after burning, such as the increase in exchangeable cations and phosphorus found on these sites. Broadcast burning can also reduce competing vegetation, and temporarily cause a

Table 6. Ten-year-old lodgepole pine growth response.

Site	Location	Ht (cm)	Dia (mm)	Inc (cm)
ESSFmc	Echo	274	67	44
ESSFmc	McKendrick	323	80	58
ESSFmc	Herron	175	45	.
SBSmc2	Helene	281	70	43
SBSmc2	Walcott	347	72	54
*Regional SBS average**		237	-	46
ICHmc1	Kinskuch A	312	72	53
ICHmc1	Kinskuch B	297	67	56
ICHmc1	Kinskuch C (not burned)	258	49	43
Regional ICH average		287	-	40

** average height and increment for ten-year-old plantations in the Prince Rupert Forest Region* partial sterilization of the upper soil from the fire, which could lead to a reduction in antagonistic soil organisms.

Conclusions

Broadcast burning of low to moderate severity in the Prince Rupert Forest Region had effects on soils comparable to those reported in other fire studies. Forest floors were immediately altered through cation release, pH increases, and nitrogen and carbon losses. Much of the site nutrients were redistributed from forest floor and logging slash to mineral soils over the ten-year monitoring period. There was little evidence of deleterious effects of broadcast burning on total soil nutrient mass because nutrients released by logging slash and forest floors were either retained on site by mineral soils, or because losses were too small or inconsistent to detect. Tree growth on the burned sites was better than regional averages, despite the possible deficiencies of nitrogen and sulphur indicated by foliar analysis.

Wildfire is a natural part of forest disturbance, but currently in the Prince Rupert Forest Region a minimal amount of broadcast burning is occurring because of concerns over air quality, fire escapes, and high treatment costs relative to mechanical treatments. The results from the operational monitoring program demonstrate the low impacts to site productivity from well-executed broadcast burns. This is reassuring, given our observations of good tree growth on burned sites, in addition to the unknown but likely important roles of fire in forest ecology. In this regard, broadcast burning can be recommended as a tool in forest management.

A more complete description of the operational broadcast burning monitoring project can be obtained from the Forest Sciences section in Smithers. This research project was initiated and maintained by Anne Macadam, and the ten-year results and discussion completed by Marty Kranabetter.