Fire Management today

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From the Ground Up: Wildland Fire Fuels

Also Inside:

- Opinions on Wildland Fire Smoke
- Recruiting a Diverse Workforce
- Trail Cameras Capture Fire Behavior
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Addendum

In Issue 70(2), page 31, the article, The National Park Service: A History of Wildland Fire in Resource Management, by Roberta D'Amico and Bill Halainen should have included the following references:

Rothman, H.A. 2006. A Test of Adversity and Strength: Wildland Fire in the National Park System. Available at <http://www.nps.gov/fire/fire/fir_wil_history.cfm>.

Cones, G. and Keller, P. 2008. Lessons Learned – Managing Naturally-Ignited Fire: Yesterday, Today and Tomorrow. Video and document available at <http://www.wildfire-lessons.net/Additional.aspx?Page=131>.

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September 2010

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On the Cover:

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Duff mounds like these, formed in high-elevation ponderosa pine at the Meadow Smith old-growth restoration project on the Flathead National Forest, MT, often form at the base of mature trees. Prolonged smoldering in duff mounds can lead to decreased vigor, enhanced susceptibility to bark beetle attack, and potentially tree death. Photo: Christopher Keyes, University of Montana, Missoula.

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.
- *Discipline:* What we do, we will do well. Fiscal, managerial, and operational discipline are at the core of our ability to fulfill our mission.

Firefighter and public safety is our first priority.

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by Tom Harbour
Director, Fire and Aviation Management
Forest Service, Washington, DC

Looking to the Future

One thing is certain in our business—if we wait long enough, things will change! This seems to be the case in everything we do. *Fire Management Today* (FMT) is not immune. Over the past year, I made a decision that I hope will make the publication a more "nimble" periodical. FMT has moved from a subject-specific magazine to one that will allow its authors to write about those topics that are current and relevant to what is happening now. It will no longer be necessary to wait until a particular edition is being prepared.

Smoke from the Deep Harbor Fire levels off at sunset. Wenatchee National Forest, WA. Photo: Eli Lehmann, Forest Service, Mount Baker–Snoqualmie National Forest, Concrete, WA, 2004.

I have been the Director of Fire and Aviation Management (FAM) for the Forest Service for more than 5 years. All along, I have said that it is my goal to be an effective Director for a decade before I step down. In the last 5 ½ year period, I have seen my share of changes and have had input into many of the changes that have directly impacted "you," as an employee, and "us," as an agency and partner in the world of wildland fire management. As I ponder the future and think about the things that are important to me as the Director—building a "cohesive strategy" with recognition of the need for a national intergovernmental wildland fire framework, continuing implementation, adaptation, identification, and evolution of doctrine and risk management; building a wildland fire profession with professional ethics, a code of conduct, philosophy, and professional qualifications; creating equity and opportunity in fire and aviation management; better aligning the expectations of the land with ecologic fire dynamics of vegetation; and building a strong FAM team, the next 4 ½ years will go quickly!

In the upcoming editions of *Fire Management Today*, I will take you along on my journey through the remainder of my tenure as Director and discuss each one of these "legacy items" in depth, beginning next edition with a discussion about the "cohesive strategy."

Until then, as we approach our work each day, make risk management the priority *every* day in *every* action we take. Apply the concepts of doctrine to your actions. Let's think about how we make decisions, how we apply those decisions, and how we can improve our profession. If you do, each of us will return safely to our loved ones at the end of the day—nothing is more important! ■

Pitching Theories From the Duff Mound

Emily C. Garlough and Christopher R. Keyes

Crown fires, fire whirls, blowups, conflagrations—presented with these eye-catching phenomena in the dynamic field of fire research, garnering attention for smoldering duff mounds is a challenge. Whereas extreme fire behavior leaves immediate and prominent scars, the deleterious effects of duff mound consumption may take several years to become apparent. Yet if the goal of prescriptive burning is to protect large trees and improve forest health, then this rather unsung subject deserves some attention. The benefit to fire managers is a better understanding of fuel factors and the avoidance of unintended consequences.

Prolonged smoldering combustion in duff mounds at the base of trees causes cambial injury and fine root mortality.

