Capturing Crown Fire Behavior on Wildland Fires—The Fire Behavior Assessment Team in Action

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The ability to understand and predict fire behavior is important for a number of fire management activities, such as planning effective fuel reduction treatments, designing fire-resilient landscapes near the wildland-urban interface, planning and managing prescribed fires, providing for firefighter safety, and supporting wildland fire operations. Fire behavior models have been developed to predict the occurrence and characteristics of surface and crown fire behavior based on laboratory data (Rothermel 1972, Viegas 2004), outdoor experimental fires (Stocks and others 2004), and wildfire observations (Rothermel 1991).

Quantitative measurements of free-burning wildland fires are important to the validation and further development of fire behavior prediction models (Lentile and others 2007, Ottmar 2011). Laboratory and experimental fires cannot replicate many of the scale-dependent fire behavior characteristics that occur on wildland fires in larger, complex landscapes involving the interactions of fire with variable topography, weather, and atmospheric conditions.

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The International Crown Fire Modeling Experiment (ICFME) (Stocks and others 2004) and FROSTFIRE (Hinzman and others 2003) are examples of high-intensity, field-scale fire experiments that provided valuable information of fire behavior. Nonetheless, these experiments still cannot replicate some of the conditions that are found in free-burning wildland fires.

While still not perfect, advancements in technology have made it possible to gather fire behavior data on actively burning wildland fires (Butler and others 2010, Jimenez and others 2007). The Adaptive Management Services Enterprise Team (AMSET: a subunit of the Forest Service) formed the Fire Behavior Assessment Team (FBAT) to gather such detailed fire behavior data.

FBAT is a unique team that specializes in measuring fire behavior on prescribed burns and wildland fires. FBAT includes 6 to12 qualified fireline employees with at least 1 crew boss or (more typically) 1 division supervisor. The primary team goals are to (1) measure fire behavior and effects and their relationships to prefire fuels, fire history, and treatments; (2) measure fire effects on archeological and biological values; and (3) build a dataset useful for calibration of consumption, smoke production, and fire behavior models. FBAT also actively collaborates and shares data with interested land managers and research groups.

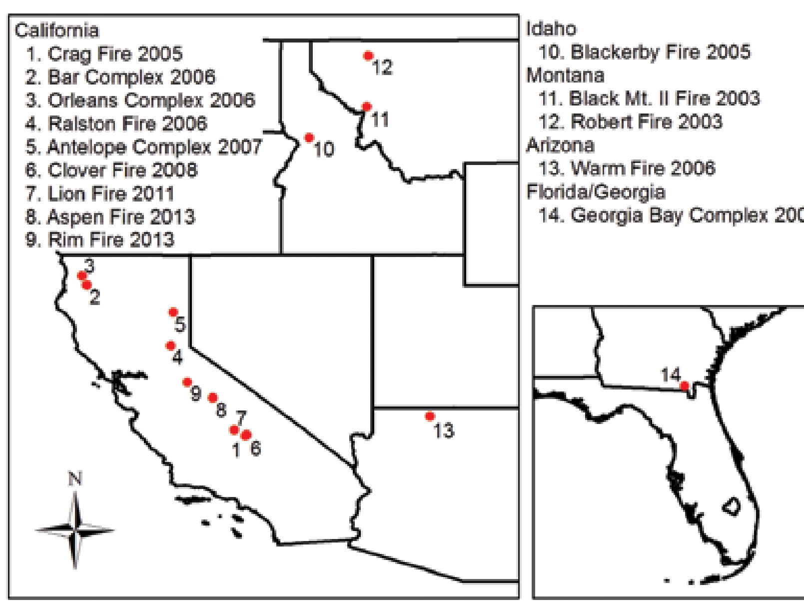


Figure 1.–*Location of all the wildland fires where data has been collected from 2003 through 2013 by the Fire Behavior Assessment Team.*

A Brief History—Chasing Fires

Created in 2002, FBAT (initially called the Rapid Response Team) worked closely with personnel at the Forest Service's Missoula Fire Lab and Missoula Technology and Development Center to build equipment to monitor and measure fire behavior. The team initially tested the equipment in the Wolf Wildland Fire Use Fire project in Yosemite National Park in 2002.

