Canopy-Fuel Characteristics of Conifer Forests

Miguel G. Cruz and Martin E. Alexander

Conifer forest stands are comprised of living and dead biomass in four separate fuel strata according to their vertical distribution and effects on fire behavior (see figure 1):

- Ground fuels—principally the duff layer of the forest floor;
- Surface fuels—the litter layer of the forest floor, mosses and lichens, dead down woody debris, herbaceous vegetation, and short to medium-height shrubs;
- Ladder or bridge fuels—tall shrubs, understory conifer trees and loose bark, lichens, and dead branches on tree boles located in the space between the top of the surface fuel stratum and the bottom of the canopy-fuel stratum; and
- Canopy fuels—chiefly the live and dead needle foliage, twigs, small branchwood, and aerial lichens and mosses associated with the overstory tree cover.

It is generally accepted that a distinct separation exists between surface fuels and canopy fuels: an open trunk space in which ladder or bridge fuels vary widely in their abundance. Collectively, the four strata constitute a forest fuel complex. An indication of the variation in canopy-fuel weight by height above ground is given in figure 2.

Many aspects of crown fire behavior have been found to be strongly linked to extrinsic canopy-fuel characteristics:

- Canopy-base height,
- Canopy-fuel load,
- Canopy-bulk density, and
- Foliar moisture content.

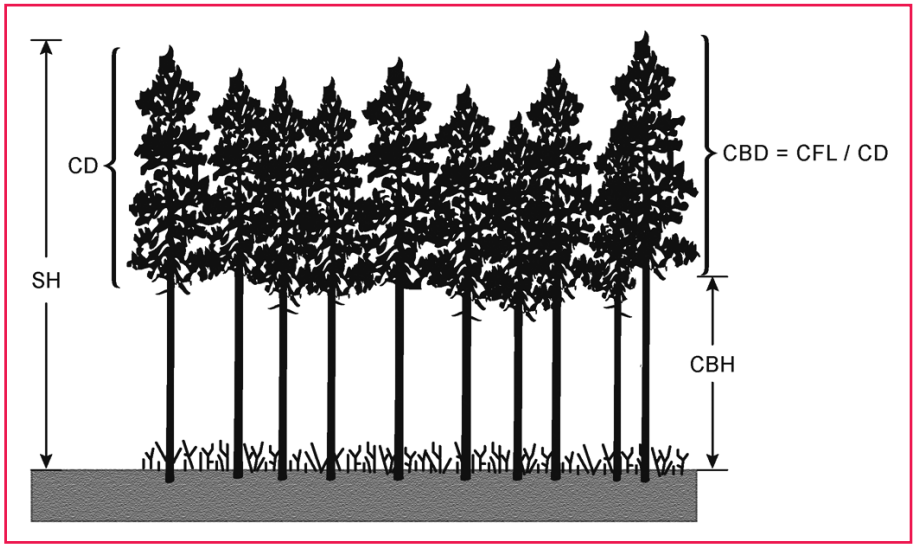

Figure 1.—*Profile of a stylized conifer forest stand illustrating several stand and canopy-fuel characteristics: stand height (SH), crown depth (CD), canopy-base height (CBH), canopy-fuel load (CFL), and canopy-bulk density (CBD).*