Relatively little is known about duff mounds as a unique fuel type other than that excessive duff mound consumption often leads to injury and mortality for large trees (Ryan and Frandsen 1991, Swezy and Agee 1991, Stephens and Finney 2002, Varner et al. 2007, Hood et al. 2007). Prolonged smoldering combustion in duff mounds at the base of trees causes cambial injury and fine root mortality, but it is unclear which of these processes ultimately leads to tree death. Previous studies have shown that tree death can be predicted by the amount of cambial injury, but we have yet to determine how tree survival is affected by the combination of cambial death and fine root mortality.

Emily Garlough is a senior firefighter for the Forest Service Lolo Hotshots, based in Missoula, MT. She was a graduate research assistant in the College of Forestry and Conservation at the University of Montana, Missoula, when she completed this research. Christopher Keyes is a research associate professor of forestry and is director of the Applied Forest Management Program at the University of Montana, Missoula.

Duff mounds like these, formed in high-elevation ponderosa pine at the Meadow Smith old-growth restoration project on the Flathead National Forest, MT, often form at the base of mature trees. Prolonged smoldering in duff mounds can lead to decreased vigor, enhanced susceptibility to bark beetle attack, and potentially tree death. Photo: Christopher Keyes.

Until this relationship can be established, informed burning decisions must be based on what we do know—that smoldering combustion in duff mounds delivers substantial heat exposure that may lead to fine root mortality and cambial injury, possibly leading to reduced vigor, enhanced susceptibility to bark beetle attack, and potentially tree death (Ryan and Frandsen 1991, Swezy and Agee 1991, Miyanishi 2001, Varner et al. 2007).

Duff Mound Smoldering Combustion

Duff mounds are largely consumed in a process known as smoldering combustion (Frandsen 1987, Miyanishi 2001), which spreads about 1,000 times slower than the slowest spreading surface fire (Frandsen 1987). The spread of smoldering combustion in duff relies on the balance between the energy required to vaporize and drive off water and the energy released in the combustion process. The properties of duff that influence water-holding abilities therefore affect smoldering behavior of the material.

Results from combustion experiments using both forest floor duff and peat moss have shown that the probability of sustained smoldering is strongly influenced by duff moisture content and is partially dependent on bulk density and mineral content. The likelihood that sustained smoldering will take place decreases as any of these properties increase after some threshold has been reached (Hartford 1989).

Water requires a large amount of energy to evaporate, so duff moisture content acts as a significant heat sink in the combustion process (Wein 1983). Densely packed duff with high bulk densities may reduce the oxygen concentration and extinguish smoldering combustion. The probability of ignition decreases as the ratio of mineral content to organic material increases, as mineral content absorbs heat that would have contributed to combustion (Hungerford et al. 1995). Frandsen (1987) developed an ignition test to determine the influence of mineral content and moisture content on ignition. He reported that peat moss with less than 10 percent mineral content would not smolder if moisture content was 110 percent or greater.

Whereas extreme fire behavior leaves immediate and prominent scars, the effects of duff mound consumption may take several years to become apparent.

The current state of knowledge concerning duff mound consumption indicates the importance of moisture content within upper and lower duff layers and the importance of mineral content in the lower duff layer. In a recent study of old-growth ponderosa pine duff mounds, we found the upper and lower duff layers to differ significantly for factors known to influence consumption, including moisture content and mineral content as well as depth, bulk density, and composition.

The moisture content threshold for smoldering combustion was 57 percent and 102 percent, respectively, for upper and lower duff—no samples burned above these thresholds. A mineral content threshold was found for lower duff—samples with greater than 55 percent mineral content did not burn. Bulk density is commonly thought to be a limiting factor in duff consumption (Hartford 1989, Hungerford et al. 1995), yet our study found that the natural range of bulk densities for the upper and lower duff layers was too low to prohibit burning. Thus, to get the most accurate data to estimate the likelihood that duff mounds will be consumed, we recommend that managers sample for moisture content of both upper and lower duff layers and mineral content of lower duff prior to burning.

The probability of sustained smoldering in duff mounds is influenced by duff moisture content, mineral content, and bulk density. A sample of moisture content of the upper and lower duff layers and mineral content of the lower duff layer will help to estimate the likelihood that duff mounds will be consumed during a prescribed burn. Photo: Christopher Keyes.