Since its inception, FBAT has collected weather, fuels, and fire behavior data from 14 wildland fires (figure 1) and several operational and experimental prescribed burns. In addition, FBAT members have visited numerous other wildland fires. At these fires, however, FBAT members did not collect data because of monitoring issues, such as access, safety, or fire progression; team members arrived after the fire was brought under control; or the fire did not reach the monitoring sites.

Monitored fire behavior ranged from slow backing flame fronts to active crown fire runs. A number of so-called extreme fire behavior features were captured in video footage, including fire whirls, ember and firebrand ignition of spot fires, coalescence of spot fires, and merger of such spot fires with the main flame front. Complete data was gathered on a total of 98 sites burned by wildland fire and 32 sites within prescribed fires, including research burns.

Data Collection

Once deployed on a wildland fire incident, FBAT works within the incident management system for safety and updates regarding fire behavior and operation plans. In coordination with the division supervisor, the team then determines where to set up the equipment near the active fire edge and gather fuels data. Site selection takes into account the weather forecast and likelihood of an area burning, yet offering safe access and egress for FBAT. Each selected site takes about an hour to set up fire behavior equipment and perform a fuels inventory (figure 2). Over the years, fire behavior equipment has been modified and upgraded—for example, to include an anemometer and dual heat flux sensors—as a result of input from both operations and research personnel.

Fire Behavior Equipment

Video camera. FBAT sets up one or two video cameras in stainless steel, fire-resistant boxes. The camera is started by a trigger connected to a network of wires and thermistors. When any of the wires are burned through by the fire, the camera is switched. Each camera contains a digital videotape that can record 80 minutes of footage.

In the view of each camera are three photo reference markers (the poles in figure 2) at a known distance from the camera and painted in 1-foot (0.3-m) increments to aid in estimating flame dimensions. These markers, added in 2006, are also used to estimate rate of spread of the fire.

Temperature sensors (thermocouples). Type K thermocouple sensors are connected to data loggers to collect detailed flame temperature data. These sensors are installed at different heights on a pole. Individual thermocouples are also set up in a diamond pattern and attached to smaller data loggers buried in stainless steel canisters. The pattern (with the poles at its center) creates eight defined triangles, enabling calculation of the rate of spread and direction of the flame front (Simard and others 1982).

Heat flux sensor. Heat flux is measured through a dual sensor containing both a radiometer and total heat flux transducer. Convective heat flux is computed from the dif-

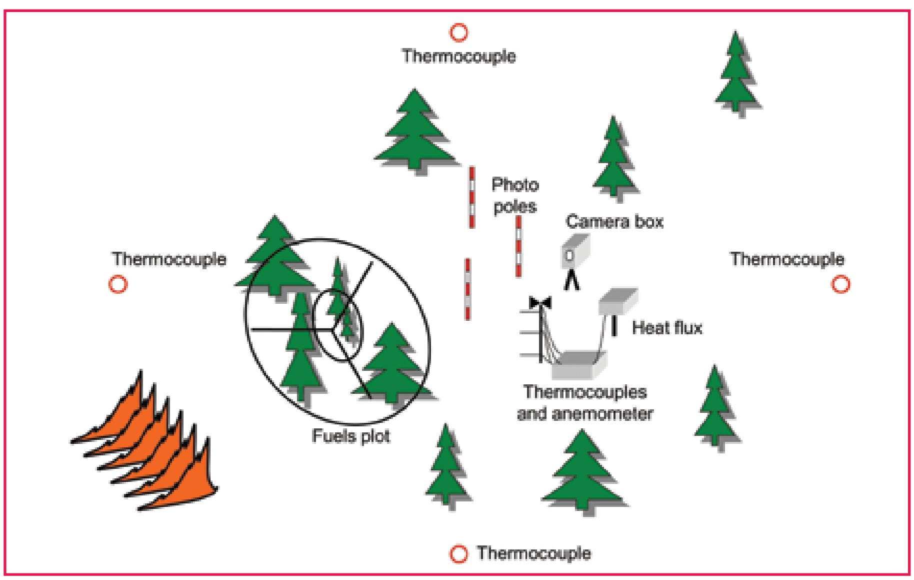


Figure 2.–*Site schematic with the typical site orientation based on predicted fire behavior. Each site includes both fire behavior equipment (camera, anemometer, and thermocouples) and a fuels inventory plot. Schematic is not drawn to scale.*

ference between the measured total and radiant heat fluxes. These sensors are connected to the same data logger as the vertically mounted thermocouples.