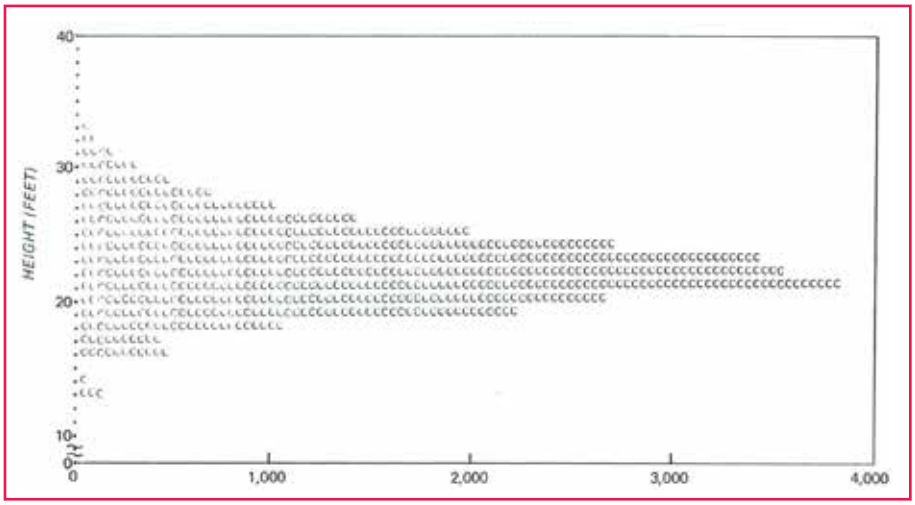

Figure 2.—*Graph of canopy-fuel weight with height above ground in a 32-year-old red pine plantation (from Sando and Wick 1972).*

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One of the main problems in determining the canopy-base height is the lack of a universally accepted definition for the lower limit of the canopy-fuel stratum.

Various intrinsic canopy-fuel characteristics (for example: the variation in foliar heat content) have yet to been seen as major factors in determining any particular element of crown fire behavior.

Canopy-Base Height

One of the main problems in determining canopy-base height (CBH) is the lack of a universally accepted definition for the lower limit of the canopy-fuel stratum (Fernández-Alonso and others 2013, Cruz and others 2004). Van Wagner (1977) defined CBH as the average height from the ground surface to the lower live crown base of the overstory trees in a conifer forest stand. Cruz and others (2003, 2010) adopted the same definition in relating tree and stand characteristics to the estimation of CBH (figure 3) in which the stand height (SH) represents the average of all trees in the stand rather than the dominant or top tree height (see also Cruz and Alexander 2012).

Canopy-Fuel Load

Canopy-fuel load (CFL) represents the quantity of fuel per unit area that would typically be consumed in the overstory trees of a conifer forest stand during the crowning process—in other words, the "available" canopy fuel. As Van Wagner (1977) notes: "Visual experience suggests that the principal crown fuel consumed is the live foliage and that little else burns except in unusually intense fires." Admittedly, smaller quantities of both dead and live woody material, bark flakes, and lichens and mosses may also be combusted. The CFL is a product of stand structure characteristics (figure 4).

