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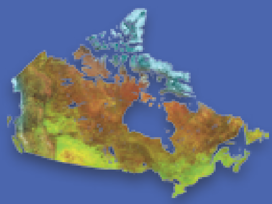

Photo Guide for Quantitatively Assessing the Characteristics of Forest Fuels in a Jack Pine – Black Spruce Chronosequence in the Northwest Territories

N. Lavoie, M.E. Alexander, and S.E. Macdonald

INFORMATION REPORT NOR-X-419

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Northern Forestry Centre
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ABSTRACT

Descriptions of fuels and their quantification are used in several aspects of forest management and research. However, collecting site-specific data can be tedious, time-consuming, and expensive. Fuel photo guides, with their pictorial catalogs and accompanying fuel descriptions and quantitative information, represent a quick and easy alternative to objectively assessing the characteristics of forest fuels in a given area. This report augments the existing fuel photo guides of North American forest stands and vegetation types. Summary information and color photographs are presented for a jack pine (*Pinus banksiana* Lamb.) – black spruce (*Picea mariana* (Mill.) BSP) chronosequence in the south-central part of the Northwest Territories, Canada. Eight stands, initiated after stand-replacing crown fires and ranging in age from 1 to 108 years, were documented. The information presented here includes a description of each site, quantification of fuels by fuel strata, vertical distribution of the ladder and crown fuels, and visual representations of the stands in the form of general profile and stereopair photos.

RÉSUMÉ

La description et la quantification des combustibles sont utilisées dans le cadre de plusieurs activités relevant de l'aménagement forestier et de la recherche en foresterie. La collecte de données propres à un site en particulier peut cependant être une tâche de longue haleine, harassante et coûteuse. Il existe néanmoins une alternative simple et rapide à la détermination objective des caractéristiques des combustibles d'une région donnée : les guides photo des combustibles forestiers, catalogues illustrés contenant des informations descriptives et quantitatives. Ce rapport vient s'ajouter aux guides existants sur les peuplements forestiers et les types de végétations en Amérique du Nord. Il présente de brèves informations et des photographies en couleur portant sur une chronoséquence de pins gris (*Pinus banksiana* Lamb.) et d'épinettes noires (*Picea mariana* (Mill.) BSP) située dans le centre-sud des Territoires du Nord-Ouest, au Canada. Des données ont été recueillies sur huit peuplements issus d'une régénération causée par des feux de cime et dont l'âge varie entre 1 et 108 ans. Les informations fournies comprennent la description de chaque site, la quantification des combustibles en fonction des strates, la distribution verticale des combustibles étagés et des combustibles de cime et des représentations visuelles des peuplements sous forme de profil général et de couples de photographies stéréoscopiques.

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INTRODUCTION

The makeup of forest fuel complexes must be understood before the interaction between fire and its environment can be examined constructively. To achieve this, the student must be able to appraise forests and wild lands in general from the point of view of their fire potential. In figurative terms, it is like viewing the forest through a different pair of glasses, the kind worn constantly by skilled fire control men. The vegetative cover, living and dead, is then perceived as potential fuel, capable of being ignited and burned under certain conditions.

—Brown and Davis (1973)

Research and operational experience over the years have shown that the ignition, behavior, immediate impacts, and long-term effects of wildland fire are determined in part by preburn fuel characteristics and burning conditions, which in turn determine the amount of fuel consumed (Barrows 1951; Martin and Brackebusch 1974; Martin et al. 1976, 1979; Chandler et al. 1983; Maxwell and Ward 1983; Pyne et al. 1996; DeBano et al. 1998; Omi 2005).

The description and quantification of fuels are used in several aspects of fire management. For example, such information is needed for predicting and documenting fire behavior, for planning and monitoring the mechanical treatment of the fuels, for quantifying the amount of fuel consumed and smoke emitted in association with prescribed burning and wildfires, for predicting and assessing the effects of fire, and for preparedness planning (Stocks and Kauffman 1997; Sandberg et al. 2001; Alexander and Thomas 2006; Alexander 2007). Information about fuels can also be pertinent to many other aspects of forest land management and forestry research (e.g., Kasischke et al. 1995; Stelfox 1995; Lee et al. 1997; de Groot et al. 2009), including carbon accounting (Kull et al. 2006).

The following fuel components are usually observed in a natural forest stand:

- duff, the combined fermentation and humus layers of the forest floor, including buried, highly decayed wood;
- a layer of loose surface litter, consisting primarily of leaf and needle cast, bark flakes, and cone scales;
- various species of ground-covering mosses and lichens;
- other ground vegetation (e.g., shrubs, herbs, forbs, grasses, and sedges);
- dead and downed woody debris of various sizes (e.g., twigs, branches, limbs, and logs);
- the live-tree understory, consisting primarily of seedlings and small saplings;
- the live-tree overstory (canopy), comprising needle and leaf foliage, live and dead twigs and branches, bark flakes, and aerial lichens and mosses; and
- dead tree stems resulting from natural mortality and various disturbances, as well as the fire-killed snags associated with the parent stand.

These fuel components are commonly classified into four more or less distinct strata according to their effects on fire behavior (Fig. 1): ground, surface, ladder, and crown. Collectively, these strata constitute a “fuel complex” (Merrill and Alexander 1987).

Field methods and computational procedures have been developed for sampling and summarizing the four strata in a forest fuel complex (e.g., Muraro 1971; Lawson 1973; Walker and Stocks 1975; Alexander et al. 2004). A high degree of accuracy is generally required for certain types of research studies and management applications, such as the initial development and validation of burning prescriptions (McRae et al. 1979; McCaw 1991). However, the site-specific description and quantification of fuel characteristics can be tedious, time-consuming, and expensive. Photographic methods of quickly assessing fuel characteristics may offer a suitable alternative to conducting detailed measurements of fuels in the field in cases where the fire management application does not require a high level of detail and accuracy (Brown 1978).

The concept of using photographs as a tool for quantitatively assessing fuel complexes is not

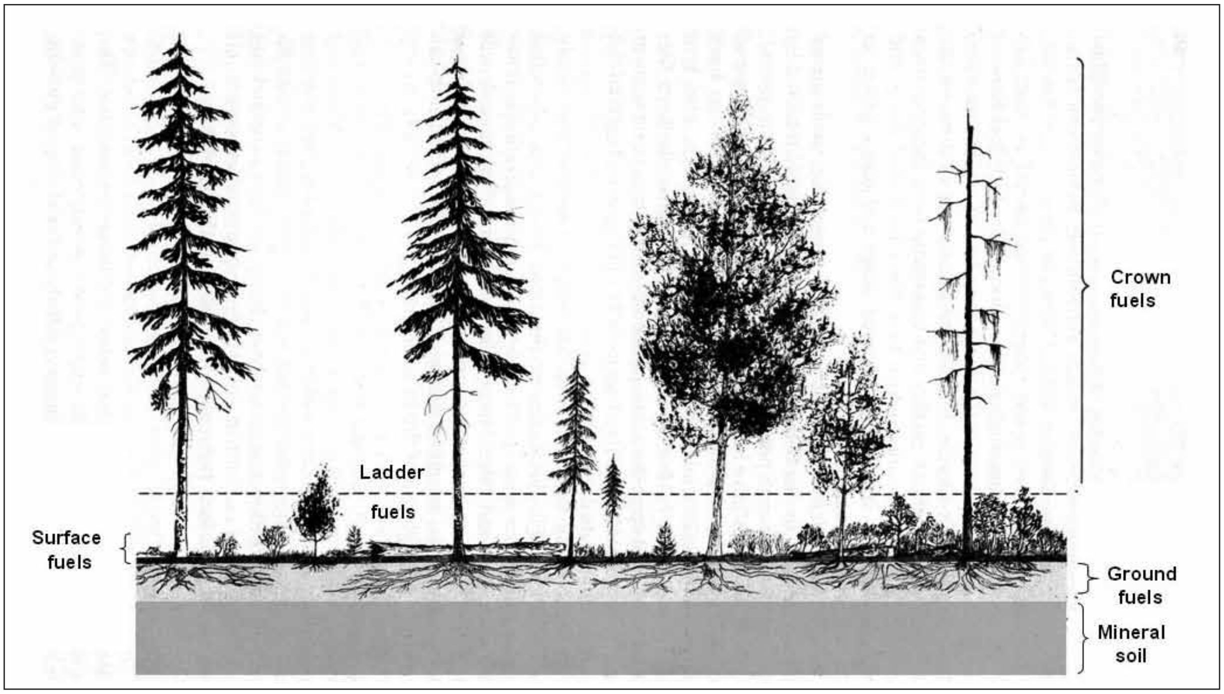


Figure 1. Profile of a stylized forest stand showing the location and classification of the various strata of the fuel complex (adapted with permission from Brown and Davis [1973] *Forest fire: control and use.* 2nd edition © The McGraw-Hill Companies Inc).

new. Various approaches to using photography in wildland fire research and management have been explored in the past (e.g., Morris 1970; Muraro 1970; Fahnestock and Key 1971; Kiil 1971; Kirby and Hall 1979), and imaginative uses of photography for fuel assessment continue to be examined.

For many years, representative photos of certain fuel complexes without any accompanying quantitative data have been used in various fuel-type classification schemes (e.g., USDA Forest Service 1938, 1968; Moore et al. 1942; Wendell et al. 1962; Fahnestock 1970). This approach continues to this day (e.g., Anderson 1982; DeGroot 1993; Garvey and Mille 1999; McCarthy et al. 1999; Scott and Burgan 2005).

Muraro (1971) is believed to have been the first to present quantitative information about fuels in connection with photographs of sampled forest stands. The pictorial aspect of a fuel photo guide facilitates visual associations between the sampled fuels and other fuel complexes where a fire is expected to burn similarly. The associated numeric data can be used to estimate the fuel characteristics for the stand or area of interest.

The USDA Forest Service (1974) initiated the National Fuel Classification and Inventory System in the United States in the mid-1970s with the specific objectives of generating quantitative fuels data, a photo series of fuels, a training tool for managers, and a rationale for fuel treatments. One of the principal initial goals of the system was to develop photo series for "activity fuels" (i.e., those residues resulting from land management activities such as clear-cutting and thinning), as distinct from natural fuel residues (Bergstrom 1977).

The early emphasis on producing photo series for activity fuels in the United States gradually gave way to the development of photo series for natural forest stands and nonforested vegetation types (e.g., grasslands and shrublands). A similar trend occurred in Canada (e.g., British Columbia Ministry of Forests 1984). A few of the published photo series included information about and photographs of both natural and activity fuels.

At least 52 fuel photo guides are known to have been produced in North America to date (Table 1) and work is ongoing in certain regions (e.g., Rideout-Hanzak 2006). The development of such series has also been undertaken in South America (Ottmar et al. 2001, 2004a), Europe (Cruz 2005), and Mexico (Alvarado-Celestino et al. 2008). The concept has now been extended to assessing the fuel characteristics of specific fuel strata of forest stands, such as the canopy (Scott and Reinhardt 2005) or surface fuel loads around tree bases (Brose 2009).

The presentation formats for data about fuels and the associated photographs have changed over the years. Initially, the photos were of the standard, wide-angle variety (Neelands 1974; Magill 1989), but the inclusion of stereopairs (Dwyer 1956) has gradually become popular (Ryan and Johnson 1979).