Anemometer. An anemometer was added to the equipment setup in 2007 to capture site-specific winds to augment fire behavior measurements. The anemometer captures the 10-second average wind speed at about 4.5 feet (1.4 m) above ground surface. The anemometer is constructed of plastic cups, so wind data is only collected prior to arrival of the flame front, which often melts the cups. Wind direction estimates were later added to the data from video of noncombustible flagging attached to the photo poles. Anemometer data is logged in the same data logging system collecting thermocouple and heat flux data.

Fuels Inventory

Fuels are inventoried prior to and after the flame front passage through an instrumented site. Surface and ground fuels are inventoried with one to three planar fuel transects (Brown 1974). Understory vegetation (seedlings, shrubs, grasses, and forbs) is estimated using type and density categories (Burgan and Rothermel 1984). Two variable radius prism plots are established for pole-sized and overstory trees in which species, vigor, diameter, height to crown base, and total tree height are recorded. Afterward, stand structure calculations are completed using the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) (Crookston and Dixon 2005, Rebain 2010). Fuel samples are collected to estimate litter, dead woody, and live vegetation fuel moisture (including foliar moisture content). Postfire measurements include char, scorch, and torch heights for each tree. Sampling methods are added when a change in vegetation type warrants or if local units are interested in monitoring the effect of fire on specific plant species.

(A) Members of the Fire Behavior Assessment Team setting up the fire-resistant video cameras and radiant heat flux sensor on the Crag Fire in 2005 (photo: Rosalind Wu, Forest Service) and (B) gathering fuels data near the anemometer on the Georgia Bay Complex in 2007 (photo courtesy of Adaptive Management Services Enterprise Team).

Black Mountain II Fire Case Study: Crown Fire Behavior Captured

The Black Mountain II Fire on the Lolo National Forest in Montana was started on August 8, 2003, by lightning. The fire was contained at 7,061 acres (2,857 ha) and exhibited mixed severity, from low-intensity surface fire to active crown fire. The fire exhibited active crown fire prior to the arrival of FBAT, including a 5-mile (8-km) run. The first round of sites installed by FBAT did not burn. In the second monitoring attempt, FBAT collected data on two adjacent sites on the upper-third portion of a steep (50–55 percent grade), northeast-facing slope. At one site, the vegetation was predominantly dense Douglas-fir (*Pseudotsuga menziesii*) forest with scattered individuals or patches of open ponderosa pine (*Pinus ponderosa*) forest; the second site was predominately open ponderosa pine forest. These sites are hereafter referred to as the “dense” and “open” sites, respectively. The fire reached the sites in the afternoon of August 21 at approximately 3:20 p.m.

Prefire Site Characteristics

Tree density was 469 trees/acre (1,159 trees/ha) in the dense site and 294 trees/acre (726 trees/ha) in the open site. Estimated canopy bulk densities were 0.018 pounds (lb) per cubic feet (ft^3) (0.29 kg/m^3) on the dense site and 0.007 lb/ft^3 (0.12 kg/m^3) on the open site. Canopy base height was 19.7 feet (6.0 m) and 7.9 feet (2.4 m) on the dense and open sites, respectively. Fine fuel load (litter, 1-hour dead-down woody debris, and live herbaceous and woody fuels) was higher in the dense site—37 tons/acre (83 t/ha)—than the open site—14 tons/acre (32 t/ha). Likewise, total fuel load (the sum of ground, surface, and live fuels) was 106 tons/acre (237 t/ha) for the dense site and 62 tons/acre (139 t/ha) for the open site.

