PREDICTING AND INTERPRETING FIRE INTENSITIES IN ALASKAN BLACK SPRUCE FORESTS USING THE CANADIAN SYSTEM OF FIRE DANGER RATING[1]

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ABSTRACT: A graph has been constructed for determining one of five possible head fire intensity classes as well as the general type of fire (i.e., surface, intermittent crown or continuous crown) for Canadian Forest Fire Behavior Prediction System Fuel Type C-2 (Boreal Spruce) based on the Initial Spread Index and Buildup Index components of the Canadian Forest Fire Weather Index System as inputs. An accompanying table offers free-burning fire potential and wildfire suppression interpretations.

In July 1992, after several seasons of informal field testing, Alaska's interagency fire management community decided to adopt the Canadian Forest Fire Danger Rating System (CFFDRS) in lieu of continuing to use the U.S. National Fire Danger Rating System. The CFFDRS actually comprises two primary subsystems or modules -- the Canadian Forest Fire Weather Index (FWI) System and the Canadian Forest Fire Behavior Prediction (FBP) System (Stocks et al. 1989). The six standard component outputs of the FWI System (Van Wagner 1987) are relative numerical ratings for various aspects of ignition ease, fire persistence and potential fire behavior for a reference fuel type (i.e., mature jack or lodgepole pine forest) on flat ground based largely on continuous or fire weather observations (i.e., temperature, relative humidity, 10-m open wind speed 24-hour accumulated rainfall amount, if any) recorded at noon local standard time or 1:00 p.m. daylight time (Turner and Lawson 1978).

The FBP System on the other hand provides actual quantitative estimates of certain fire behavior characteristics (e.g., spread rate, intensity, fuel consumption, type of fire, fire size and shape) for specific weather conditions, fuel types and topographic situations (Forestry Canada Fire Danger Group 1992). Two components of the FWI System, specifically the Initial Spread Index (ISI) and Buildup Index (BUI), are major inputs in the FBP System. The ISI and BUI are relative numerical ratings that incorporate the combined effects of short- and long-term weather conditions on potential rate of fire spread and fuel available for combustion, respectively (Canadian Forestry Service 1984).

As an aid to fostering a greater appreciation of the CFFDRS amongst Alaskan fire managers, a head fire intensity class graph (fig. 1) for FBP System Fuel Type C-2 (Boreal Spruce) has been prepared similar to the one presented by Alexander and De Groot (1988, 1989), utilizing the mathematical relationships and related criteria (e.g., ISI versus head fire rate of spread, ground and surface fuel consumption versus BUI) contained in Forestry Canada Fire Danger Group (1992). A computerized version of the head fire intensity class graph has also been developed by Per Pedersen (personal communication) of the USDI Bureau of Land Management's Alaska Fire Service at Fort Wainwright, which allows the user to plot the values for a multitude of fire weather network stations by administrative unit (e.g., district, region, area).

The FBP System is based largely on empirical data derived from experimental fires and wildfires, supplemented by simple physical principles. Some of the basic data included in the head fire rate of spread equations for FBP System Fuel Type C-2 was obtained from previous Alaskan studies (Johnson 1964,