One of the latest innovations is a new method of sampling fuels, developed by Keane and Dickinson (2007a, 2007b), which is called the photoload sampling technique. This technique involves visually comparing fuel conditions in the field with a so-called photoload sequence (a series of downward-looking, close-up oblique photographs of gradually increasing loads of synthetic fuel beds) to estimate the fuel loads of dead and downed woody surface materials of various sizes and of the understory vegetation (i.e., shrubs and herbaceous plants). A field evaluation of this technique against other fuel-sampling methods at five locations in western Montana produced encouraging results (Sikkink et al. 2009). More recently, Sikkink et al. (2009) outlined a procedure for combining measurements of the depth of litter and duff in forest stands with the photoload sampling technique to estimate total loads of ground and surface fuels.

The most recent development in the field of fuel photo guides has been the creation of a digital photo series based largely on the photo series for natural fuels (Ottmar et al. 2003b; Ottmar 2008) undertaken over the years by the Fire and Environmental Resource Applications Team of the United States Department of Agriculture Forest Service, Pacific Northwest Research Station (Wright et al. 2007). The digital photo series is a web-based application that provides ready access to the database and photos for the natural fuels photo series (http://depts.washington.edu/nwfire/dps/). The British Columbia Ministry of Forests and Range has recently developed a similar product (http://bcwildfire.ca/AboutUs/Organization/Kamloops/FuelPlot/).

The present fuel photo guide is an outgrowth of a larger research project examining the temporal aspects of flammability of forest stands in the south-central part of the Northwest Territories (Lavoie et al. 2002; Lavoie 2004). The project specifically examined the fuel and potential fire dynamics associated with the jack pine (*Pinus banksiana* Lamb.) – black spruce (*Picea mariana* (Mill.) BSP) fuel complex found in the area (Lavoie 2004).

The fuel photo guide developed for this forest-stand type is believed to be the first to focus on a fire-origin chronosequence, based on the same measurements for a series of comparable sites of different ages since disturbance by fire (Whelan 1995). This approach of substituting "space for time" (Pickett 1989) overcomes the obvious problems associated with monitoring fuel development or succession over long periods.

In the project carried out by Lavoie (2004), 13 stands, ranging in age from 1 to 108 years since the last stand-replacing crown fire, were sampled during the 1999 and 2000 field seasons. Quantitative data and photographic documentation are presented here for eight stands, which are representative of the eight different times since fire that were considered by Lavoie (2004). Despite an extensive ground and aerial reconnaissance of the study area in 1998, no stands older than 108 years could be located. Similarly, no stands between 6 and 20 years of age were found that had not been affected by local gathering of fuelwood.

Table 1. Summary of photo series for various forest and wildland fuel complexes completed in North America to date

Reference	Geographic location(s)	Fuel, stand, and/or vegetation type(s)	Type of fuel	
			Natural	Activity[a]
Alexander (1978)	North-central Colorado	Lodgepole pine	+	
Alvarado-Celestino et al. (2008)	Mexico	Temperate and montane subtropical forests, montane shrublands	+	
Battaglia et al. (2005)	North-central Colorado	Meadow, spruce, lodgepole pine, limber pine, ponderosa pine, quaking aspen, Douglas-fir	+	
Baxter (2009)	Alberta	Grass	+	
Blank (1982)	Michigan	Jack pine		+
Blonski and Schramel (1981)	Southern Cascades and northern Sierra Nevada (California)	Mixed conifer – pine, mixed conifer – fir, ponderosa pine, lodgepole pine, white fir, red fir, mountain hemlock	+	
British Columbia Ministry of Forests and H.I.S. Ventures Ltd. (1992a)	Southern British Columbia, Kamloops Forest Region	Montane and lower subalpine forests	+	
British Columbia Ministry of Forests and H.I.S. Ventures Ltd. (1992b)	Southern British Columbia, Kamloops Forest Region	Montane and lower subalpine forests		+
British Columbia Ministry of Forests and H.I.S. Ventures Ltd. (1992c)	Southern British Columbia, Nelson Forest Region	Motane and lower subalpine forests	+	
Brose (2009b)	Pennsylvania and New Jersey	Mixed-oak forests	+	+
Brown and Simmerman (1986)	Wyoming and Idaho	Aspen	+	
Fischer (1981b)	Montana	Grand fir – larch – Douglas-fir, western hemlock, western hemlock – western redcedar, western redcedar	+	
Fischer (1981c)	Montana	Interior ponderosa pine, ponderosa pine – larch – Douglas-fir, larch – Douglas-fir, interior Douglas-fir	+	
Fischer (1981d)	Montana	Lodgepole pine, Engelmann spruce – subalpine fir	+	
Hawkes et al. (1997)	Northeastern British Columbia	White spruce – subalpine fir	+	+
Koski and Fischer (1979)	North Idaho	Western hemlock, grand fir, western redcedar		+
Lynch and Horton (1983)	Northeast (United States)	Loblolly pine, eastern white pine, pitch pine, Virginia pine	+	+
Maxwell (1982)	South Dakota	Ponderosa pine, spruce	+	+
Maxwell and Ward (1976a)	Washington and Oregon	Coastal Douglas-fir – hemlock, coastal Douglas-fir – hardwood		+
Maxwell and Ward (1976b)	Washington and Oregon	Ponderosa pine, ponderosa pine and associated species, lodgepole pine		+
Maxwell and Ward (1979)	Sierra Nevada (California)	Mixed conifer, true fir		+
Maxwell and Ward (1980a)	Pacific Northwest (United States)	Douglas-fir – hardwood, hardwood, Douglas-fir – hemlock, subalpine fir, mixed conifer, lodgepole pine, ponderosa pine and associated species, ponderosa pine, brush, juniper, grass	+	
Muraro (1971)	Central British Columbia	Lodgepole pine	+	

Table 1. Concluded

Reference	Geographic location(s)	Fuel, stand, and/or vegetation type(s)	Type of fuel	
			Natural	Activity[a]
Ottmar and Hardy (1989)	Coastal Oregon	Second-growth Douglas-fir – western hemlock, western hemlock – Sitka spruce, red alder		+
Ottmar and Vihnanek (1998)	Alaska	Black spruce, white spruce	+	
Ottmar and Vihnanek (1999)	Midwest (United States)	Red and white pine, northern tallgrass prairie, mixed oak	+	
Ottmar and Vihnanek (2000)	Southeast (United States)	Longleaf pine, pocosin, marshgrass	+	
Ottmar and Vihnanek (2002)	Alaska	Hardwoods, spruce	+	
Ottmar et al. (1990)	Cascade Range (Oregon)	Douglas-fir – hemlock		+
Ottmar et al. (1998)	Interior Pacific Northwest (United States)	Mixed conifer (with mortality), western juniper, sagebrush, grassland	+	
Ottmar et al. (2000a)	Southwest (United States)	Piñon–juniper, sagebrush, chaparral	+	
Ottmar et al. (2000b)	Rocky Mountains (United States)	Lodgepole pine, quaking aspen, gambel oak	+	
Ottmar et al. (2002)	Lake States (United States)	Jack pine	+	
Ottmar et al. (2003a)	Southeast (United States)	Sand hill, sand pine scrub, hardwoods – white pine	+	
Ottmar et al. (2004b)	Western United States	Oregon white oak, California deciduous oak, mixed conifer (with shrub)	+	
Ottmar et al. (2007a)	Central Montana	Sagebrush with grass, ponderosa pine–juniper	+	
Ottmar et al. (2007b)	Southern Arizona and New Mexico	Oak – juniper	+	
Ottmar et al. (2010)	Eastern Oregon	Sagebrush	+	
Popp and Lundquist (2006)	Southern Wyoming	Lodgepole pine, mixed conifer, spruce – fir	+	+
Reeves (1988)	Eastern Texas	Grass, clear-cut, seed tree, loblolly pine, shortleaf pine, loblolly/shortleaf pine, slash pine, longleaf pine, and hardwood	+	+
Sanders and Van Lear (1988)	South Carolina	Mixed pine – hardwood clear-cuts		+
Scholl and Waldrop (1999)	Southeast, Upper Coastal Plain (United States)	Loblolly pine, longleaf pine		+
Stebleton and Bunting (2009)	Great Basin (United States)	Sagebrush steppe and juniper woodlands	+	
Stocks et al. (1990)	Northern Ontario	Jack pine, black spruce, white spruce, trembling aspen, mixedwood	+	
USDA Forest Service (1997)	Southwest (United States)	Ponderosa pine (precommercial thinning, partial cut, natural), white fir, juniper, mixed conifer	+	+
Vihnanek et al. (2009)	Southeast (United States)	Post-hurricane	+	
Wade et al. (1993)	South Carolina	Longleaf pine, loblolly pine (post-hurricane)	+	
Wearn et al. (1982)	Northeastern Ontario	Boreal mixedwood		+
Weise et al. (1997)	Sierra Nevada (California)	Giant sequoia	+	
Wilcox et al. (1982)	Northeast United States	Northern hardwood, oak–hickory	+	+
Wright et al. (2002)	Hawaii	Grassland, shrubland, woodland, forest	+	
Wright et al. (2006)	Northeast United States	Hardwood, pitch pine, red spruce – balsam fir	+	

[a]Activity fuels are residues resulting from land management activities such as clear-cutting and thinning.

METHODS

Study Area and Site Selection

The study area was located in the Hay River District of the South Slave Forest Region, Northwest Territories. The stands were selected within the rectangular zone delimited by 61º36′00″N, 117º12′00″W and 61º03′06″N, 119º11′01″W (Fig. 2). This area is part of the Upper Mackenzie (B.23a) forest region described by Rowe (1972) and of the Hay River Lowland (64) ecoregion of the Taiga Plains ecozone (Ecological Stratification Working Group 1995).

The jack pine – black spruce forest-stand type represented in this fuel photo guide is best described as a variant of forest cover type 1 (jack pine) as defined by the Society of American Foresters (Eyre 1980). In this forest-stand type, the black spruce establishes following fire at the same time as the jack pine but commonly remains confined to the understory for many decades because of its generally slower growth rate. White spruce (*Picea glauca* (Moench) Voss), trembling aspen (*Populus tremuloides* Michx.), and, to a certain extent, balsam poplar (*Populus balsamifera* L.) may also be present as minor components of a given stand.

The study area is classified as having a subhumid midboreal ecoclimate and is characterized by short, warm summers and long, cold winters. The annual temperature is about −2.5°C, and the region receives, on average, 350–450 mm of precipitation each year (Ecological Stratification Working Group 1995). The fire weather and fire danger climatology of the study area were described in detail by Lavoie et al. (2007).

The stands selected for the fuel photo guide originated from stand-replacing crown fires, were located on flat terrain, and belonged to the same chronosequence (i.e., they were taken to represent different ages in the same successional sequence). The site index, representing the potential height reached at 50 years, was 13.2 m and was the same for all stands of the chronosequence. This site index corresponds to Plonski's (1974) site class 3 and the low productivity class (site index below 14 m) of Béland and Bergeron (1996).

Careful site selection and stem analysis were used to maximize the likelihood that these stands belonged to the same continuum of stand development (Lavoie 2004). Tree rings in the ground-level sections used for stem analysis were counted to determine the time since fire or the stand age for the four sampled stands that were more than 20 years old.

The well-documented mature (71 years old) jack pine – black spruce stand (Alexander et al. 2004) studied during the International Crown Fire Modelling Experiment (ICFME) (Stocks et al. 2004a) is located in the same study area (Fig. 2) and was chosen as a reference point for the chronosequence; it was designated as site P10. Three of the sampled stands in the fuel photo guide (sites P9, P8, and P6, for periods of 1, 2, and 3 years, respectively, since fire) were associated with experimental plots burned during the ICFME project (Stocks et al. 2004b). Fire history information supplied by the Government of the Northwest Territories was used to date the 5-year-old stand (site P14).

