Scientific and Technical Articles/ Articles scientifiques et techniques

Fire Potential in the Spruce Budworm-damaged Forests of Ontario

by

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Abstract

An experimental burning program was carried out in Ontario between 1978 and 1982 to document quantitatively fire behavior in balsam fir killed by spruce budworm. Forest fire potential in budworm-killed balsam fir stands was shown to be significantly higher for a number of years following stand mortality. Crown breakage and windthrow, with resultant fuel complex rearrangement and increased surface fuel loads, peaked 5-8 years after mortality. Fire potential was greatest during this period, decreasing gradually as balsam fir surface fuels began to decompose and understory vegetation proliferated. Fires occurring prior to "green-up" in the spring behaved explosively with continuous crowning, high spread rates, and severe problems with downwind spot fires. Summer fires in this fuel type did not spread at all in the early years following mortality; however, sufficient woody surface fuel accumulation 4-5 years after mortality permitted summer fire spread.

Résumé

Un programme de feux expérimentaux a été réalisé en Ontario entre 1978 et 1982 afin d'obtenir des données quantitatives sur le comportement des incendies dans les sapins baumiers tués par l'infestation de la tordeuse des bourgeons de l'épinette. Le risque d'incendie dans les peuplements tués par la tordeuse s'est révélé beaucoup plus élevé pendant un certain nombre d'années après la mort des peuplements. Les bris de cimes et les chablis, qui modifient l'agencement des combustibles et augmentent les combustibles à la surface, ont atteint un sommet 5 à 8 ans après la mort. Le risque de feu a été le plus élevé au cours de cette période, puis a diminué graduellement quand les débris de sapins baumiers à la surface du sol ont commencé à se décomposer, et la végétation du sous-étage, à proliférer. Les feux allumés avant le débourrement au printemps ont présenté un comportement explosif, se traduisant par une propagation de cimes en cimes, des vitesses élevées de propagation et de graves problèmes de dissémination de l'incendie du côté sous le vent. En été, les incendies dans les peuplements de ce type ne se sont pas propagés du tout les premières années, mais 4 ou 5 ans après la mort il y avait une accumulation suffisante de combustibles ligneux à la surface pour permettre la propagation.

Introduction

The most recent spruce budworm (*Choristoneura fumiferana* [Clem.]) outbreak in eastern North America has resulted in the widespread mortality of balsam fir (*Abies balsamea* [L.] Mill.) and, to a lesser extent, white spruce (*Picea glauca* [Moench] Voss) across eastern Canada. Millions of hectares were affected in Ontario, where balsam fir is not a commercially valuable species, but grows, often as an understory component, in a heterogeneous mix with a variety of tree species in both the boreal and Great Lakes-St. Lawrence forest regions (Rowe 1972). In 1975, fire and forest managers in Ontario expressed growing concern over the potential increase in possible forest fire control problems

associated with large-scale balsam fir mortality. In the past, opinions varied among fire managers about the seriousness of wildfires in this fuel type, although entomologists and others studying the spruce budworm over the past 60 years often referred to an increased forest fire hazard as a result of budworm damage (e.g., Graham 1923, Swaine *et al.* 1924, Prebble 1950, Baskerville 1975). In addition, historical records indicate that several major forest fires have occurred in areas devastated by previous spruce budworm infestations. Prominent examples are the 1825 Miramichi fire in New Brunswick (Flieger 1971), the 1936 Isle Royale fire in Minnesota (Hansen *et al.* 1973), and the 1948 Chapleau-Mississagi fire in Ontario (Stocks and Walker 1973).