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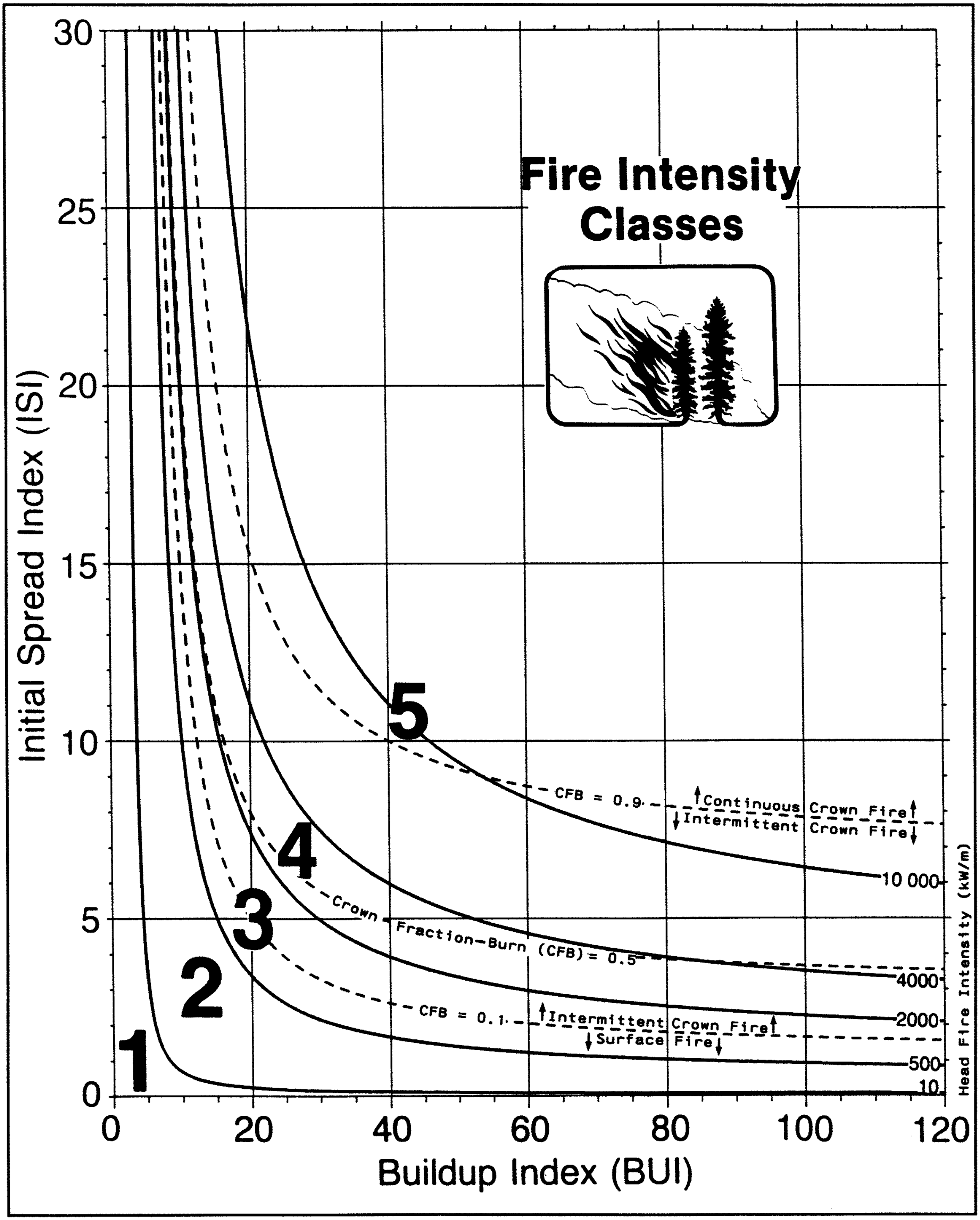

Figure 1. Head fire intensity class graph for Canadian Forest Fire Behavior Prediction System Fuel Type C-2 (Boreal Spruce) on level to gently undulating terrain and at 85% foliar moisture content. Refer to table 1 for the associated fire control and fire behavior interpretations.

Table 1. Interpretations associated with the head fire intensity class graph for Canadian Forest Fire Behavior Prediction System Fuel Type C-2 (Boreal Spruce) on level to gently undulating terrain and at 85% foliar moisture content.