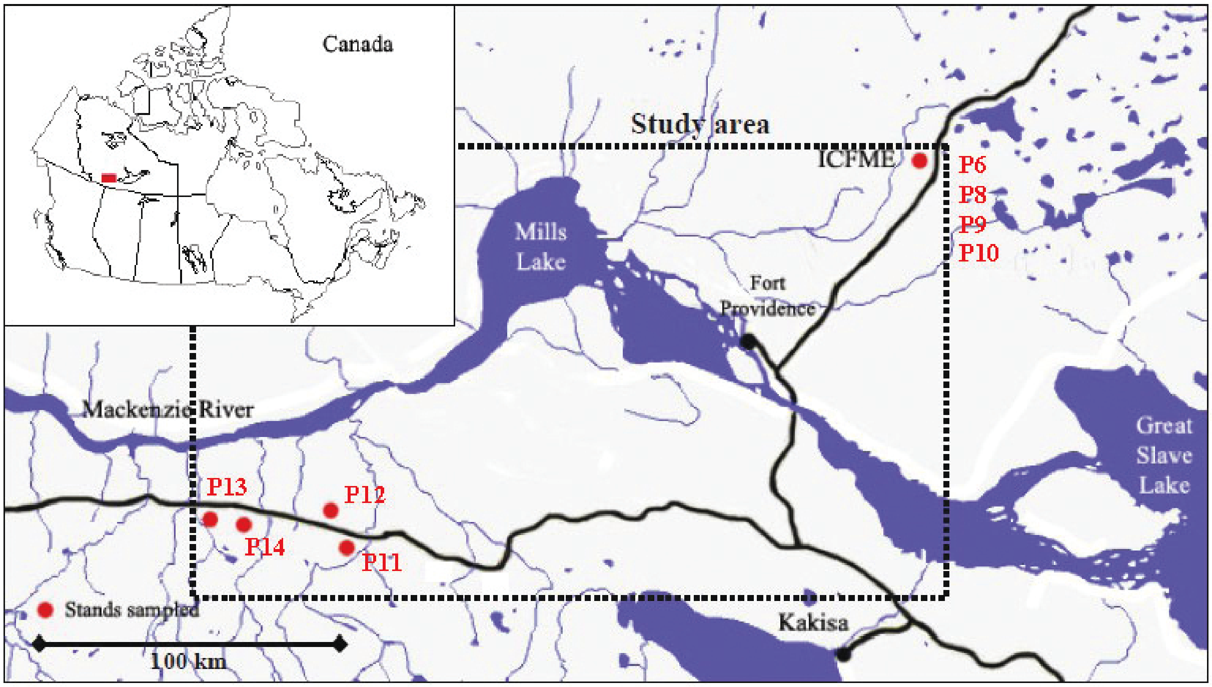


Figure 2. Map of the general study area in the Northwest Territories, Canada. The study area is denoted by the red rectangular box in the inset map of Canada. In the main map, the red dots represent the general locations of the sampled stands (designated by the letter P combined with a number). The location of the research site for the International Crown Fire Modelling Experiment (ICFME) is also indicated. The reference stand (P10, at 71 years since fire) and three additional stands (P9 for 1 year since fire, P8 for 2 years since fire, and P6 for 3 years since fire) were all located within the ICFME study site. In addition, site P14 represented 5 years since fire, site P12 represented 21 years since fire, site P11 represented 57 years since fire, and P13 represented 108 years since fire.

Stand and Fuel Characteristics

Ground, surface, ladder, and crown fuels were systematically inventoried in each of the sampled stands (Fig. 3). The sampling methods used were chosen to be compatible, whenever possible, with the measurements made on the experimental plots associated with the ICFME project (Alexander et al. 2004) and with the standards of the Canadian Forest Service (CFS) fire research group. The information presented in the photo series for each stand and fuel characteristic represents the mean value of measurements for a given stand.

The overstory trees, defined as stems with diameter at breast height (DBH) of 3.0 cm or more (Alexander et al. 2004), were inventoried using the point-centered quarter method (Cottam and Curtis 1956; Mueller-Dombois and Ellenberg 1974; Mitchell 2005). At least 23 sampling points were systematically located in each sampled stand. At each sampling point, the total height and the live crown base height (LCBH) of the four trees selected for point-centered quarter purposes were measured with a clinometer. The DBH of each tree was measured with a diameter tape, and the species and status (live or dead) were noted. Finally, the percent canopy cover was measured at each sampling location in each stand with a convex spherical densiometer (Lemmon 1957).

The understory trees, defined as stems with DBH less than 3.0 cm, were inventoried at alternate sampling points (11 or 12 in total) using a circular fixed plot with radius 2 m (Avery 1967). The same measurements were taken for these trees as for the overstory trees, except that for trees with a total height of less than 1.3 m, diameter at the base of the tree (i.e., at ground level) was measured instead of DBH.

The data for the overstory and understory tree stems allowed calculation of stand density, stand basal area, average DBH, average height, and average LCBH for the live and dead trees of all species present in the sampled stands and the summation of those values for the stand as a whole. This information, combined with

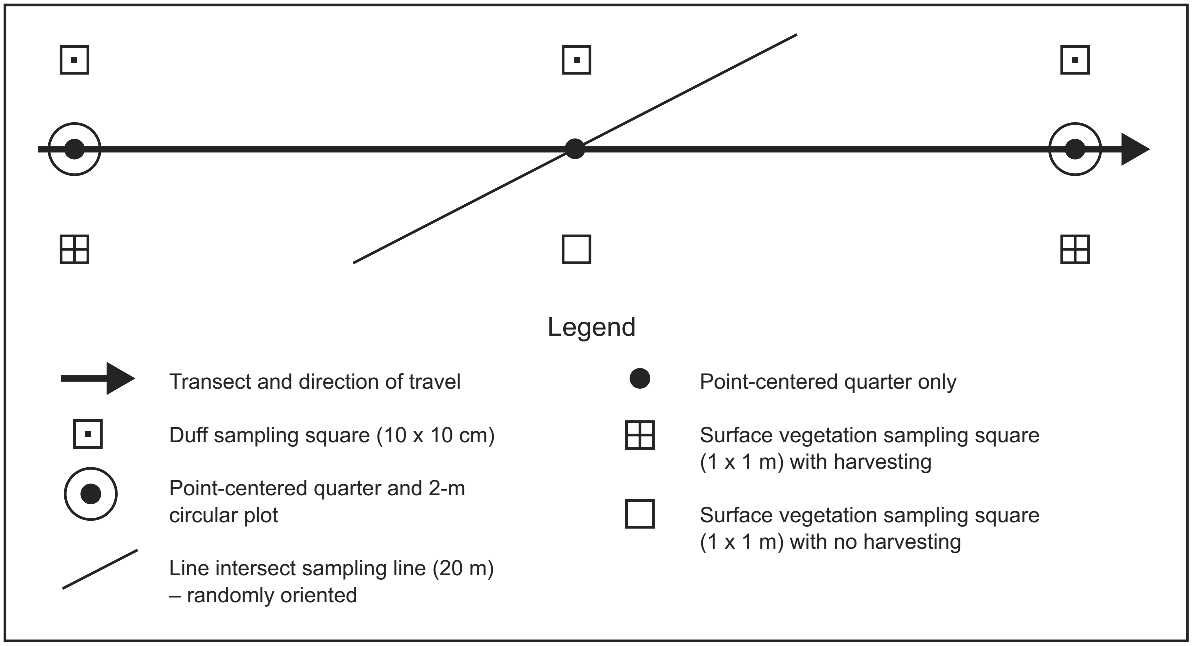


Figure 3. Layout of transect used to sample stands for the fuel photo guide.

allometric tree crown biomass equations (Lavoie 2004), yielded the vertical distribution profile of the load and bulk density of the fine, fire-carrying ladder and crown fuels (i.e., needles, bark flakes, and live and dead branches less than 0.5 and 0.5–1.0 cm in diameter) in each stand.

Dead and downed woody debris was measured using the line (or planar) intersect method (Van Wagner 1968, 1982; Brown 1974; Brown et al. 1982). A minimum of 11 randomly oriented 20-m long transects were located along a main transect within each sampled stand. The diameter of each woody fuel particle at the point of intersection with the randomly oriented 20-m line intersect sampling line determined its roundwood size class. Twigs and branches less than 7.0 cm in diameter were tallied; if required a "go-no-go gauge" (Brown 1974), with openings of 0.5, 1.0, 3.0, 5.0, and 7.0 cm (McRae et al. 1979), was used as a guide. The roundwood size classes followed the metric classification scheme used by the CFS fire research group (McRae et al. 1979; Van Wagner 1982). Herein they are defined as <0.5, 0.5–1.0, 1.0–3.0, 3.0–5.0, and 5.0–7.0 cm, although it is readily acknowledged that these class limits should, strictly speaking, be mutually exclusive (i.e., they should be expressed as <0.5, 0.50–0.99, 1.0–2.99, 3.00–4.99, and 5.00–6.99 cm).

Calipers were used to measure the diameter of any downed log with a diameter of 7.0 cm or more that was found to be intersecting the sampling line. The tree species and condition (i.e., sound or decayed) of each sampled log was noted. For consistency with the methods of Alexander et al. (2004) for the ICFME project, the equations and constants presented by Nalder et al. (1999) were used for computing dead and downed roundwood fuel loads.

A minimum of eight 1 × 1 m quadrats were used to inventory the surface vegetation. The percent cover, to the nearest 1%, of the species present in each quadrat was first determined through an ocular estimate from above, and average height was measured to the nearest centimeter with a metric ruler. The species constituting the surface vegetation were identified in the field following Johnson et al. (1995) and Porsild and Cody (1980); a list of common and scientific names is given in Appendix 1. Only the most common mosses and lichens, in terms of percent cover, were identified. At every second sampling point, all of the vegetation (except for mosses and lichens, which were included in the forest floor sampling) was harvested by clipping at ground level and was then sorted into herbs or shrubs. All of the clipped samples were taken to the laboratory and oven-dried at 85ºC to constant weight. These dry weights were then expressed as fuel loads (kg/m^2). In the 2- to 5-year-old sampled stands, tree seedlings (regardless of height) were also considered in the 1 × 1 m quadrats. They were counted by species to determine their density, and their heights were measured. It was assumed that all of the understory vegetation, including tree seedlings, was less than 0.5 cm in diameter or thickness.

The ground fuels sampled consisted of the litter, fermentation, and humus layers of the forest floor at each site. At each sampling point, a 10 × 10 cm square was delimited. Using a sharp knife and scissors, the forest floor profile was sectioned into 2-cm depth class intervals (Stocks 1987a, 1987b, 1989; Alexander et al. 2004). At the four corners of each sampling square, the total depth of the humus layer was measured, and those measurements were averaged. Each layer was carefully transferred into a metal tin, which was then sealed. The samples were transported to the laboratory, where they were oven-dried at 85ºC to constant weight. They were then weighed to obtain final dry weights. This sampling procedure provided information on the total depth, load (i.e., dry weight per unit area), and bulk density (i.e., dry weight per unit volume) of each sampled segment or layer and for the forest floor as a whole.

Photo Documentation

General guidelines regarding the photography of forest fuel complexes presented by Maxwell and Ward (1980b), Fischer (1981a), and Ottmar and Vihnanek (1998) were followed where applicable. For this project, a pictorial catalog (Muraro 1971) was developed by taking photographs in each plot that was inventoried. A representative portion of the stand was selected in the area where fuels had been assessed. A 1.8-m long range pole, with alternating 30.5 cm wide sections painted in contrasting colors (i.e., black and white), was located 10 m in front of the camera to serve as a reference and to provide scale (cf. Stocks et al. 1990; DeGroot 1993). The Canadian Forest Fire Danger Rating System logo sign (DeGroot 1993), measuring 30 × 30 cm, was mounted to the range pole. Single and stereopair photographs were taken using a 35-mm digital camera. The three-dimensional image provided by the stereopair photos greatly improved the ability to assess the fire-fuels and forest structure in each sampled stand.