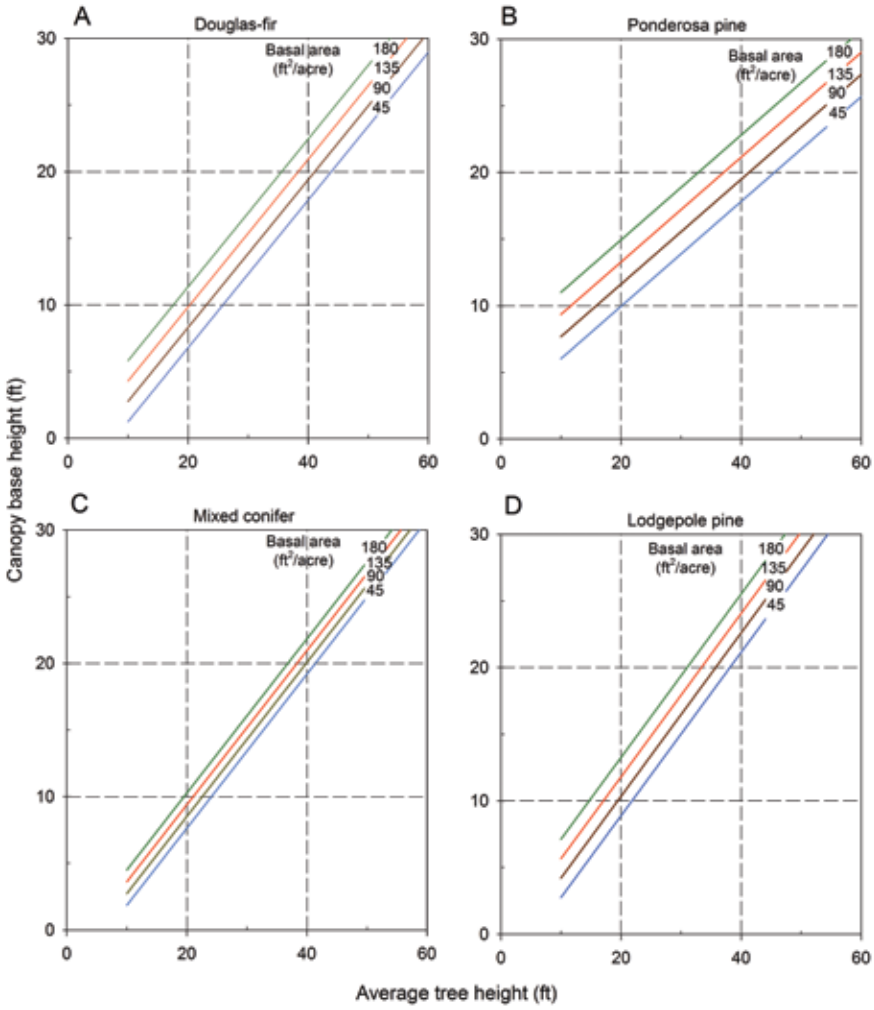

Figure 3.—*Canopy-base height of four western U.S. conifer forest fuel types as a function of average stand height and basal area (from Cruz and others 2003).*

The Fuel Strata Gap Concept

Fuel strata gap (FSG) is defined as the distance from the lower limit of the crown fuel stratum that can sustain vertical fire propagation and the top of the surface fuel layer. FSG is equivalent to canopy-base height (CBH) in the absence of appreciable ladder fuels when the surface fuel height is minimal. The FSG concept was introduced by Cruz and others (2004) to overcome the issue of the application of the CBH term to two distinct physical situations: (1) the silvicultural definition of only live foliage and (2) the fire modeling definition incorporating ladder fuels (Scott and Reinhardt 2001).

Canopy-Bulk Density

Canopy-bulk density (CBD) represents the amount of available crown fuel within a unit volume of the overstory trees in a conifer forest stand. The CBD is computed by dividing the CFL by the canopy depth (CD). The CD in turn is the stand height (SH) minus the CBH where the SH is the average height of all overstory trees in the stand. Thus, CBD is a reflection of stand structure characteristics (figure 5).

Foliar Moisture Content

Foliar moisture content (FMC) represents a weighted average of composite moisture content for the various needle ages found within the crowns of the trees in a conifer stand; this can also include other live and dead fuels (for example, lichens, mosses, and twigs). Upon emergence in the spring, new needles have very high levels of FMC (for example: 250–300 percent oven-dry weight basis), steadily decrease in FMC to approximately