An experimental burning program has been under way in Ontario since 1969, as a cooperative endeavor of the Great Lakes Forestry Centre (GLFC) Forest Fire Research Unit and

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the Ontario Ministry of Natural Resources (OMNR) to develop fuel type-specific fire behavior guidelines for forest fire management (Stocks 1977, Stocks and Alexander 1980, Stocks 1986). The procedure has been to identify important fuel types, locate a suitable and representative site, lay out a series of experimental burning plots surrounded by adequate firebreaks, inventory the fuels, monitor fire weather on site, and conduct a series of controlled experimental fires under a broad range of fire weather conditions to observe and document fire behavior parameters in a quantitative manner. The dead balsam fir fuel type was included in this program, and a field study was initiated in 1976 and completed in 1982. The purpose of the study was twofold: (1) to evaluate the rate and magnitude of change within the balsam fir fuel complex following mortality, and (2) to assess quantitatively the impact of these changes on forest fire behavior. A more detailed report on this investigation was presented at a CANUSA Spruce Budworms Symposium in 1984 (Stocks 1985).

Study Area Description

After an extensive search, a study site was located near the Aubinadong River (latitude 46°53'N, longitude 83°24'W) in central Ontario, on which balsam fir was the primary tree species. Most of the balsam fir were dead or dying. Owing to logging in the early 1960s and the absence of wildfires since ca. 1770, there was an extremely sparse overstory of decadent white pine (*Pinus strobus* L.), jack pine (*Pinus banksiana* Lamb.), white spruce and birch (*Betula* spp.) on the site, but it was underlain with a continuous substratum of dead balsam fir and partially defoliated black spruce (*Picea mariana* [Mill.] B.S.P.) (Fig. 1). Systematic sampling revealed that more than 2 100 dead balsam fir stems per hectare were present; these accounted for 80% of the stems ≥ 3.0 cm in diameter at breast height dbh on the site, and averaged 9.6 cm dbh and 8.2 m in height. An average of 850 dead balsam fir per hectare < 3.0 cm dbh were also present.

The most recent spruce budworm infestation began in the Aubinadong River area in 1972 (Howse *et al.* 1973) and defoliation continued in succeeding years until by 1977 all balsam fir on the study area had died and top breakage was beginning.

Methods

A series of 10 2-ha experimental burning plots was established at the site in 1976. Each plot was 141.4 $\times$ 141.4 m and was surrounded by a 20-m-wide fireguard, bulldozed to mineral soil (Fig. 2). Three additional plots of the same dimensions were later established in 1982. A complete fire weather station was established on site, and daily (1200 hr LST) observations of temperature, relative humidity, wind velocity, and precipitation were made to calculate the various fuel moisture codes and fire behavior indices of the Canadian Forest Fire Weather Index (FWI) System (Anon. 1984).

(a) Fuel Complex Description

A systematic grid pattern was established on each experimental burning plot, and a variety of sampling techniques was utilized to inventory in detail the quantity and distribution of all ground, surface and crown fuels.

Ground fuels, which consist of the organic material layer above the mineral soil, were sampled at 36 locations in each burning plot. Samples 0.5 $\times$ 0.5 m were cut from the forest floor and sectioned horizontally into 2-cm-thick layers. The

Figure 1(a) and (b). Dead balsam fir and spruce in the understory, and decadent pine and spruce in the overstory, Aubinadong River experimental burning study area.

weight of each layer was determined by oven-drying and adjusting for ash content.

In this study surface fuels were considered to consist of both down and dead roundwood material on the ground and low herbaceous and shrub vegetation. The line intersect sampling technique (Van Wagner 1968) was used to inventory woody surface fuels on 36 permanent 15-m transects in each burning plot, and these transects were remeasured annually to monitor surface fuel accumulation resulting from balsam fir crown breakage and windthrow. Vegetation weights were

Figure 2. Arrangement of 2-ha burning plots with 20-m firelines, Aubinadong River experimental burning study area.

determined by collecting and oven-drying biomass samples from 21 subplots (2 × 3 m) in each burning plot.