Fire Intensity Class	Description of Probable Fire Potential and Implications for Wildfire Suppression†
1	New fire starts are unlikely to sustain themselves due to moist surface fuel conditions. However, new ignitions may still take place from lightning strikes or near large and prolonged heat sources (e.g., camp fires, windrowed slash piles) but the resulting fires generally do not spread much beyond their point of origin and if they do, control is very easily achieved. Mop-up or complete extinguishment of fires that are already burning may still be required provided there is sufficient fuel and it is dry enough to support smouldering combustion*. Color code is GREEN. **[< 10 kW/m]**
2	From the standpoint of moisture content, surface fuels are considered sufficiently receptive to sustain ignition and combustion from both flaming and glowing firebrands. Fire activity is limited to creeping or gentle surface burning with maximum flame heights of less than 1.3 m (≈ 4 ft). Control of these fires is fairly easy but can become troublesome as adverse fire impacts can still result, and fires can become costly to suppress if not attended to immediately. Direct manual attack by "hotspotting" around the entire fire perimeter by firefighters with only hand tools and water from back-pack pumps is possible; a "light" helicopter(s) with bucket is also very effective. Fireguard constructed with hand tools should hold. Color code is BLUE. **[10-500 kW/m]**
3	Both moderately and highly vigorous surface fires with flames up to just over 1.5 m (≈ 5 ft) high or intermittent crowning (i.e., torching) can occur. As a result, fires can be moderately difficult to control. Hand-constructed fire guards are likely to be challenged and the opportunity to "hotspot" the perimeter gradually diminishes. Water under pressure (e.g., fire pumps with hose lays) and heavy machinery (e.g., bulldozer, "intermediate" helicopter with a bucket) are generally required for effective action at the fire's head. Color code is YELLOW. **[500-2000 kW/m]**
4	Burning conditions have become critical as intermittent crowning and short-range spotting is common place and as a result control is very difficult. Direct attack on the head of a fire by ground forces is feasible for only the first few minutes after ignition has occurred. Otherwise, any attempt to attack the fire's head should be limited to "medium" or "heavy" helicopters with buckets or fixed-wing aircraft, preferably dropping long-term chemical fire retardants; control efforts may fail. Until the fire weather severity abates, resulting in the subsidence of a fire run, the uncertainty of successful control exists. Color code is ORANGE. **[2000-4000 kW/m]**
5	Intermittent crown fires are prevalent and continuous crowning is also possible as well in the lower end of the spectrum. Control is extremely difficult and all efforts at direct control are likely to fail. Direct attack is rarely possible given the fire's probable ferocity except immediately after ignition and should only be attempted with the utmost caution. Otherwise, any suppression action must be restricted to the flanks and back of the fire. Indirect attack with aerial ignition (i.e., helitorch and/or A.I.D. dispenser), if available, may be effective depending on the fire's forward rate of advance. **[> 4000 kW/m]** The situation should be considered as "explosive" or super critical in the upper portion of the class. The characteristics commonly associated with extreme fire behavior (e.g., rapid spread rates, continuous crown fire development, medium- to long-range spotting, firewhirls, massive convection columns, great walls of flame) is a certainty. Fires present serious control problems as they are virtually impossible to contain until burning conditions ameliorate. Direct attack is rarely possible given the fire's probable ferocity except immediately after ignition and should only be attempted with the utmost caution; an escaped fire should in most cases, be considered a very real possibility. The only effective and safe control action that can be taken until the fire run expires is at the back and up along the flanks. Color code is RED. **[> 10 000 kW/m]**

†THE ABOVE <u>SHOULD NOT</u> BE USED AS A GUIDE TO FIREFIGHTER SAFETY AS WILDLAND FIRES CAN BE POTENTIALLY DANGEROUS OR LIFE THREATENING AT ANY LEVEL OF FIRE INTENSITY.

*General rule(s) of thumb: certainly when the Drought Code (DC) or Buildup Index (BUI) components of the Canadian Forest Fire Weather Index System exceeds about 300 or is greater than around 40, respectively, one can generally expect ground or subsurface fires. <u>Please note</u>, however, these threshold values are for moderately well-drained sites but in actual fact they will vary according to soil type and drainage conditions and should be determined locally on the basis of past wildfire suppression and/or prescribed burning experience.

Dymess and Norum 1983). The FBP System Fuel Type C-2 is described as being (from Forestry Canada Fire Danger Group 1992)

> "...characterized by pure, moderately well-stocked black spruce stands on lowland (excluding *Sphagnum* bogs) and upland sites. Tree crowns extend to or near the ground and dead branches are typically draped with bearded lichens (*Usnea* sp.). The flaky nature of the bark on the lower portion of stem boles is pronounced. Low to moderate volumes of down woody material are present. Labrador tea (*Ledum groenlandicum* Oeder) is often the major shrub component. The forest floor is dominated by a carpet of feather mosses and/or ground-dwelling lichens (chiefly *Cladonia*). *Sphagnum* mosses may occasionally be present, but they are little hinderance to surface fire spread. A compacted organic layer commonly exceeds a depth of 20-30 cm."