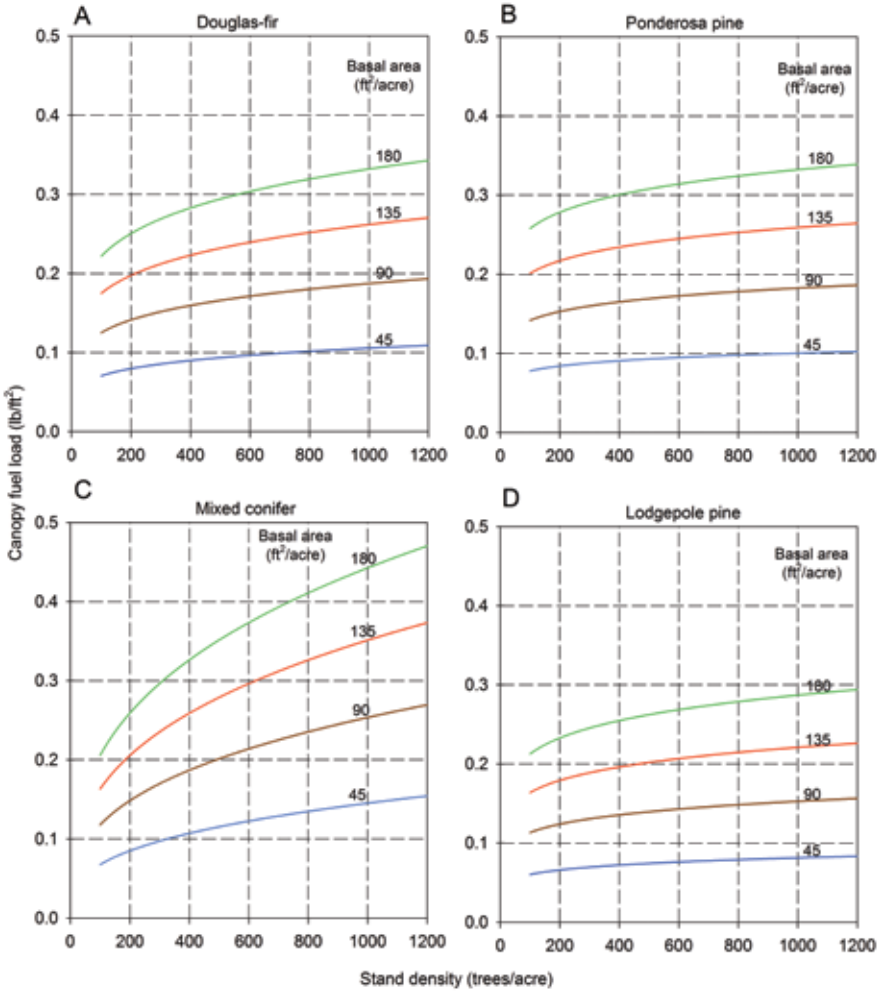

Figure 4.–*Canopy-fuel load of four U.S. Interior West conifer forest fuel types as a function of stand density and basal area (from Cruz and others 2003).*

Sampling of coniferous tree foliage has revealed a common pattern during the fire season: a period of relatively low foliar moisture content values in the spring and early summer commonly referred to as the "spring dip."

Take Note!

Various authors (for example: Scott and Reinhardt 2001, Reinhardt and others 2006) have come to define canopy-bulk density (CBD) as the maximum 10-feet (3-m) running mean of a vertical canopy-fuel profile and canopy-base height (CBH) as the lowest point in the profile, where CBD is ≥0.000749 pounds per cubic foot (0.012 kg/m^3). These authors also defined the canopy-fuel load (CFL) as the needle foliage plus the <0.762 inches (0.3 cm) diameter live and <1.52 inches (0.6 cm) diameter dead twig material. These definitions of CBH, CFL, and CBD are used in various fire behavior modeling systems, such as the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) (Rebain 2010) and Fuel Management Analyst Plus (Maples) (Carlton 2005). Strictly speaking, these adjustments or modifications are not compatible with Van Wagner's (1977) semi-empirical models for crown fire initiation and propagation (Cruz and Alexander 2012).