Fuel weights of dead balsam fir crowns were determined by destructively sampling 45 stems of various sizes. Crown fuels were separated into roundwood diameter size classes, oven-dried and weighed. Regression equations for individual crown component weights were developed with dbh as the independent variable (Kent 1978). Crown weights for black spruce were calculated according to relationships developed in an earlier Ontario study (Walker and Stocks 1975). The regression equations were combined with stem density data to derive crown fuel loads for each burning plot. No estimate of deciduous aerial fuels was attempted in this study since hardwood trees were a minor component of the Aubinadong River forest and did not contribute to overall fire behavior.

(b) Experimental Burning

In the planning of this experimental burning program consideration was given to two factors peculiar to the transitional nature of insect-killed fuels. Stand deterioration following mortality was suspected of having an important influence on subsequent fire behavior, since tree tops and branches would be closer to the ground and therefore more available for combustion. Consequently, experimental fires were planned over a number of years so that surface fuel accumulation and its subsequent effect on fire behavior could be measured. Stand breakup after mortality also has the effect of increasing the amount of solar radiation reaching the forest floor, so that understory shrubs and herbaceous plants flourish. It was thought that this would greatly retard the behavior of fires occurring during the summer and hence both spring and summer fires were planned for comparison purposes.

Between 1978 and 1982, six successful experimental fires were conducted, and two others were attempted, at the Aubinadong River site. Two fast-spreading fires were conducted in the spring of 1978, but poor weather later in the summer precluded any further burning. In 1979 two fires were attempted, one during and one after the flushing of understory vegetation, but both failed to spread. A severe wildfire situation in northwestern Ontario during the spring and summer of 1980 depleted resources available for experimental burning. The next experimental fire was carried out in the spring of 1981. This fire escaped the confines of the plot because of a wind shift soon after ignition, and burned over the remaining seven plots and 40 ha of surrounding budworm-killed forest. As a result, three additional plots were established late in 1981 at

the Aubinadong River site, and were burned in 1982 — one under spring conditions, one during and one after understory flushing ("green-up"). One of the 1982 spring fires was ignited mysteriously when no one was present to monitor fire behavior and as a result no spread rate data were collected. However, the plot had been instrumented for burning, so that fuel consumption information could be determined.

Permanent dead and down woody surface fuel transects were remeasured annually and balsam fir top breakage was checked on all plots to ascertain the rate and quantity of surface fuel accumulation at the site. Between 1977 and 1982, average surface fuel loadings increased from 0.4 to 1.4 kg/m² and balsam fir top breakage rose steadily from 5 to 70%.

The ignition, control and suppression of all experimental fires were the responsibility of OMNR fire management staff. Several well-equipped fire suppression crews, with helicopter and water bomber support, were used on each experimental fire. GLFC Fire Research Unit staff monitored and documented fire behavior parameters on each fire, through aerial and ground observation.

Prior to ignition, surface fuels and downed tops were reassessed, and 300 depth-of-burn pins were placed systematically throughout the burning plot with a horizontal "I"-bar on each pin flush with the top of the organic layer (McRae *et al.* 1979). Moisture content samples were collected from selected fuels on each plot, and fire weather observations were updated immediately before each experimental fire.

All experimental fires were ignited along a windward plot boundary and allowed to spread with the wind to achieve an equilibrium spread rate as quickly as possible and thereby simulate a freeburning wildfire. Plots were ignited along two adjacent boundaries if the wind was blowing directly on a plot corner rather than a side. Forward rate of spread was determined by timing the arrival of the fire front at preselected grid points and, on particularly fast-spreading fires, by photography from a helicopter. General aspects of fire behavior were documented with both 35 mm slide and 8 mm motion picture film.

Post-burn sampling was carried out within a few hours of each fire. Surface fuels were remeasured on each transect to determine postburn loads and therefore surface fuel consumption. Crown fuel consumption was ocularly estimated for systematically-located stems throughout each plot. Depth-of-burn pins were measured, averaged for each plot, and converted to the amount of fuel consumed with the aid of the weight values determined previously for each organic layer.