Photographic examples of all the FBP System fuel types are presented in Forestry Canada Fire Danger Group (1992) and De Groot (1993). The graph and the corresponding interpretations (table 1[3]) are of value to both Canadian and Alaskan fire management agencies alike because the black spruce-Labrador tea-cladonia-feathermoss fuel complex is prevalent not only in the northern regions of Canada but throughout much of interior Alaska and selected coastal areas (Eyre 1980). In preparing the head fire intensity class graph for FBP System Fuel Type C-2 (fig. 1), the topography was assumed to be flat (i.e., 0% slope) and foliar moisture content (FMC) was set equal to 85% (i.e., a worst case scenario). Variations in slope steepness and FMC would be more easily accommodated in any of the computerized versions of the FBP System that exist (e.g., Lee and Anderson 1991, REMSOFT INC. 1993). Other than these explicit assumptions, homogeneous conditions are assumed to prevail (i.e., constant wind velocity and continuous forest cover), and a fire is considered to be at or have reached an equilibrium or *quasi* steady-state rate of spread, regardless of the source of ignition (i.e., effectively a "line of fire" as opposed to a single point).

The concept of fire intensity in the FBP System refers to the rate of heat energy release per unit of time per unit length of fire front (Byram 1959). Numerically it is equal to the product of the net heat of combustion (a standard value of 18 000 kJ/kg has been used here), the amount of ground, surface, and as appropriate, crown fuel consumed in the active flaming portion of the fire front, and the linear rate of spread. The latter quantity is generally but not exclusively referenced to the "head" of the fire perimeter. In the International System (SI) of units, fire intensity is expressed in kilowatts per metre (kW/m) where 1 kW/m is equal to approximately 0.29 Btu/sec-ft. Fire intensity is one of the principal factors influencing the difficulty of containing a wildfire because it is directly related to flame size and in turn radiation levels as well as crowning and spotting potential (*cf.* Alexander 1992).

The hyperbolas of head fire intensity depicted in figure 1, which reflect the generalized guidelines presented in table 1 as synthesized from various sources (e.g., Alexander and De Groot 1988, Alexander and Lanoville 1989, Alexander 1994), implies that there are relatively distinct differences in fire characteristics and the effectiveness of various fire suppression resources between fire intensity classes; note in figure 1 and table 1 that the fifth class actually spans two ranges in fire intensity (i.e., 4 000 - 10 000 and > 10 000 kW/m), which in most instances can be considered as one for practical purposes although some users may wish to distinguish six rather than five head fire intensity classes (Alexander and De Groot 1989). However, in reality there are gradations between classes rather than abrupt changes. The crown fraction burn (CFB) (i.e.,

[3]Byram's (1959) flame length-fire intensity relation was used to derive the estimates of flame height quoted in table 1. The idea of assigning green and blue color codes to fire intensity classes 1 and 2, respectively, might appear odd to some people because if the natural color spectrum was adopted, the order would be reversed. However, table 1 follows the same color code scheme as originally advocated by Nelson (1964) and Brown and Davis (1973) for fire danger classes and which therefore has been subsequently used or advocated by the senior author (Alexander 1994, Alexander and De Groot 1988, Alexander and Lanoville 1989, Merrill and Alexander 1987) and used in whole or in part by others (e.g., Lanoville and Mawdsley 1990). This apparent contradiction may in fact stem from philosophical differences as to which colors provide the best psychological effect.

the degree of potential crown fuel consumption expressed as a proportion of the total number of tree crowns) versus type of fire criteria employed in the FBP System has been used to delineate the transitions between surface fires/intermittent crowning (CFB = 0.1) and intermittent/ continuous crown fire development (CFB = 0.9); an intermediate value (CFB = 0.5) has also been plotted. Some of the curves portraying lines of equal fire intensity and CFB cross over rather than perhaps more logically parralleling each other even though they are both determined by essentially the same controlling variables. This apparent anomally is really simply a reflection of the relative contribution of the quantity of ground and surface versus crown fuel consumption as a result of different burning conditions (e.g., a low BUI and high ISI in contrast to a high BUI and low ISI combination).