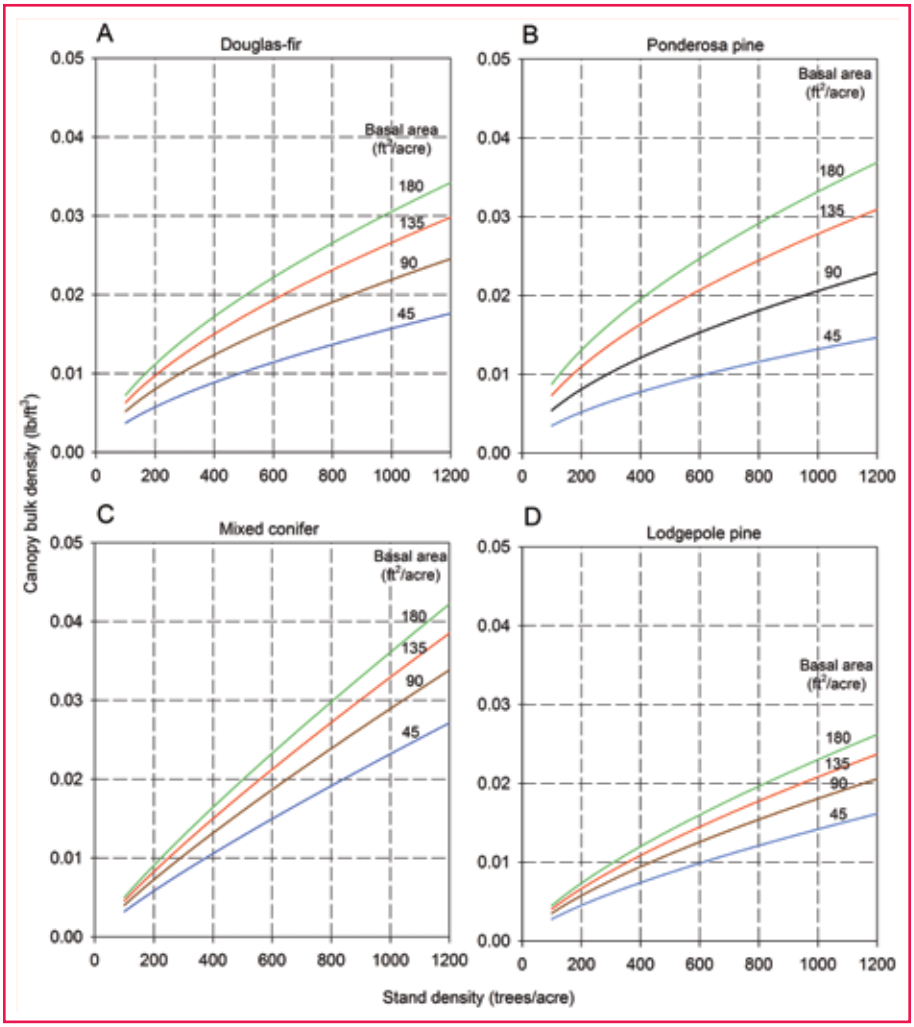

Figure 5.–*Canopy-bulk density of four western U.S. conifer forest fuel types as a function of stand density and basal area (from Cruz and others 2003).*

The Canopy-Fuel Characteristics Calculator

The regression equations developed Cruz (2003) for estimating the canopy-base height, bulk density, and fuel load in ponderosa pine, lodgepole pine, Douglas-fir, and mixed conifer forest stand types—based on three stand characteristics (average height, basal area, and stand density)—have been programmed into a Microsoft Excel spreadsheet (Alexander and Cruz 2010). The software is available for downloading the spreadsheet at <http://www.frames.gov/partner-sites/applied-fire-behavior/cfis>.

125–140 percent by the end of the first growing season (figure 6), and then decrease in FMC very gradually in the years that follow.

Repeated FMC sampling of coniferous tree foliage at several locations across Canada and in adjacent areas of the northern continental United States and Alaska has revealed a common pattern during the fire season: namely, a period of relatively low FMC values in the spring and early summer before the emergence of new needles (Alexander 2010). This phenomenon is commonly referred to as the "spring dip."

Field Estimation

Direct measurement of canopy-fuel characteristics can be an expensive and time-consuming activity. While a number of indirect methods have been tried for estimating CBD, for example, none have proven to be adequate (Alexander and Cruz 2014).

Tables have been constructed for use in making quick and reliable estimates of CBH, CFL, and CBD from visual observations or field measurements of stand height, basal area, and stand density for several different Interior West conifer forest stand types of the United States (Alexander and Cruz 2014). The construction of the tables is based on regression equations previously developed by Cruz and others (2003) and evaluated by Cruz and Alexander (2012). The approach used could no doubt be extended to other conifer forest types.