Weather and Fuel Moisture Conditions

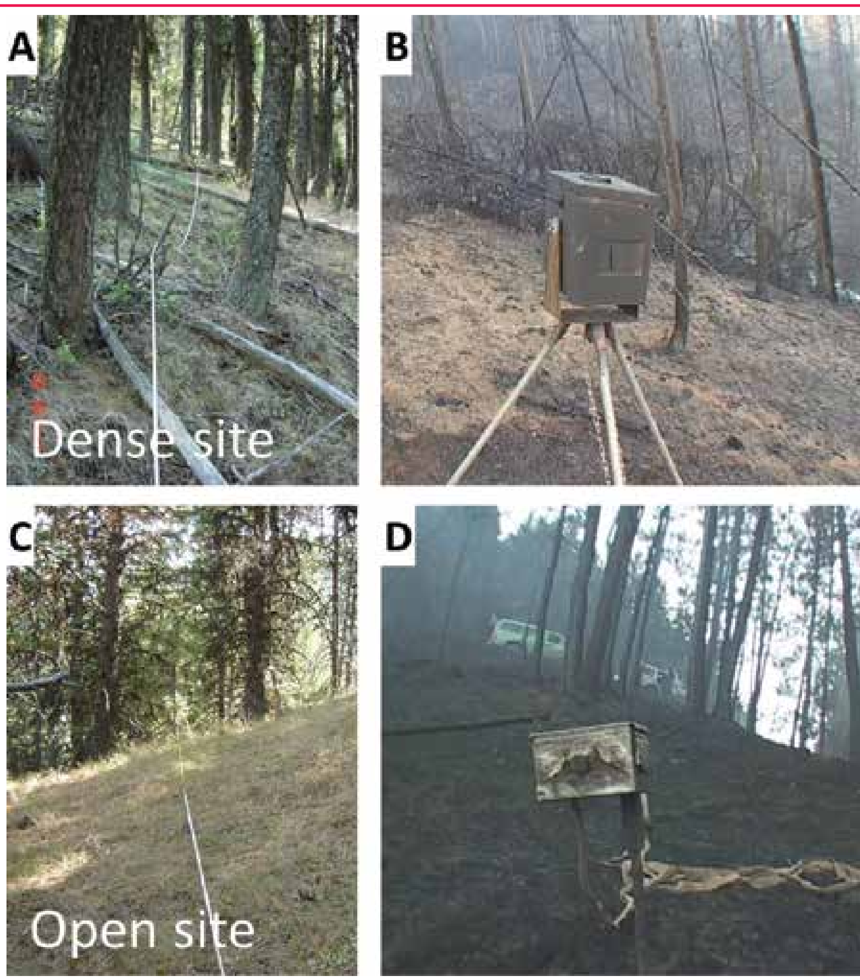
Between 3:00 and 4:00 p.m., at the nearby ridgetop weather station, 20-feet (6.1 m) open winds reached no more than 2 to 7 miles/hr (3 to 11 km/hr) and averaged less than 1 mile/hr (1.5 km/hr). The temperature was 73 °F (23 °C) and relative humidity was 20 percent. Onsite fuel moistures from the late morning were 70 to 87 percent for foliage of the lower branches of conifer trees, 50 to 72 percent for the shrubs, and between 4 and 7 percent for litter and arboreal lichens.

Observed Fire Behavior

At each site, FBAT measured or inferred several fire behavior characteristics. All ground, surface, understory vegetation, and fine canopy fuels were consumed on both the dense and open sites. Video images showed a solid "wall" of flame from the surface up through the canopy, indicative of an active crown fire. The estimated rate of spread was almost three times faster in the dense site—188–215 chains/hour (63–72 m/min)—than the open site—69–81chains/hour (23–27m/min). Temperatures exceeded the manufacturer's short-term heat ratings for the thermocouples—1,800 °F (982 °C)—at the dense site and peaked at 1,112 °F (600 °C) at the open site.