Frontal fire intensity figures for each experimental fire, in kilowatts per metre (kW/m), were calculated according to the following equation (Byram 1959):

$$I = Hwr$$

where H is the fuel's low heat of combustion, in kilojoules per kilogram (kJ/kg), w is the weight of fuel consumed (in the active flaming zone), in kilograms per square metre (kg/m²), and r is the rate of spread in metres per second (m/s). For the purpose of calculating frontal fire intensity values, all organic and surface fuel consumption (both woody material and surface vegetation) measured for each fire was considered to have been consumed in the flaming front. In addition, dead balsam fir aerial fuels ≤ 1.0 cm in diameter and all live spruce

foliage were assumed to have been consumed in the active flaming zone. Any consumption of rotten logs or standing balsam fir boles was considered to be a result of smoldering after the passage of the fire front, and therefore was not considered in intensity calculations. An average low heat of combustion of 17 000 kJ/kg was assumed for all fires.

Results and Discussion

Ground, surface and crown fuel information for the Aubinadong River experimental burning site is summarized in Table 1. Forest floor fuel weights are averaged for all burning plots and show a dense, compact organic mantle, as would be expected in the absence of fire for more than 200 years. Surface litter reflected the heterogeneous nature of the stand, and consisted of a mixture of feather mosses, conifer needles and hardwood leaves. Roundwood surface fuel loads for solid

material averaged approximately 1 kg/m² (based on 1977 sampling), a figure typical for mixedwood stands in Ontario. However, large rotten and punky logs resulting from general stand decadence and earlier logging operations increased overall surface fuel loads significantly, although this material was far too moist to contribute to the combustion process during the experimental fires. Crown fuel loads reflected the preponderance of dead balsam fir and the fine cured material found in balsam fir crowns.

The realities of conducting experimental fires in as volatile a fuel type as spruce budworm-killed balsam fir made the completion of the burning program as initially planned, an impossibility. The inability to complete summer fires during the 1978-1980 period, combined with the loss of eight plots in the 1981 fire, resulted in a 5-year total of six successful fires.

Table 1. Characteristics of the spruce-budworm killed balsam fir fuel complex at the Aubinadong River experimental burning study area^a

Item		$\bar{x}$	SD	S $\bar{x}$
Forest floor depth (cm)		7.5	0.7	0.2
Organic layer weight by depth class (kg/m ²):	0.2 cm	0.825	0.052	0.031
	2-4 cm	1.214	0.180	0.060
	4-6 cm	1.687	0.286	0.096
	6-8 cm	2.233	0.562	0.187
	8+ cm	1.975	0.718	0.239
	TOTAL	7.934		
Phytomass (kg/m ²): herbaceous plants shrubs		0.028	0.015	0.006
		0.165	0.061	0.025
	TOTAL	0.193		
Surface fuel load by roundwood diameter size class (kg/m ²) ^b :	0.1 cm	0.127	0.039	0.012
	1-3 cm	0.257	0.065	0.021
	3-7 cm	0.417	0.096	0.031
	7+S cm	0.315	0.582	0.184
	7+R cm	3.163	0.590	0.187
	TOTAL	4.279		
Crown fuel load by roundwood diameter size class (kg/m ²):				
	balsam fir			
	≤ 1 cm	0.997	0.283	0.085
	≤ 3 cm	1.557	0.387	0.117
	TOTAL CROWN	4.286	1.187	0.358
	black spruce			
	≤ 1 cm	0.539	0.403	0.122
	≤ 3 cm	0.642	0.415	0.125
	TOTAL CROWN	0.932	0.693	0.209
	TOTAL	8.953		

^aWhere $\bar{x}$ represents the mean, SD the standard deviation, and S $\bar{x}$ the standard error of the mean.

^bWhere S represents soundwood and R represents rotten or punky wood.