Theoretically, both the ISI and BUI have "open-ended" scales (i.e., a higher value is always possible with increasing fire weather severity). The maximum values depicted in figure 1 therefore constitute a compromise in terms of practicality. To determine the fire intensity class, simply find the point on the graph where the ISI and BUI (using either actual or forecasted values) intersect. For example, on the day that the 1983 Rosie Creek Fire (Juday 1985, Juday and Dyrness 1985) made its major run (June 2) near Fairbanks, Alaska, the standard daily 1:00 p.m. ADT values of the ISI and BUI at the international airport weather station were 18 and 114, respectively (Alexander 1991) -- this places it in the upper reaches of **Fire Intensity Class 5.** Eyewitness observations, photographs taken during the fire run and the post-burn evidence itself (e.g., complete flame defoliation of tree crowns over large areas) all atest to the extreme fire behavior and intensities that occurred on this day. Note that the current weather conditions alone as reflected by the ISI would have been insufficient to properly gauge the fire intensity potential on this day and the key role played by the BUI in appraising the cumulative drying that had taken place in the medium and heavy fuels[4].

In practice, the fire intensity class will be determined from index values calculated for an individual fire weather station and then applied to an "area of influence" (*cf.* Turner and Lawson 1978) or by interpolation between network stations (e.g., Lee and Anderson 1989). In either case, the proviso is made that the index values may be inaccurate (and in turn possibly the fire intensity class) if they don't constitute a reasonably representative sampling of the weather acting on the general area or the specific location being assessed. In most cases, the basic observation time values of the ISI and BUI will be applied to the fire intensity class graph/table in order to obtain a general indication of fire potential and implications for fire suppression across a broad geographical area. For other times of the day or for site-specific predictions, it is paramount that the manner in which the ISI is calculated is as vigorous as practically possible, especially with respect to the timeliness and representativeness of the wind speed input (Forestry Canada Fire Danger Group 1992).

It is worth noting that the fire intensity class graph and table **do not** directly consider the quantity of the individual resource or mix of resources (e.g., number of firefighter(s), helicopter(s) with a bucket(s), and/or airtanker(s) etc.) to dispatch to a newly reported wildfire in order to contain it within a specified period of time. This must still be inferred from a knowledge of potential fire size and the rate of perimeter growth at the probable time of arrival by initial attack forces, both of which can also be predicted using the FBP System.

Figure 1 and table 1 were primarily intended as decision support guides for use in wildfire management. However, in addition to their value in contingency planning for a possible "escape(s)" on prescribed fires, the head fire intensity class graph/table are also applicable to instances where a strip head fire ignition pattern is

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[4]The 1:00 p.m. ADT fire weather observations and the other four FWI System components at the Fairbanks international airport were (from Alexander 1991): dry-bulb temperature 23.5°C (74°F); relative humidity 33%; 10-m (33-ft) open wind 21 km/h (13 mph); 4 days since greater than 0.6 mm (0.02 in.) of rain; Fine Fuel Moisture Code (FFMC) 92.7; Duff Moisture Code (DMC) 114; Drought Code (DC) 209; and Fire Weather Index (FWI) 49.

employed involving widely spaced ignition lines, except within the immediate influence of the junction zone where merging fire fronts will produce flame heights that will be considerably higher than in adjacent areas (Rothermel 1985) -- in other words, greater fire intensities than apparent burning conditions would otherwise indicate. The graph and table should not be considered as strictly relevant to other more complex ignition patterns (e.g., centre firing).

Informal experience with the fire intensity class graph and table during the 1994 wildfire season in Alaska was very encouraging. However, comparisons based on casual observations need to be followed up by formal evaluations with existing documentation available on wildlfires (and prescribed fires) as exemplified, for example, by Pearce and Alexander (1994). In a sense this has been done for the Rosie Creek Fire (Alexander 1991) and a host of other possibilities exist assuming the relevant weather data is available to calculate the FWI System components (e.g., Hardy and Franks 1963, Spencer and Hakala 1964, Hakala et al. 1971, Franks 1974, Barney et al. 1978, McBride 1978, Viereck and Dyrness 1979, Viereck et al. 1979, Norum 1982). Furthermore, in the future the completion of individual fire reports should be undertaken with the same rigour as an initial attack productivity and effectiveness study currently in progress by Hirsch (1995). Although this is not the place to debate the relative supremacy of Canadian versus American fire danger rating/fire behavior prediction systems in Alaska, an intercomparison of FBP System Fuel Type C-2 projections with Norum's (1982) fire behavior guide would constitute a worthy investigation, perhaps under the auspices of the International Boreal Forest Research Association's Stand Replacement Fire Working Group (Fosberg 1992).

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