Lessons Learned/ Working Into the Future

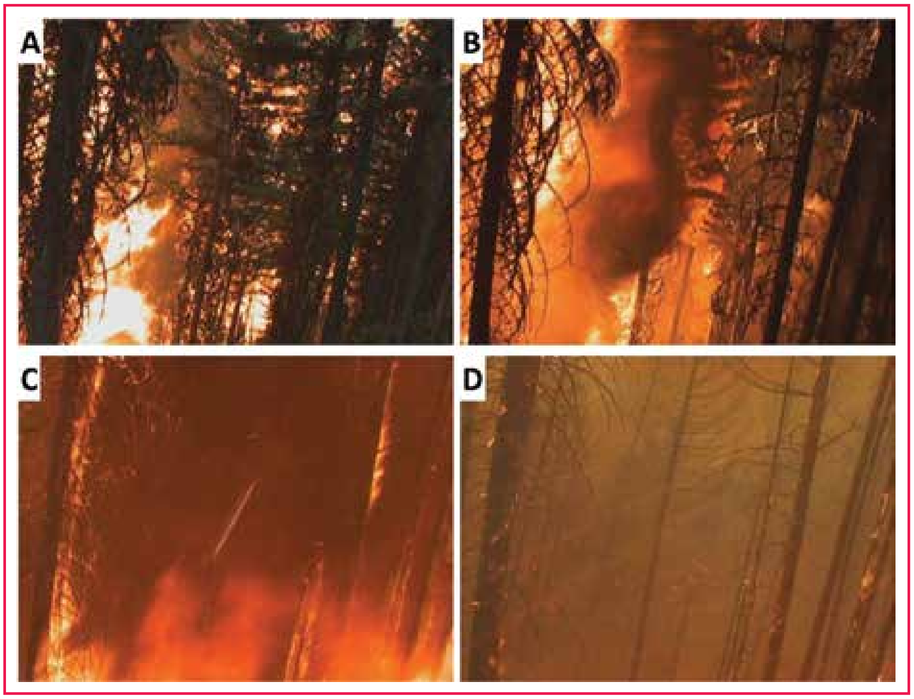
Installing complex sensors and making fuel measurements ahead of an actively burning wildland fire is incredibly difficult. Yet, the fire behavior data gained on free-burning, active wildfires cannot be collected in any other way. Over 11 years of data collection by FBAT, many valuable lessons have been learned about equipment needs and sampling protocols. Continued refinement and addition of data collection and sensors makes the data that much more valuable. The inclusion of the poles for future video analysis, the anemometer for site-specific winds, and the addition of the rate of spread sensors are all enhancements to the original videocamera equipment.



Prefire (A and C) and postfire (B and D) photos of the dense and open sites monitored on the Black Mountain II Fire. Photos courtesy of Adaptive Management Services Enterprise Team.

Challenges abound, and equipment survivability has been a central issue. Equipment will likely fail at a certain point in time because of high temperatures associated with intense fire; however, keeping the failures to a minimum is a goal. Although natural fuel configuration at the monitoring site ideally should be retained for data accuracy, some clearing is needed to prevent equipment loss: if the equipment is lost, there is no data collected to offset the loss. Procedures now include clearing large fuels around the data boxes and burying the boxes deeper.

High-intensity wildfires in coniferous systems appear to be occurring more frequently and are burning more area than ever before. In order to better understand and predict wildfire behavior, there is a need to continue this type of work. FBAT will continue to refine and adapt data collection methodologies to better capture data that is meaningful and useful for both researchers and practitioners by improving existing and future fire behavior modeling systems, validating fuel consumption models to predict fire effects and smoke production, and relating fire behavior to initial and long-term fire effects. In addition, FBAT is creating a valuable archive of video images that can be used for training in fire safety, human factors, and sociological applications.



Time series photos from a fire-resistant video camera during the Black Mountain II Fire in Montana in 2003 as the active crown fire passed the camera in the dense site. Photos courtesy of Adaptive Management Services Enterprise Team.

How Can You Work With FBAT?

FBAT is available to gather data on wildfires as well as prescribed fires. Deployment is ordered via the National Interagency Resource Ordering and Status System. For instance, FBAT began a partnership with two wildland fire modules on the Stanislaus National Forest in California in the summer of 2013. For more information about working with FBAT, contact Carol Ewell (cewell@fs.fed.us). For more information about FBAT and past fire reports, visit <http://www.fs.fed.us/adaptivemanagement/projects/FBAT/FBAT.shtml>.