A representative close-up photograph of the bark flakes on the lower portion of the trees (i.e., in the trunk space of each stand) was taken at “eye level” (i.e., about 1.5 m above ground). Observations of the experimental fires carried out during the ICFME research project (Stocks et al. 2004b; Taylor et al. 2004) reaffirmed the significant role of bark flakes as a ladder fuel in the development of vertical fire and crowning (Lawson 1973; Alexander 1998) and as a source of firebrands in spotting (Muraro 1971; Quintilio et al. 1977).

RESULTS

The quantitative data summaries for the ground, surface, ladder, and crown fuel strata and the associated photo documentation for each of the eight sampled stands are presented in Figures 4 to 11. The order of the fuel photo guide follows the development of a jack pine – black spruce stand through time after a stand-replacing fire (i.e., 1, 2, 3, 5, 21, 51, 71, and 108 years). Table 2 provides explanatory information about the site, stand, and fuel characteristics presented in the fuel photo guide. The statistical summary presented in Table 3 gives some indication of the variability in fuel characteristics within a single stand age and between stand ages.

The composite figure for each sampled stand is presented on facing pages. The first page contains photos of the general stand profile, an in-stand view, the close-up view of bark flakes, basic data about the site and stand, data on the vertical distribution of ladder and crown fuels, and the quantitative description of stand structure and composition. The graphic display of the data for vertical distribution of fuels (i.e., in 1-m vertical layers) allows for the simultaneous display of both fuel load and bulk density (Alexander et al. 2004; Stocks et al. 2004b).

The second page of each figure includes the stereopair photographs, the attributes of ground and surface fuels, and a summary of the entire fuel complex. In this series, the high density of live trees in the stands up to 5 years old reflects the postfire regeneration response of jack pine (de Groot et al. 2004a, 2004b).

Fuel loads in this report are reported in kilograms per square meter (kg/m^2), as suggested "for general use" by Van Wagner (1978). To convert kilograms per square meter to tonnes per hectare (t/ha) for a large-scale mental image, the value should be multiplied by 10 (i.e., 1.0 kg/m^2 = 10 t/ha). Similarly, for fuel bulk density, Van Wagner (1978) suggested kilograms per cubic meter (kg/m^3) for general use and grams per cubic centimeter (g/cm^3) for a small-scale mental image.

The "fines" component of the ground fuel strata available for combustion was assumed for the purposes of this report to be the top 2.0 cm of the forest floor (typically encompassing the litter layer), given the mean depth of burning observed during the ICFME experimental fires (Stocks et al. 2004b). This layer of the forest floor was therefore absent from the sampled stands for the periods from 1 to 5 years since fire (Figs. 4–7) but was present in the sampled stands for the periods from 21 to 108 years since fire (Figs. 8–11).

For the surface fuels, the "fines" were considered to be the sum of the dead and downed woody fuels less than 1.0 cm in diameter and the understory vegetation (Hunt and Crock 1987; Sneeuwjagt and Peet 1998). With respect to the ladder and crown fuels, the fines or available fuel load was presumed to comprise the total amount of bark flakes, needles, and live and dead twigs less than 1.0 cm in diameter.

Table 2. User notes to the fuel photo guide for quantitatively assessing forest fuel characteristics in a jack pine – black spruce chronosequence[a]

Site information	+ All the stands were part of the same chronosequence. + All of the data in this section is the same for the eight sites represented by the photo series, except for location and elevation of the stand.
Stand information	+ The data presented for each "time since fire" was collected for the specific site identified in the field "Site ID" (for site identification). + The site index, representing the potential height reached by the stand at 50 years based on dominant and codominant trees, was the same for all stands of the chronosequence. + All stands were located on flat terrain and had no slope (and thus no aspect or slope exposure).
Vertical distribution of the canopy fine fuels	+ The graph presents in 1-m sections six fine fuel components: needles, jack pine bark flakes, and two roundwood diameter classes (<0.5 and 0.5–1.0 cm) for both live branches (LBr) and dead branches (DBr). + Data for both fuel load and bulk density are displayed in the graph.
All trees	+ Average tree density is first presented for overstory, understory, and seedlings (all species and conditions grouped). + Average tree density is then redistributed by status (live or dead) and by species, where Pine = jack pine, Spruce = black spruce with a minor component of white spruce, and Aspen = trembling aspen with a minor component of balsam poplar. Total is presented for all trees. + Average basal area is presented according to species and condition. Total is presented for all trees.
Overstory/understory trees	+ DBH is the average diameter at breast height (i.e., as measured at about 1.3 m above ground). + DBH and height are presented for live and dead trees. Total is for all trees taken together. + LCBH is the average live crown base height.
Forest floor	+ The bulk density (i.e., dry weight per unit volume) is provided for the whole forest floor profile as well as the top 2.0 cm depth layer. + The fuel load (i.e., dry weight per unit area) is provided for the whole forest floor profile as well as for the top 2.0 cm depth layer. + The average depth of the forest floor represents the entire profile from the top of the litter layer down to the mineral soil.
Dead and downed woody material[b]	+ The fuel load of the dead and downed woody material is presented for six different roundwood diameter classes. The total (sum of the diameter classes) is also provided.
Understory vegetation	+ Average values are provided for fuel quantity or load, percent cover, and maximum height of herbs and shrubs. + The total values provided for the fuel load and percent cover of the understory vegetation include other species that were not part of those two categories. Total fuel load does not include moss and lichen, but total cover does. + A percent cover of "+" for an understory species indicates cover less than 0.5%. All values were rounded to the nearest whole number.
Summary of fuel information[b]	+ The average forest biomass load (excluding roots and woody debris buried in the forest floor) and the load of the "fine" fuels (i.e., fuels <1.0 cm in diameter or thickness) are presented for the four strata of a forest fuel complex considered in the inventory: ground fuels, surface fuels, ladder fuels, and crown fuels. The latter two categories were combined to represent the canopy fuels.

[a]Scientific names of trees and other plants mentioned in this table and in Figures 4–11 are presented in Appendix 1.
[b]Small discrepancies in fuel loads (<0.1 kg/m²) between a listed total and the sum of values is the result of rounding.

Table 3. Sampling statistics associated with the principal characteristics displayed in the fuel photo guide

Fuel information			P9: 1 year since fire			P8: 2 years since fire			P6: 3 years since fire			P14: 5 years since fire		
Stratum	Quantity		*n*[a]	SD[b]	Range	*n*	SD	Range	*n*	SD	Range	*n*	SD	Range
All trees	Canopy cover (%)	Total	24	4	8–22	25	5	13–32	25	4	8–28	28	4	9–29
Overstory trees	DBH[c] (cm)	Total	96	2.5	NA	100	2.7	NA	100	2.7	NA	112	5.9	NA
	Height (m)	Total	64	3.1	NA	100	3.1	NA	100	3.6	NA	112	3.6	NA
	LCBH[d] (m)	Total	NA[e]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Understory trees	Height (m)	Total	85	0.8	NA	127	1.1	NA	131	1.0	NA	1489	0.4	NA
	LCBH (m)	Total	NA	NA	NA	NA	NA	NA	NA	NA	NA	1478	0.2	NA
Forest floor	Bulk density (kg/m^3)	0–2 cm	24	88.1	97.5–553.3	25	124.2	86.0–636.4	25	40.7	81.5–245.5	28	136.8	78.0–682.0
	Bulk density (kg/m^3)	Total	24	90.3	94.6–553.3	25	126.5	82.5–636.4	25	37.3	88.1–242.9	28	131.1	102.3–682.0
	Load (kg/m^2)	0–2 cm	24	1.1	0.8–4.7	25	0.8	1.0–4.6	25	1.0	0.9–4.9	28	1.4	1.6–7.0
	Load (kg/m^2)	Total	24	1.4	0.8–5.2	25	2.3	1.0–9.1	25	3.5	0.9–14.4	28	2.1	2.1–9.1
	Depth (cm)	Total	24	1.0	0.2–3.6	25	1.8	0.3–6.3	25	2.3	0.8–9.7	28	1.6	1.0–7.5
Dead and downed woody debris	Load (kg/m^2)	<0.5	11	0.002	0.000–0.006	12	0.002	0.000–0.007	12	0.001	0.000–0.002	14	0.050	0.000–0.173
	Load (kg/m^2)	0.5–1.0	11	0.004	0.000–0.014	12	0.004	0.002–0.016	12	0.003	0.000–0.011	14	0.033	0.005–0.116
	Load (kg/m^2)	1.0–3.0	11	0.048	0.055–0.197	12	0.060	0.034–0.227	12	0.061	0.044–0.210	14	0.078	0.023–0.323
	Load (kg/m^2)	3.0–5.0	11	0.099	0.085–0.383	12	0.115	0.044–0.442	12	0.114	0.000–0.387	14	0.132	0.000–0.448
	Load (kg/m^2)	5.0–7.0	11	0.151	0.096–0.578	12	0.155	0.000–0.495	12	0.200	0.097–0.680	14	0.174	0.000–0.600
	Load (kg/m^2)	>7.0	11	0.609	0.210–1.918	12	0.256	0.000–0.862	12	0.673	0.000–1.947	14	1.188	0.000–4.402
	Load (kg/m^2)	Total	11	0.740	0.488–2.797	12	0.301	0.540–1.368	12	0.704	0.395–2.618	14	1.528	0.088–5.503
Understory vegetation	Load (kg/m^2)	Herbs	11	0.006	0.001–0.018	13	0.007	0.001–0.025	13	0.019	0.003–0.068	14	0.059	0.012–0.247
	Load (kg/m^2)	Shrubs	11	0.015	0.000–0.042	13	0.009	0.001–0.030	13	0.058	0.000–0.201	14	0.079	0.010–0.279
	Load (kg/m^2)	Total	11	0.019	0.003–0.057	13	0.014	0.002–0.055	13	0.051	0.017–0.203	14	0.117	0.072–0.493