The burning conditions (fire weather observations and fire danger ratings) associated with all attempted experimental fires are summarized in Table 2, and Table 3 outlines the documented impact (fuel consumption) and fire behavior (rate of spread and frontal fire intensity) characteristics of the six successful experimental fires.

The range of fire weather conditions, as indicated by the component codes and indices of the FWI System (Table 2), was narrower than initially planned, with fires being conducted only under high-to-extreme fire danger conditions. Despite this narrow range and the limited number of fires conducted, a strong relationship between the Initial Spread Index (ISI) and the forward rate of fire spread (Table 3) is evident.

The relationship between forest floor fuel consumption and the Buildup Index (BUI) shows a weak trend, probably because of the limited number of fires in the data set. Surface fuel consumption is a function of the quantity of such fuel present on site and does not correlate well with the fuel moisture codes of the FWI System. Dead balsam fir fuel cures while standing for a number of years and does not respond to wetting and drying in the same fashion as the fuels represented by the fuel moisture codes of the FWI System. Although additional data are needed to expand or legitimize the relationship between fire impact/behavior parameters and the codes and indices of the FWI System, the fire behavior exhibited in this experimental burning program permits a number of important conclusions.

Table 2. Fire weather conditions and fire danger ratings associated with the Aubinadong River experimental fires in dead balsam fir.

Exp. fire no.	Date of burning	Dry-bulb temperature (°)	Relative humidity (%)	10-m open wind (km/h)	Days since rain ^b	Canadian Forest Fire Weather Index (FWI) System components ^a					
						FFMC	DMC	DC	ISI	BUI	FWI
1	23-05-78	24.0	29	12	3	91.6	25	55	9.5	25	15
2	25-05-78	27.5	34	7	5	93.1	36	70	9.1	36	17
A ^c	06-06-79	20.0	39	15	5	88.9	21	105	7.7	28	13
B ^c	18-07-79	25.0	31	12	16	91.3	46	173	9.2	55	22
3 ^d	17-05-81	13.0	34	18	3	88.1	29	97	8.1	32	15
4	25-05-82	27.0	26	14	5	92.9	46	136	12.6	50	26
5	06-06-82	26.5	32	16	5	91.6	49	185	11.7	59	26
6	27-06-82	23.0	49	9	2	87.0	32	270	4.5	50	12

^aAbbreviations: FFMC — Fine Fuel Moisture Code; DMC — Duff Moisture Code; DC — Drought Code; ISI — Initial Spread Index; BUI — Buildup Index; FWI — Fire Weather Index. See Anon, 1984 for definitions of components.

^bAmount ≥ 0.6 mm

^cIncomplete fires (i.e., ignition failed to spread)

^dEscaped fire.

Table 3. Fire impact on forest fuels and fire behavior characteristics of the Aubinadong River experimental fires in dead balsam fir.

Exp. fire no.	Depth of burn (cm)	Fuel consumed (kg/m ²)						Head fire spread rate (m/min)	Frontal fire intensity (kW/m)
		Forest floor	Dead + down	roundwood	Minor vegetation	Crown material ^a	Total		
			< 7.0 cm class	≥ 7.0 cm class					
1	2.8	1.292	0.245	0.049	0.044	1.621	3.251	54.1	49 832
2	3.4	2.058	0.493	0.052	0.096	1.776	4.475	18.3	23 203
3	1.2	0.479	0.489	0.205	0.138	1.339	2.650	15.2	11 413
4	2.5	1.129	0.467	0.153	0.163	0.884	2.796	82.0	64 960
5	3.2	1.523	0.540	0.513	0.158	0.924	3.658	—	—
6	2.1	0.880	0.515	0.539	0.170	1.294	3.398	11.5	11 072

^aIncludes all dead balsam fir roundwood fuels ≤ 1.0 cm in diameter plus black spruce foliage.