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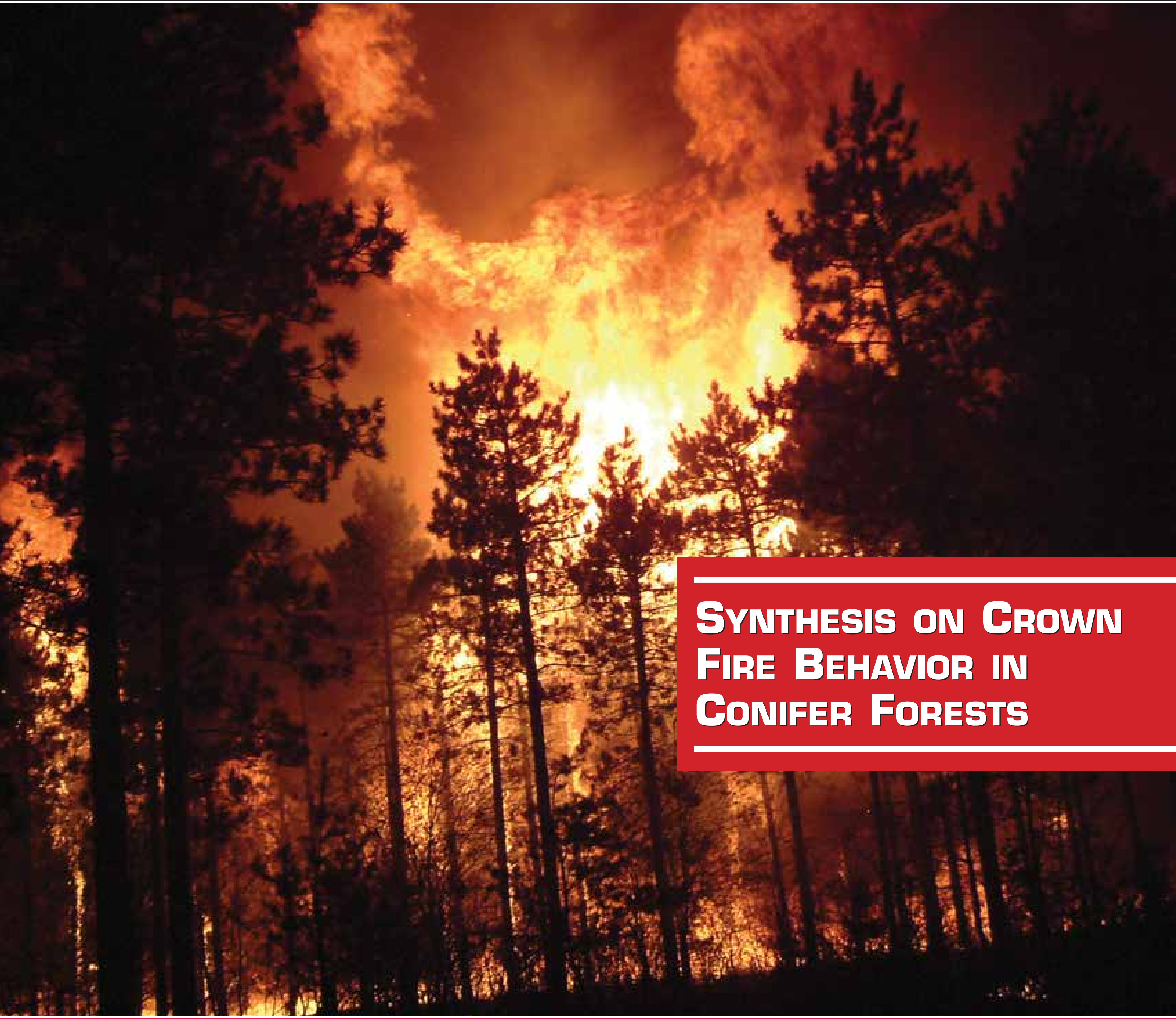

Synthesis on Crown Fire Behavior in Conifer Forests

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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.

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Contents

Short Features