Table 3. Concluded

Fuel information			P12: 21 years since fire			P11: 57 years since fire			P10: 71 years since fire			P13: 108 years since fire		
Stratum	Quantity		*n*	SD	Range	*n*	SD	Range	*n*	SD	Range	*n*	SD	Range
All trees	Canopy cover (%)	Total	25	14	17–75	25	11	27–67	25	7	20–48	23	11	31–70
Overstory trees	DBH (cm)	Total	100	1.2	NA	100	2.2	NA	1012	5.4	NA	92	5.6	NA
	Height (m)	Total	100	0.8	NA	99	2.3	NA	1011	3.3	NA	92	4.2	NA
	LCBH (m)	Total	99	0.6	NA	89	1.7	NA	688	3.8	NA	74	3.8	NA
Understory trees	Height (m)	Total	694	1.5	NA	582	1.0	NA	1152	1.1	NA	278	0.5	NA
	LCBH (m)	Total	454	1.1	NA	535	0.5	NA	898	0.5	NA	258	0.3	NA
Forest floor	Bulk density (kg/m^3)	0–2 cm	25	31.7	52.0–171.1	25	24.1	30.5–140.0	24	21.3	16.5-110.0	23	36.6	8.0–133.5
	Bulk density (kg/m^3)	Total	25	45.3	59.4–239.2	25	45.8	26.2–252.1	24	42.3	54.1-200.9	23	28.2	11.5–146.7
	Load (kg/m^2)	0–2 cm	25	0.5	1.0–3.1	25	0.5	0.6–2.8	24	0.4	0.3–2.2	23	0.7	0.2–2.7
	Load (kg/m^2)	Total	25	2.9	1.6–13.1	25	3.7	2.1–14.4	24	6.0	2.0–23.7	23	6.8	0.7–35.2
	Depth (cm)	Total	25	1.4	1.2–7.6	25	1.8	2.5–9.9	24	2.9	3.0–12.0	23	5.2	5.3–24.0
Dead and downed woody debris	Load (kg/m^2)	<0.5	12	0.012	0.005–0.050	12	0.006	0.012–0.034	89	0.009	0.019–0.061	11	0.007	0.008–0.031
	Load (kg/m^2)	0.5–1.0	12	0.014	0.022–0.060	12	0.021	0.027–0.094	89	0.013	0.010–0.062	11	0.018	0.011–0.074
	Load (kg/m^2)	1.0–3.0	12	0.118	0.055–0.504	12	0.113	0.218–0.540	89	0.085	0.023–0.476	11	0.086	0.000–0.306
	Load (kg/m^2)	3.0–5.0	12	0.161	0.043–0.596	12	0.244	0.000–0.759	89	0.132	0.000–0.678	11	0.066	0.000–0.229
	Load (kg/m^2)	5.0–7.0	12	0.363	0.000–0.964	12	0.173	0.000–0.598	89	0.230	0.000–1.440	11	0.112	0.000–0.305
	Load (kg/m^2)	>7.0	12	1.618	0.107–4.816	12	0.506	0.000–1.354	89	0.754	0.000–3.283	11	0.523	0.000–1.534
	Load (kg/m^2)	Total	12	1.904	0.805–6.098	12	0.542	0.331–2.041	89	0.930	0.344–4.469	11	0.628	0.077–2.183
Understory vegetation	Load (kg/m^2)	Herbs	12	0.006	0.001–0.019	12	0.019	0.007–0.073	8	0.024	0.004–0.075	11	0.030	0.001–0.084
	Load (kg/m^2)	Shrubs	12	0.115	0.000–0.400	12	0.010	0.001–0.033	8	0.028	0.000–0.083	11	0.136	0.000–0.416
	Load (kg/m^2)	Total	12	0.118	0.003–0.419	12	0.025	0.011–0.087	8	0.031	0.006–0.086	11	0.133	0.001–0.417

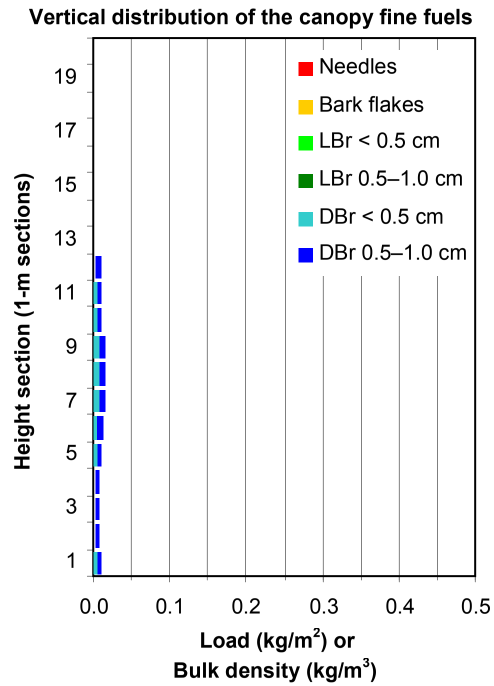
[a] *n* = sample size.
[b] SD = standard deviation.
[c] DBH = diameter at breast height.
[d] LCBH = live crown base height.
[e] NA = not applicable.

Site information

Site location:	61° 36'N, 117° 12'W
Elevation:	195 m
Prov./Territ.:	Northwest Territories
Forest region:	Upper Mackenzie (B.23a)
Ecoregion:	Hay River Lowland (64)
Ecozone:	Taiga Plains

Stand information

Site ID:	P9
Main tree species:	Jack pine, black spruce
Time since fire:	1 year
Crown closure:	15%
Site index (50 years):	13.2 m
Slope:	0%



All trees

Density (stems/ha)	Overstory	Understory	Seedlings
	6 299	5 637	149 565

		Pine	Spruce	Aspen	Total
Density (stems/ha)	Live	149 565	0	0	161 501
	Dead	7 032	4 903	0	
Basal area (m^2/ha)	Live	–	–	–	29.3
	Dead	28.2	1.2	–	

Overstory trees (≥ 3 cm DBH)

		Pine	Spruce	Aspen	Total
DBH (cm)	Live	–	–	–	7.2
	Dead	7.4	4.2	–	
Height (m)	Live	–	–	–	9.8
	Dead	10.5	5.8	–	
LCBH (m)	Live	–	–	–	–

Understory trees (< 3 cm DBH)

		Pine	Spruce	Aspen	Total
Height (m)	Live	–	–	–	1.2
	Dead	0.6	1.4	–	
LCBH (m)	Live	–	–	–	–

Figure 4a. Photos and accompanying site, stand, and vertical fuel information for jack pine – black spruce stand: 1 year after fire. DBH = diameter at breast height, DBr = dead branches, ID = identification, LBr = live branches, LCBH = live crown base height. Note: 1.0 kg/m^2 = 10 t/ha.

Forest floor

Depth (cm)	Bulk density (kg/m^3)	Fuel load (kg/m^2)	Avg. depth (cm)
< 2.0	193.2	2.3	
Total	189.8	2.6	1.6

Dead and downed woody material

Diameter (cm)	Load (kg/m^2)	Diameter (cm)	Load (kg/m^2)
< 0.5	0.00	3.0–5.0	0.21
0.5–1.0	0.01	5.0–7.0	0.33
1.0–3.0	0.11	> 7.0	0.91
		Total	1.58

Understory vegetation

	Load (kg/m^2)	Cover (%)	Avg. height (cm)	Max. height (cm)
Herbs	0.01	4.7	8.7	40.0
Shrubs	0.02	6.6	18.4	35.0
Total	0.02	11.3		

Main species (avg. % cover)
Prickly rose (3), willow (3), Bicknell's geranium (2), twinflower (1), shrubby cinquefoil (+), small bedstraw (+)

Summary of fuel information

Fuel complex stratum	Fine fuels load (kg/m^2)	Total biomass load (kg/m^2)
Ground	0.00	2.62
Surface	0.03	1.60
Ladder and crown	0.14	14.93
Total	0.17	19.15

Figure 4b. Photos and accompanying ground and surface fuel information for jack pine – black spruce stand: 1 year after fire. Note: 1.0 kg/m^2 = 10 t/ha.

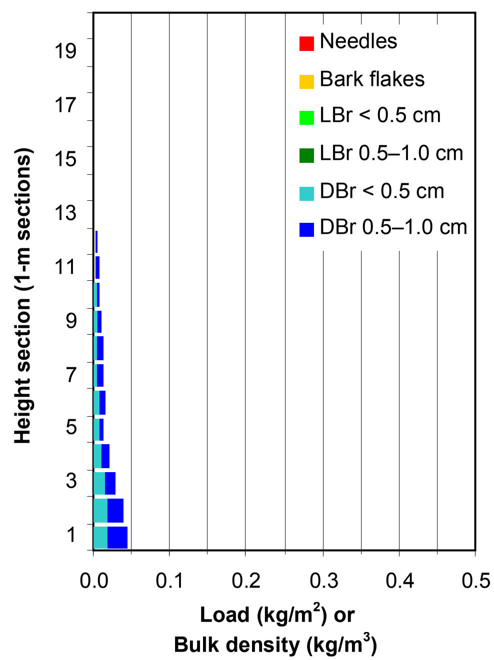
Site information

Site location:	61° 36'N, 117° 12'W
Elevation:	195 m
Prov./Territ.:	Northwest Territories
Forest region:	Upper Mackenzie (B.23a)
Ecoregion:	Hay River Lowland (64)
Ecozone:	Taiga Plains

Stand information

Site ID:	P8
Main tree species:	Jack pine, black spruce
Time since fire:	2 years
Crown Closure:	19%
Site index (50 years):	13.2 m
Slope:	0%

Vertical distribution of the canopy fine fuels



All trees

Density (stems/ha)	Overstory	Understory	Seedlings
	8 885	7 774	88 800

		Pine	Spruce	Aspen	Total
Density (stems/ha)	Live	84 800	4 000	0	105 459
	Dead	4 059	12 600	0	
Basal area (m^2/ha)	Live	–	–	–	31.5
	Dead	22.1	9.4	–	

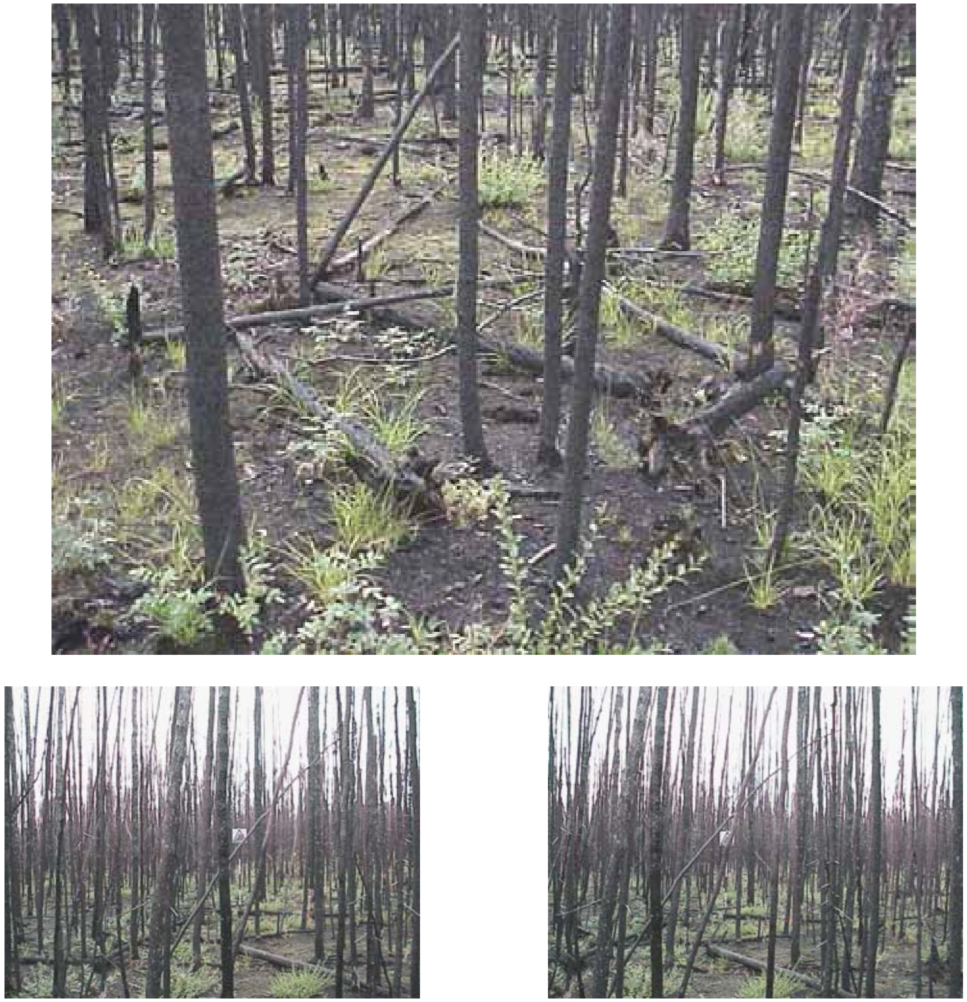
Overstory trees (≥ 3 cm DBH)

		Pine	Spruce	Aspen	Total
DBH (cm)	Live	–	–	–	6.0
	Dead	8.1	4.4	–	
Height (m)	Live	–	–	–	7.6
	Dead	10.0	5.8	–	
LCBH (m)	Live	–	–	–	–

Understory trees (< 3 cm DBH)

		Pine	Spruce	Aspen	Total
Height (m)	Live	–	–	–	2.1
	Dead	1.1	2.2	–	
LCBH (m)	Live	–	–	–	–

Figure 5a. Photos and accompanying site, stand, and vertical fuel information for jack pine – black spruce stand: 2 years after fire. DBH = diameter at breast height, DBr = dead branches, ID = identification, LBr = live branches, LCBH = live crown base height. Note: 1.0 kg/m^2 = 10 t/ha.