Spring fires, or those conducted prior to the flushing of understory vegetation, exhibited spectacular behavior. Balsam fir crowns were totally involved immediately after ignition (Fig. 3) and forward spread rates as high as 82 m/min were observed. In addition, balsam fir bark peels readily after mortality, and this fuel was transported in large amounts along with fine twigs and branchlets, in the convection column, starting many downwind spot fires with resulting control problems. Large water bombers were required to extinguish spot fires up to half a km downwind on all spring fires, and this type of spotting in 1981 caused the wildfire situation that destroyed a number of experimental burning plots. Balsam fir crown and surface fuel consumption was almost complete, with standing tree boles smoldering long after the passage of

Figure 3(a) and (b). Typical crown fire behavior in spruce budworm-killed balsam fir, Aubinadong River.

the fire front (Fig. 4). Fuel arrangement did not seem to be a critical factor with spring fires in this fuel type: fires behaved explosively regardless of whether balsam fir crowns were intact (as with experimental fires 1 and 2 in 1978), or largely on the ground (as with experimental fires 4 and 5 in 1982). Dead balsam fir boles and crowns, having cured while standing for a number of years, had moisture content values low enough to make virtually the whole tree readily available for combustion. In contrast, crown fires in living conifer forests consume only foliage and fine branchlets. Samples taken prior to each experimental fire indicated dead balsam fir moisture contents of roughly 5-10%, 15-20% and 30% for fine fuels, medium-sized branches and tree boles, respectively.

Figure 4. Postfire view of a typical plot, Aubinadong River experimental burning study area. Note consumption of dead balsam fir boles.

In the first few years after defoliation and mortality, fires occurring after understory flushing spread very slowly if at all. The two incomplete fires attempted in 1979 were ignited under reasonably severe burning conditions, yet failed to spread continuously. With crown defoliation and the subsequent opening of the tree canopy, understory vegetation proliferates very quickly in this fuel type. The "greening up" of understory vegetation occurs very quickly over a 2-week period, usually early in June. This moist green layer restricts any interaction between dry surface and crown fuels, effectively preventing fire spread. After 4-5 years, however, enough dead and down surface fuel accumulates through balsam fir decomposition to offset this dampening effect of understory vegetation, and summer fires will spread through the fuel complex. Experimental fire No. 6 was an example of this type of fire.

Although no autumn (September-October) experimental fires were conducted in this study, it seems reasonable to assume that fires occurring after understory vegetation has cured would, under similar weather conditions, behave the same as spring fires. However, autumn fire weather in central Ontario is usually much less severe, with higher relative humidities, lower temperatures, and much shorter day-lengths.

The information gathered during the Aubinadong River experimental burning program is being combined with other fire behavior data from a number of major Canadian fuel types to develop the Canadian Forest Fire Behavior (FBP) System (Lawson *et al.* 1985). When complete the FBP System will enable forest fire managers to predict fire behavior more precisely under various weather, fuel, and topographic conditions.

In summary, the Ontario experimental burning program in budworm-killed balsam fir has definitely shown that forest fire potential increases significantly for a number of years after mortality in this fuel type, even though the Aubinadong River site may be considered an extreme example with a very heavy concentration of dead balsam fir. Defoliation itself is no cause for concern from the standpoint of potential fire behavior, but when repeated defoliation causes widespread balsam fir mortality, the potential for dangerous fire behavior and severe fire control problems increases dramatically. Each of the six successful experimental fires conducted in this study reached intensity levels well beyond the control capability of any forest fire agency. Crown breakage and windthrow, with resulting

rearrangement of the fuel complex and corresponding high surface fuel loads, reach a peak 5-8 years after mortality. Forest fire potential is greatest during this period, decreasing gradually as balsam fir fuel on the ground begins to decompose and understory vegetation continues to proliferate (Fig. 5).

Figure 5. Schematic representation of spring and summer fire potential in Ontario spruce budworm-killed balsam fir stands, as influenced by surface fuel accumulation and understory vegetation.

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