Several FMC studies undertaken in the United States and Canada (figure 6) were summarized by Keyes (2006). FMC can be also estimated by direct measurement (Jolly and Hadlow 2012, Norum and Miller 1984) or indirectly using empirical models based on calendar date and other environmental factors (Alexander 2010). One example of the latter approach is the *Calculator of Foliar Moisture Content in Pitch Pine* (<http://www.umass.edu/nebarrensfuels/ma_barrens/montague/#needles>).

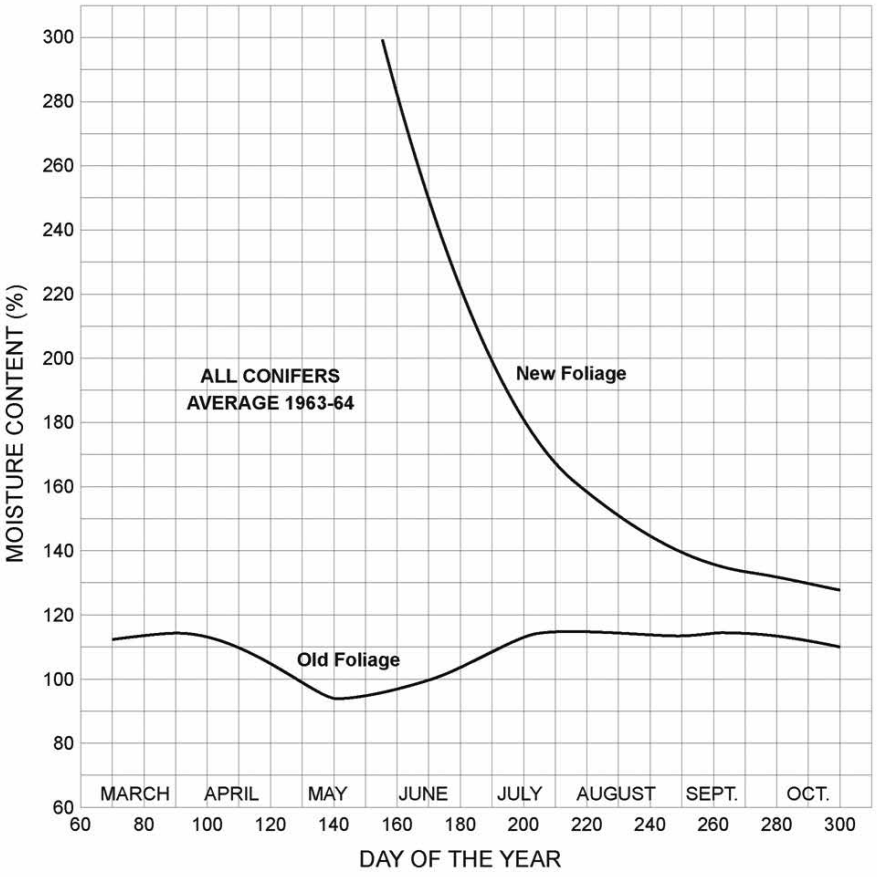

Figure 6.–*The average seasonal trends in the moisture content of old and new needle foliage for conifer tree species sampled at the Petawawa Forest Experiment Station near Chalk River, Ontario, Canada, over the course of 2 years (from Van Wagner 1977).*