Forest floor

Depth (cm)	Bulk density (kg/m³)	Fuel load (kg/m²)	Avg. depth (cm)
< 2.0	185.7	2.7	
Total	181.1	4.4	3.1

Dead and downed woody material

Diameter (cm)	Load (kg/m²)	Diameter (cm)	Load (kg/m²)
< 0.5	0.00	3.0–5.0	0.25
0.5–1.0	0.01	5.0–7.0	0.21
1.0–3.0	0.12	> 7.0	0.28
		Total	0.87

Understory vegetation

	Load (kg/m²)	Cover (%)	Avg. height (cm)	Max. height (cm)
Herbs	0.01	3.0	12.7	50.0
Shrubs	0.01	6.1	21.9	35.0
Total	0.02	17.8		

Main species (avg. % cover)
Fire moss (9), prickly rose (3), willow (3), fireweed (1), sedge (+)

Summary of fuel information

Fuel complex strata	Fine fuels load (kg/m²)	Total biomass load (kg/m²)
Ground	0.00	4.45
Surface	0.02	0.88
Ladder and crown	0.23	13.73
Total	0.25	19.06

Figure 5b. Photos and accompanying ground and surface fuel information for jack pine – black spruce stand: 2 years after fire. Note: 1.0 kg/m^2 = 10 t/ha.

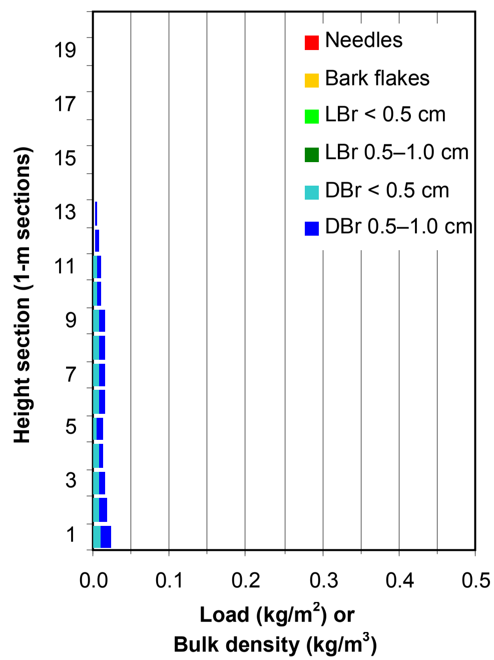
Site information

Site location:	61° 36'N, 117° 12'W
Elevation:	195 m
Prov./Territ.:	Northwest Territories
Forest region:	Upper Mackenzie (B.23a)
Ecoregion:	Hay River Lowland (64)
Ecozone:	Taiga Plains

Stand information

Site ID:	P6
Main tree species:	Jack pine, black spruce
Time since fire:	3 years
Crown closure:	16%
Site index (50 years):	13.2 m
Slope:	0%

Vertical distribution of the canopy fine fuels



All trees

	Overstory	Understory	Seedlings
Density (stems/ha)	8 169	8 019	33 200

		Pine	Spruce	Aspen	Total
Density (stems/ha)	Live	24 400	8 800	0	49 388
	Dead	7 413	8 776	0	
Basal area (m^2/ha)	Live	–	–	–	33.8
	Dead	29.7	4.1	–	

Overstory trees (≥ 3 cm DBH)

		Pine	Spruce	Aspen	Total
DBH (cm)	Live	–	–	–	6.7
	Dead	7.3	4.5	–	
Height (m)	Live	–	–	–	8.3
	Dead	10.3	5.7	–	
LCBH (m)	Live	–	–	–	–

Understory trees (< 3 cm DBH)

		Pine	Spruce	Aspen	Total
Height (m)	Live	–	–	–	1.8
	Dead	1.5	1.8	–	
LCBH (m)	Live	–	–	–	–

Figure 6a. Photos and accompanying site, stand, and vertical fuel information for jack pine – black spruce stand: 3 years after fire. DBH = diameter at breast height, DBr = dead branches, ID = identification, LBr = live branches, LCBH = live crown base height. Note: 1.0 kg/m^2 = 10 t/ha.

Forest floor

Depth (cm)	Bulk density (kg/m^3)	Fuel load (kg/m^2)	Avg. depth (cm)
< 2.0	156.0	2.8	
Total	159.9	6.0	3.9

Dead and downed woody material

Diameter (cm)	Load (kg/m^2)	Diameter (cm)	Load (kg/m^2)
< 0.5	0.00	3.0–5.0	0.21
0.5–1.0	0.01	5.0–7.0	0.36
1.0–3.0	0.11	> 7.0	0.44
		Total	1.12

Understory vegetation

	Load (kg/m^2)	Cover (%)	Avg. height (cm)	Max. height (cm)
Herbs	0.04	15.3	10.0	60.0
Shrubs	0.05	14.2	25.2	45.0
Total	0.08	38.2		

Main species (avg. % cover)
Willow (10), fire moss (9), sedge (4), twinflower (4), prickly rose (3), fireweed (2)

Summary of fuel information

Fuel complex strata	Fine fuels load (kg/m^2)	Total biomass load (kg/m^2)
Ground	0.00	5.99
Surface	0.09	1.21
Ladder and crown	0.19	16.35
Total	0.27	23.55

Figure 6b. Photos and accompanying ground and surface fuel information for jack pine – black spruce stand: 3 years after fire. Note: 1.0 kg/m^2 = 10 t/ha.

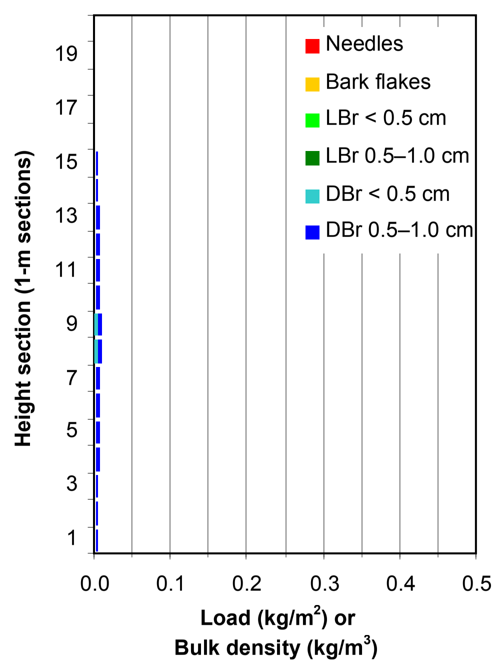
Site information

Site location:	61° 09'N, 119° 05'W
Elevation:	260 m
Prov./Territ.:	Northwest Territories
Forest region:	Upper Mackenzie (B.23a)
Ecoregion:	Hay River Lowland (64)
Ecozone:	Taiga Plains

Stand information

Site ID:	P14
Main tree species:	Jack pine, black spruce
Time since fire:	5 years
Crown Closure:	18%
Site index (50 years):	13.2 m
Slope:	0%

Vertical distribution of the canopy fine fuels



All trees

	Overstory	Understory+Seedlings
Density (stems/ha)	2 097	84 636

		Pine	Spruce	Aspen	Total
Density (stems/ha)	Live	57 637	2 501	23 873	86 733
	Dead	1 442	865	415	
Basal area (m^2/ha)	Live	–	–	0.4	26.9
	Dead	14.9	8.0	3.5	

Overstory trees (≥ 3 cm DBH)

		Pine	Spruce	Aspen	Total
DBH (cm)	Live	–	–	–	11.2
	Dead	10.9	11.4	13.3	
Height (m)	Live	–	–	–	10.3
	Dead	10.4	9.9	10.6	
LCBH (m)	Live	–	–	–	–

Understory trees (< 3 cm DBH)

		Pine	Spruce	Aspen	Total
Height (m)	Live	0.2	0.2	0.8	0.4
	Dead	3.4	1.2	1.9	
LCBH (m)	Live	0.0	0.0	0.5	0.1

Figure 7a. Photos and accompanying site, stand, and vertical fuel information for jack pine – black spruce stand: 5 years after fire. DBH = diameter at breast height, DBr = dead branches, ID = identification, LBr = live branches, LCBH = live crown base height. Note: 1.0 kg/m^2 = 10 t/ha.

Forest floor

Depth (cm)	Bulk density (kg/m^3)	Fuel load (kg/m^2)	Avg. depth (cm)
< 2.0	210.1	3.2	
Total	234.1	5.0	2.6

Dead and downed woody material

Diameter (cm)	Load (kg/m^2)	Diameter (cm)	Load (kg/m^2)
< 0.5	0.04	3.0–5.0	0.13
0.5–1.0	0.03	5.0–7.0	0.16
1.0–3.0	0.13	> 7.0	0.93
		Total	1.42

Understory vegetation

	Load (kg/m^2)	Cover (%)	Avg. height (cm)	Max. height (cm)
Herbs	0.07	35.3	13.6	100.0
Shrubs	0.12	20.0	58.4	140.0
Total	0.24	85.1		

Main species (avg. % cover)
Fire moss (29), prickly rose (13), kinnikinnick (8), rough-leaved rice grass (7), willow (5)

Summary of fuel information

Fuel complex strata	Fine fuels load (kg/m^2)	Total biomass load (kg/m^2)
Ground	0.00	4.97
Surface	0.30	1.65
Ladder and crown	0.13	12.51
Total	0.43	19.12

Figure 7b. Photos and accompanying ground and surface fuel information for jack pine – black spruce stand: 5 years after fire. Note: 1.0 kg/m^2 = 10 t/ha.

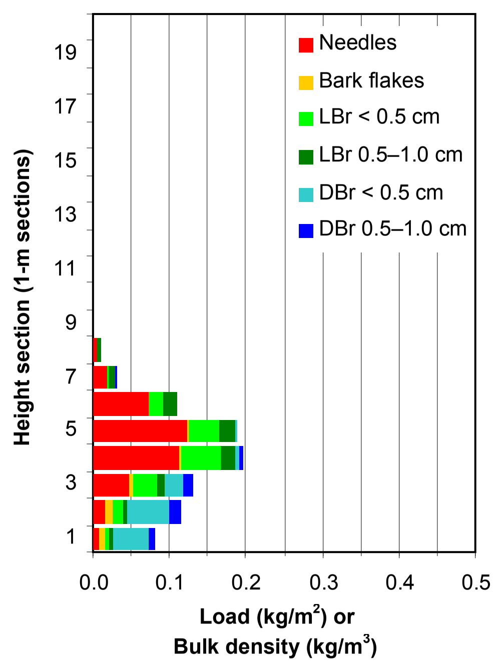
Site information

Site location:	61° 06'N, 118° 50'W
Elevation:	250 m
Prov./Territ.:	Northwest Territories
Forest region:	Upper Mackenzie (B.23a)
Ecoregion:	Hay River Lowland (64)
Ecozone:	Taiga Plains

Stand information

Site ID:	P12
Main tree species:	Jack pine, black spruce
Time since fire:	21 years
Crown closure:	55%
Site index (50 years):	13.2 m
Slope:	0%

Vertical distribution of the canopy fine fuels



All trees

		Overstory	Understory	Seedlings
Density (stems/ha)		8 099	42 482	–

		Pine	Spruce	Aspen	Total
Density (stems/ha)	Live	23 242	6 508	6 058	50 581
	Dead	11 405	367	2 999	
Basal area (m^2/ha)	Live	15.9	0.2	1.3	17.8
	Dead	0.4	0.0	0.0	

Overstory trees (≥ 3 cm DBH)

		Pine	Spruce	Aspen	Total
DBH (cm)	Live	4.3	4.5	3.9	4.3
	Dead	7.0	–	–	
Height (m)	Live	5.1	3.6	5.2	5.1
	Dead	1.7	–	–	
LCBH (m)	Live	2.6	0.0	3.2	2.6

Understory trees (< 3 cm DBH)

		Pine	Spruce	Aspen	Total
Height (m)	Live	2.9	0.5	2.9	1.8
	Dead	0.8	0.5	1.0	
LCBH (m)	Live	2.0	0.0	1.8	1.5

Figure 8a. Photos and accompanying site, stand, and vertical fuel information for jack pine – black spruce stand: 21 years after fire. DBH = diameter at breast height, DBr = dead branches, ID = identification, LBr = live branches, LCBH = live crown base height. Note: 1.0 kg/m^2 = 10 t/ha.

Forest floor

Depth (cm)	Bulk density (kg/m^3)	Fuel load (kg/m^2)	Avg. depth (cm)
< 2.0	90.7	1.7	
Total	132.4	4.8	3.6

Dead and downed woody material

Diameter (cm)	Load (kg/m^2)	Diameter (cm)	Load (kg/m^2)
< 0.5	0.02	3.0–5.0	0.26
0.5–1.0	0.04	5.0–7.0	0.37
1.0–3.0	0.23	> 7.0	1.72
		Total	2.64

Understory vegetation

	Load (kg/m^2)	Cover (%)	Avg. height (cm)	Max. height (cm)
Herbs	0.01	9.3	11.3	35.0
Shrubs	0.05	13.3	64.1	200.0
Total	0.06	24.3		

Main species (avg. % cover)
Prickly rose(6), willow (4), wild strawberry (2), bunchberry (2), fire moss (2), green alder (2)

Summary of fuel information

Fuel complex strata	Fine fuels load (kg/m^2)	Total biomass load (kg/m^2)
Ground	1.69	4.78
Surface	0.12	2.69
Ladder and crown	0.87	3.81
Total	2.68	11.28

Figure 8b. Photos and accompanying ground and surface fuel information for jack pine – black spruce stand: 21 years after fire. Note: 1.0 kg/m^2 = 10 t/ha.

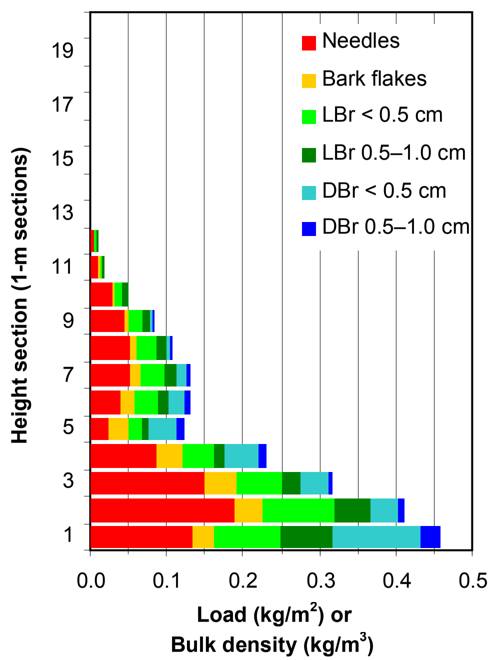
Site information

Site location:	61° 05'N, 118° 44'W
Elevation:	240 m
Prov./Territ.:	Northwest Territories
Forest region:	Upper Mackenzie (B.23a)
Ecoregion:	Hay River Lowland (64)
Ecozone:	Taiga Plains

Stand information

Site ID:	P11
Main tree species:	Jack pine, black spruce
Time since fire:	57 years
Crown closure:	47%
Site index (50 years):	13.2 m
Slope:	0%

Vertical distribution of the canopy fine fuels



All trees

		Overstory	Understory	Seedlings
Density (stems/ha)		6 585	35 626	–

		Pine	Spruce	Aspen	Total
Density (stems/ha)	Live	4 841	33 704	66	42 211
	Dead	2 923	490	188	
Basal area (m^2/ha)	Live	16.5	3.7	0.1	22.0
	Dead	1.5	0.1	0.1	

Overstory trees (≥ 3 cm DBH)

		Pine	Spruce	Aspen	Total
DBH (cm)	Live	6.5	3.8	5.4	5.7
	Dead	4.2	–	3.7	
Height (m)	Live	8.0	4.5	5.0	7.0
	Dead	5.3	–	4.1	
LCBH (m)	Live	4.8	1.7	2.5	4.1

Understory trees (< 3 cm DBH)

		Pine	Spruce	Aspen	Total
Height (m)	Live	4.7	1.3	–	1.5
	Dead	3.3	1.4	3.6	
LCBH (m)	Live	3.0	0.7	–	0.7

Figure 9a. Photos and accompanying site, stand, and vertical fuel information for jack pine – black spruce stand: 57 years after fire. DBH = diameter at breast height, DBr = dead branches, ID = identification, LBr = live branches, LCBH = live crown base height. Note: 1.0 kg/m^2 = 10 t/ha.

Forest floor

Depth (cm)	Bulk density (kg/m^3)	Fuel load (kg/m^2)	Avg. depth (cm)
< 2.0	100.7	2.0	
Total	142.4	7.9	5.5

Dead and downed woody material

Diameter (cm)	Load (kg/m^2)	Diameter (cm)	Load (kg/m^2)
< 0.5	0.02	3.0–5.0	0.24
0.5–1.0	0.06	5.0–7.0	0.15
1.0–3.0	0.34	> 7.0	0.40
		Total	1.21

Understory vegetation

	Load (kg/m^2)	Cover (%)	Avg. height (cm)	Max. height (cm)
Herbs	0.02	17.7	7.4	50.0
Shrubs	0.01	8.2	40.8	106.0
Total	0.04	50.9		

Main species (avg. % cover)
Stair-step moss (19), twinflower (7), prickly rose (5), kinnikinnick (4), bunchberry (3)

Summary of fuel information

Fuel complex strata	Fine fuels load (kg/m^2)	Total biomass load (kg/m^2)
Ground	2.01	7.89
Surface	0.11	1.25
Ladder and crown	2.04	6.91
Total	4.16	16.05

Figure 9b. Photos and accompanying ground and surface fuel information for jack pine – black spruce stand: 57 years after fire. Note: 1.0 kg/m^2 = 10 t/ha.

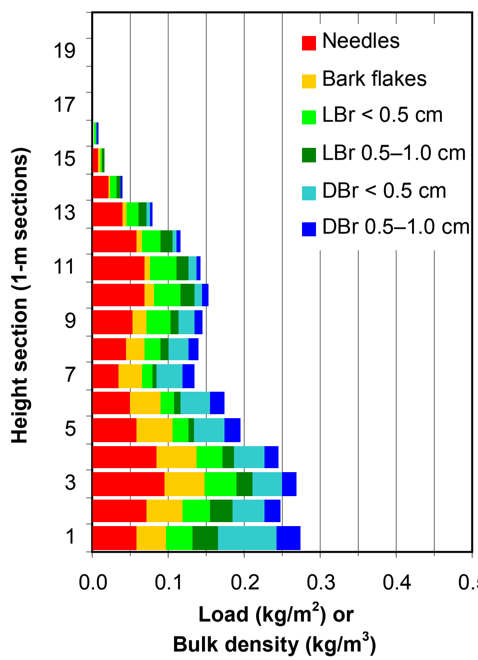
Site information

Site location:	61° 36'N, 117° 12'W
Elevation:	195 m
Prov./Territ.:	Northwest Territories
Forest region:	Upper Mackenzie (B.23a)
Ecoregion:	Hay River Lowland (64)
Ecozone:	Taiga Plains

Stand information

Site ID:	P10
Main tree species:	Jack pine, black spruce
Time since fire:	71 years
Crown closure:	29%
Site index (50 years):	13.2 m
Slope:	0%

Vertical distribution of the canopy fine fuels



All trees

Density (stems/ha)	Overstory	Understory	Seedlings
	6 635	6 649	–

		Pine	Spruce	Aspen	Total
Density (stems/ha)	Live	3 061	6 635	0	13 284
	Dead	2 594	994	0	
Basal area (m^2/ha)	Live	21.9	4.1	0.0	31.7
	Dead	4.9	0.8	0.0	

Overstory trees (≥ 3 cm DBH)

		Pine	Spruce	Aspen	Total
DBH (cm)	Live	9.6	5.2	–	7.2
	Dead	5.3	5.5	–	
Height (m)	Live	11.6	5.7	–	9.1
	Dead	8.1	5.1	–	
LCBH (m)	Live	7.9	1.6	–	5.9

Understory trees (< 3 cm DBH)

		Pine	Spruce	Aspen	Total
Height (m)	Live	4.6	1.6	–	1.7
	Dead	3.2	1.1	–	
LCBH (m)	Live	1.9	0.6	–	0.6

Figure 10a. Photos and accompanying site, stand, and vertical fuel information for jack pine – black spruce stand: 71 years after fire. DBH = diameter at breast height, DBr = dead branches, ID = identification, LBr = live branches, LCBH = live crown base height. Note: 1.0 kg/m^2 = 10 t/ha.

Forest floor

Depth (cm)	Bulk density (kg/m^3)	Fuel load (kg/m^2)	Avg. depth (cm)
< 2.0	65.6	1.3	
Total	125.8	9.4	6.9

Dead and downed woody material

Diameter (cm)	Load (kg/m^2)	Diameter (cm)	Load (kg/m^2)
< 0.5	0.04	3.0–5.0	0.27
0.5–1.0	0.03	5.0–7.0	0.33
1.0–3.0	0.20	> 7.0	0.77
		Total	1.65

Understory vegetation

	Load (kg/m^2)	Cover (%)	Avg. height (cm)	Max. height (cm)
Herbs	0.02	11.9	5.1	15.0
Shrubs	0.01	7.8	29.1	50.0
Total	0.03	40.2		

Main species (avg. % cover)
Stair-step moss (15), kinnikinnick (6), prickly rose (4), twinflower (4), shrubby cinquefoil (3)

Summary of fuel information

Fuel complex strata	Fine fuels load (kg/m^2)	Total biomass load (kg/m^2)
Ground	1.31	9.41
Surface	0.10	1.68
Ladder and crown	2.30	17.72
Total	3.72	28.81

Figure 10b. Photos and accompanying ground and surface fuel information for jack pine – black spruce stand: 71 years after fire. Note: 1.0 kg/m^2 = 10 t/ha.