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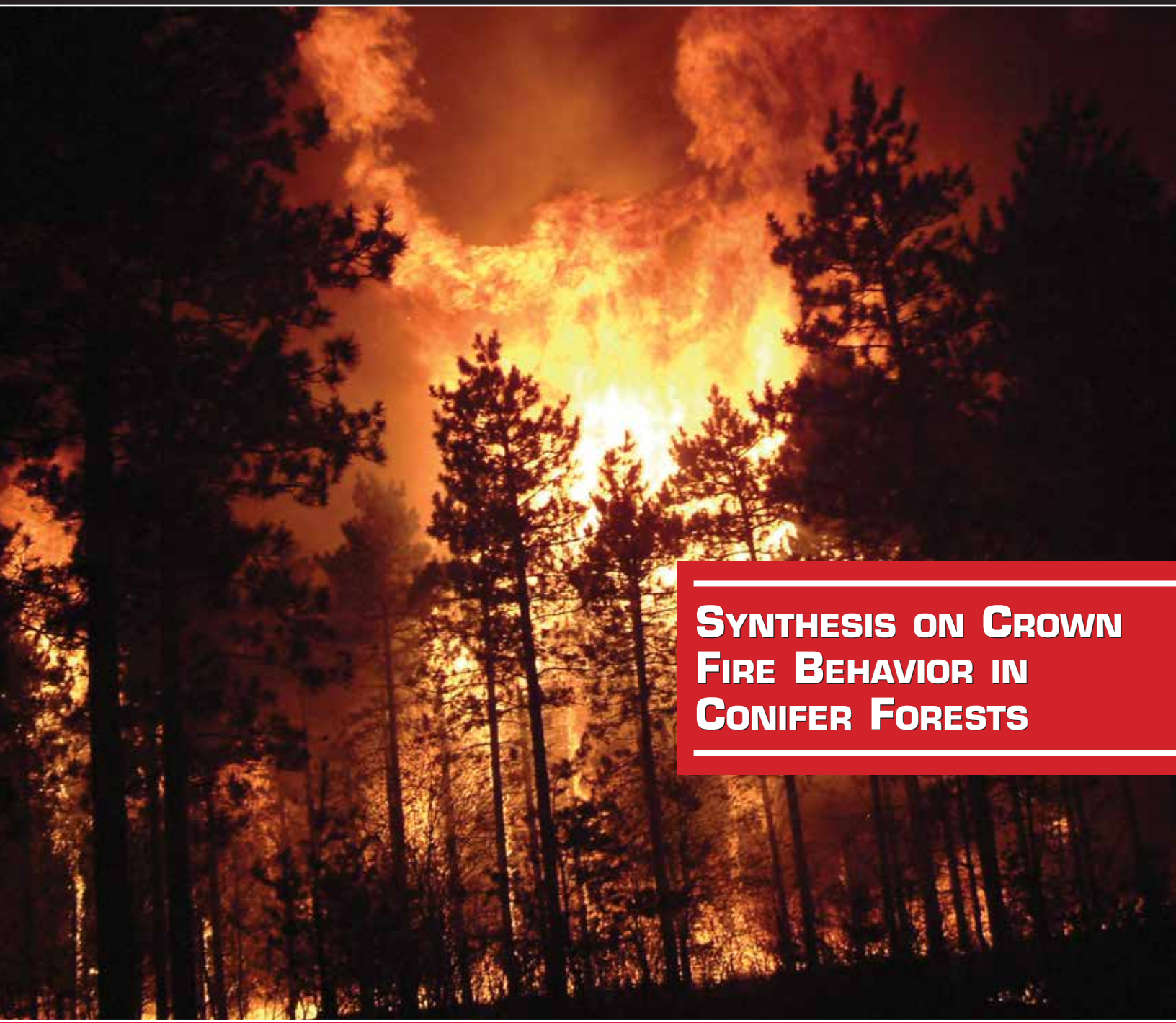

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On the Cover:

Crowning associated with the major run of the Cottonville Fire in central Wisconsin at 5:11 p.m. CDT on May 5, 2005, in a red pine plantation. Photo taken by Mike Lehman, Wisconsin Department of Natural Resources.

The USDA Forest Service's Fire and Aviation Management Staff has adopted a logo reflecting three central principles of wildland fire management:

- *Innovation:* We will respect and value thinking minds, voices, and thoughts of those that challenge the status quo while focusing on the greater good.
- *Execution:* We will do what we say we will do. Achieving program objectives, improving diversity, and accomplishing targets are essential to our credibility.
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