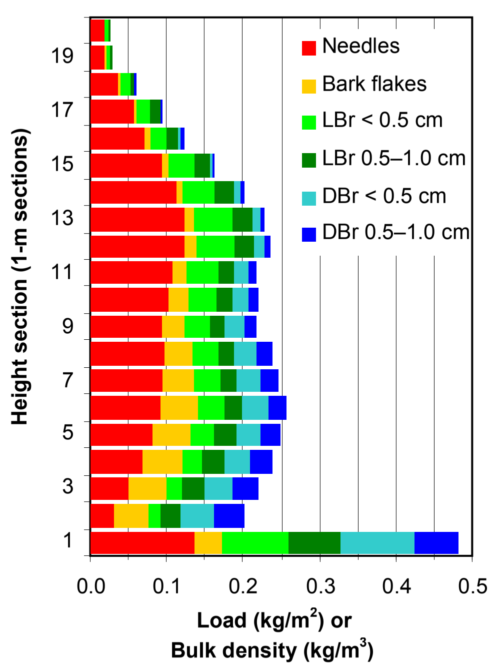
Site information

Site location:	61° 08'N, 119° 11'W
Elevation:	245 m
Prov./Territ.:	Northwest Territories
Forest region:	Upper Mackenzie (B.23a)
Ecoregion:	Hay River Lowland (64)
Ecozone:	Taiga Plains

Stand information

Site ID:	P13
Main tree species:	Jack pine, black spruce
Time since fire:	108 years
Crown closure:	52%
Site index (50 years):	13.2 m
Slope:	0%

Vertical distribution of the canopy fine fuels



All trees

		Overstory	Understory	Seedlings
Density (stems/ha)		2 973	18 435	–

		Pine	Spruce	Aspen	Total
Density (stems/ha)	Live	1 066	18 235	199	21 408
	Dead	519	925	464	
Basal area (m^2/ha)	Live	22.6	16.9	0.1	44.0
	Dead	3.9	0.5	0.0	

Overstory trees (≥ 3 cm DBH)

		Pine	Spruce	Aspen	Total
DBH (cm)	Live	16.1	11.1	–	12.5
	Dead	10.2	6.4	–	
Height (m)	Live	13.8	9.6	–	11.1
	Dead	10.7	5.9	–	
LCBH (m)	Live	9.6	4.4	–	6.7

Understory trees (< 3 cm DBH)

		Pine	Spruce	Aspen	Total
Height (m)	Live	–	0.5	2.7	0.5
	Dead	0.5	0.9	0.8	
LCBH (m)	Live	–	0.1	2.1	0.1

Figure 11a. Photos and accompanying site, stand, and vertical fuel information for jack pine – black spruce stand: 108 years after fire. DBH = diameter at breast height, DBr = dead branches, ID = identification, LBr = live branches, LCBH = live crown base height. Note: 1.0 kg/m^2 = 10 t/ha.

Forest floor

Depth (cm)	Bulk density (kg/m^3)	Fuel load (kg/m^2)	Avg. depth (cm)
< 2.0	35.9	0.7	
Total	71.6	9.9	13.6

Dead and downed woody material

Diameter (cm)	Load (kg/m^2)	Diameter (cm)	Load (kg/m^2)
< 0.5	0.02	3.0–5.0	0.07
0.5–1.0	0.04	5.0–7.0	0.13
1.0–3.0	0.11	> 7.0	0.59
		Total	0.95

Understory vegetation

	Load (kg/m^2)	Cover (%)	Avg. height (cm)	Max. height (cm)
Herbs	0.02	9.3	6.5	35.0
Shrubs	0.11	17.7	80.6	220.0
Total	0.13	95.3		

Main species (avg. % cover)

Stair-step moss (64), green alder (7), prickly rose (6), grass (2), kinnikinnick (2),Canada buffaloberry (2)

Summary of fuel information

Fuel complex strata	Fine fuels load (kg/m^2)	Total biomass load (kg/m^2)
Ground	0.72	9.94
Surface	0.18	1.07
Ladder and crown	3.73	28.40
Total	4.63	39.41

Figure 11b. Photos and accompanying ground and surface fuel information for jack pine – black spruce stand: 108 years after fire. Note: 1.0 kg/m^2 = 10 t/ha.

DISCUSSION AND CONCLUSIONS

Many foresters can readily estimate the basal area of a stand. However, the art of judging fuel loads and bulk densities is not nearly so well developed within the wildland fire management community. By referring to fuel photo guide like the one presented here and others (Table 1), land managers can familiarize themselves with fuel loads and other fuel characteristics at different stand ages (i.e., as the forest stand develops following the occurrence of a crown fire). In addition to being of value in various forms of wildland fire education, training, and research, fuel photo series can also serve a communication function among resource management disciplines. These kinds of applications may well be the most valuable aspect of a fuel photo series.

A fuel photo guide can be used as an inventory tool to quickly, easily and inexpensively estimate quantities of fuels and other characteristics of a fuel complex in situations where a high degree of accuracy is unnecessary. However, the estimation process must still be done with care. Sikkink and Keane (2008) have shown that there can be a tendency to overestimate dead and downed woody fuel loads with the photo series method. However, Wright et al. (2010) considered that Sikkink and Keane's (2008) study design was inadequate to evaluate the accuracy of these methods when measured against a series of reference points. Wright et al. (2010) felt that an incorrect use of the photo series method on the part of Sikkink and Keanne (2008) may have contributed to their inferences about the method. Finally, sampling efficiency was not adequately taken into account when evaluating the overall efficacy of the five fuel sampling methods studied by Sikkink and Keane (2008).

In principle, this operational "fuel cruising" is accomplished by comparing photos in the fuel photo guide to the stand or area of interest and selecting the photo or photos that most nearly match or bracket the situation for a given fuel component or stratum (Fig. 12). In many cases, stands of interest will fall between the ages represented in the photo series, such that interpolations will be necessary. Such interpolation should be done with caution because of the relatively large number of years between sampled stands in some cases (e.g., no stands between 6 and 20 years are depicted in the fuel photo guide) and the fact that the development of fuel characteristics over time may not be linear. However, if interpolation is used carefully, either the entire fuel complex or an individual fuel characteristic (e.g., dead and downed woody material 7.0 cm or more in diameter) can be estimated by this method.

For older stands for which there is no modern fire record (Stocks et al. 2002), users may find it useful to age the stand in question using an increment borer (Grissino-Mayer 2003). This will help in determining the appropriate reference photo when interpolating between the sampled stands displayed in the photo series.

The use of a lens stereoscope (Avery 1977) with the stereopair photos will undoubtedly help in this task. Additional guidance for the interpolation procedure has been prepared by the Fire and Environmental Resource Applications Team (Fire and Environmental Applications Team 2009).

Some fuel characteristics are undistinguishable in the photos (e.g., depth and load of the forest floor or proportions of sound versus decayed logs). This makes it difficult to determine if the conditions shown in a given photograph are representative of the situation encountered in a stand or area of interest. Given that there may be differences in site conditions and disturbance history, it is recommended that quantitative information on such fuel elements be obtained by direct, on-site measurements (Brown 1974; McRae et al. 1979; Brown et al. 1982; Potts et al. 1984) or general field observations.

Most users will be interested in the potential fire behavior of the stands included in this photo guide. Such information has been provided in other fuel photo guides through reliance on experimental fires (e.g., Wade et al. 1993), expert opinion (e.g., Fischer 1981a), and simulation modeling (e.g., Brown and Simmerman 1986; Sandberg and Ward 1981; Ward and Sandberg 1981a, 1981b) based on assumed or measured burning conditions in terms of fuel moisture(s) and wind speed(s). As outlined by Lavoie (2004),

How do you use the fuel photo guide?

In brief, the user undertakes a visual inventory of the site of interest by observing stand and fuel characteristics and then comparing them with the photographs and data in the photo guide.

It is acceptable to use the information from more than one sampled site in the photo guide when making comparisons to the site of interest in the field. For example, one might use a certain sampled site in the photo guide to assess the fuel load of the understory vegetation and a different one to assess tree density to best match the conditions for the site of interest.

Step 1: Observe a particular stand or fuel characteristic (e.g., fuel load of dead and downed woody debris <7.0 cm diameter).

↓

Step 2: Select a site or sites from the photo guide that nearly matches or brackets the observed stand or fuel characteristic.

↓

Step 3: Estimate the stand or fuel characteristic being evaluated on the basis of the data summary associated with the photo guide site by interpolation between sites.

↓

Step 4: Repeat steps 1–3 for each stand and fuel characteristic of interest.

Figure 12. General instructions and associated flow chart for using the fuel photo guide to quantitatively assess the characteristics of forest fuels in a jack pine – black spruce chronosequence. Note that certain fuel characteristics are indistinguishable in the photographs (e.g., depth of the forest floor); in this situation, some limited field sampling and/or field observations may be required. Note: 1.0 kg/m^2 = 10 t/ha.

all three of these approaches have been used in assessing the fire potential of the eight sampled stands included in this fuel photo guide (Lavoie 2004; Lavoie and Alexander 2004; Stocks et al. 2004b). Other publications are currently in preparation that will make the information about fire behavior generated by the Lavoie (2004) study more readily accessible to fire and resource managers.

Although quantification of fuel will not allow direct prediction of fire behavior, knowledge of basic fuel characteristics such as available surface fuel load, LCBH, and canopy bulk density does give some indication of crowning potential (Van Wagner 1977; Alexander et al. 2006). Furthermore, measures of the depth of the forest floor, the amount of dead and downed woody fuel, and other stand characteristics allow for judgments of resistance to fireguard construction (Murphy and Quintilio 1978; Ponto 1990).

This photo guide was developed for a particular forest cover type in the south-central part of the Northwest Territories but could be of value in other areas of Canada and perhaps even regions of the United States (e.g., the Lake States region) where similar fuel and stand conditions are encountered. One improvement that could be made to the present fuel photo guide would be to address the acknowledged data gap for stands 6–20 years old. This could be easily rectified by sampling some of the burned areas created by the ICFME experimental crown fires carried out between 1997 and 2000 (Stocks et al. 2004b). Despite this gap in data, the present publication augments the existing fuel photo guides of Canadian and US forest cover and vegetation types (Table 1).

There is a paucity of data on the characteristics of fuel complexes throughout Canada's forest regions. Additional fuel photo guide are needed to document the full range of fuel conditions along the chronosequence of other forest cover types, before and after natural or anthropogenic disturbances (e.g., fire, insect and disease outbreaks, and fuel treatments). This kind of information will be of value in the development and application of the next-generation fire danger rating system in Canada and in other environmental matters such as carbon accounting.

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APPENDIX 1

SCIENTIFIC AND COMMON NAMES OF THE PLANT SPECIES ASSOCIATED WITH THE FUEL PHOTO GUIDE

Scientific name	Common name
Trees and shrubs	
Alnus viridis ssp. *crispa* (Ait.) Turrill	Green alder
Arctostaphylos uva-ursi (L.) Spreng	Kinnikinnick
Picea glauca (Moench) Voss	White spruce
Picea mariana (Mill.) BSP	Black spruce
Pinus banksiana Lamb.	Jack pine
Populus balsamifera L.	Balsam poplar
Populus tremuloides Michx.	Trembling aspen
Potentilla fruticosa L.	Shrubby cinquefoil
Rosa acicularis Lindl.	Prickly rose
Salix spp.	Willow
Shepherdia canadensis (L.) Nutt.	Canada buffaloberry
Herbaceous plants	
Carex spp.	Sedge
Cornus canadensis L.	Bunchberry
Epilobium angustifolium L.	Fireweed
Fragaria virginiana Duchesne	Wild strawberry
Galium trifidum L.	Small bedstraw
Geranium bicknellii Britton	Bicknell's geranium
Linnaea borealis L.	Twinflower
Oryzopsis asperifolia Michx.	Rough-leaved rice grass
Mosses and lichens	
Ceratodon purpureus (Hedw.) Brid.	Fire moss
Hylocomium splendens (Hedw.) B.S.G.	Stair-step moss

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