We recognize that fire managers have busy schedules leading up to a prescribed burn, with concerns over homes, property lines, and air quality. Fuel moisture states can be monitored indirectly by observing weather patterns. However, our study revealed that duff mound moisture content is not always predictable, even after extreme rain events. Just 6 days after a historic rain event totaling 18.5 inches (47 cm), field measurements in one area showed that duff moisture content averaged just 23.9 percent for the upper duff layer and 22.9 percent for the lower duff layer. These moisture contents are far below the consumption thresholds we found in lab testing—57 percent and 102 percent, respectively, for upper and lower duff—indicating that a prescribed fire would have resulted in complete duff mound consumption for more than half of the stand's largest and oldest trees. Had burning decisions been based on weather data alone, many trees would likely have been damaged or lost. Further testing of these results is necessary to determine applicability in varied field conditions.

Future Points To Ponder

The field of duff mound moisture dynamics has tremendous opportunities for further investigation—for example, our results spur several more questions. Can the low moisture contents we saw after heavy rains be attributed to a hydrophobic nature, whereby rainfall and stemflow don't infiltrate upper soil horizons? Or, to a hydroconductive nature, whereby water rapidly infiltrates the duff and passes through to the mineral soil? What is the relationship of soil characteristics to these moisture dynamics? Temporal study of duff moisture content through the course of a fire season would be difficult to perform, but could offer a great deal of insight into duff mound wetting and drying cycles.

Duff mound moisture content is not always predictable, even after extreme rain events.

As demands for predictability in prescribed burning outcomes increase, all aspects of fuels behavior will come under scrutiny. Duff mounds may not represent the most exciting topic in fire research, but a better understanding of them can go a long way in preserving our valuable, mature trees in long-unburned stands.

Duff mounds may not represent the most exciting topic in fire research, but a better understanding of them can go a long way in preserving our valuable, mature trees in long-unburned stands.

References

Frandsen, W.H. 1987. The influence of moisture and mineral soil on the combustion limits of smoldering forest duff. Canadian Journal of Forest Research. 17: 1540–1544.

Hartford, R.A. 1989. Smoldering combustion limits in peat as influenced by moisture, mineral content and organic bulk density. In: Maciver, D.C.; H. Auld; R. Whitewood, eds. Proceedings of the 10th Conference on Fire and Forest Meteorology Ottawa, Ontario. Chalk River, ON: Forestry Canada, Netawawa Forestry Institute: 282–286.

Hood, S.; Reardon, J.; Smith, S.; Cluck, D. 2007. Prescribed burning to protect large diameter pine trees from wildfire—Can we do it without killing the trees we're trying to save? Joint Fire Science Program Final Report 03-3-2-04. 33 p.

Hungerford, R; Frandsen, W.H.; Ryan, K.C. 1995. Ignition and burning characteristics of organic soils. In: Cerulean, S.I.; R.T. Engstrom, eds. Fire in wetlands: a management perspective. Proceedings of the Tall Timbers Fire Ecology Conference, No. 19. Tallahassee, FL: Tall Timbers Research Station: 78–91.

Miyanishi, K. 2001. Duff consumption. In: Johnson, E.A., Miyanishi, K., eds. Forest fires: behavior and ecological effects. San Diego, CA: Academic Press: 437-475.

Ryan, K.C.; Frandsen, W.H. 1991. Basal injury from smoldering fires in mature Pinus ponderosa Laws. International Journal of Wildland Fire. 1:107–108.

Stephens, S.L.; Finney, M.A. 2002. Prescribed fire mortality of Sierra Nevada mixed conifer tree species: Effects of crown damage and forest floor combustion. Forest Ecology and Management. 162:261–271.

Swezy, D.M; Agee, J.K. 1991. Prescribed fire effects on fine-root and tree mortality in old-growth ponderosa pine. Canadian Journal of Forest Research. 21:626–634.

Varner, J.M.; Hiers, J.K.; Ottmar, R.D.; Gordon, D.R.; Putz, F.E.; Wade, D.D. 2007. Overstory tree mortality resulting from reintroducing fire to long-unburned longleaf pine forests: the importance of duff moisture. Canadian Journal of Forest Research. 37:1349–1358.

Wein, R.W. 1983. Fire behavior and ecological effects in organic terrain. In: Wein, R.W., Maclean, D.A., eds. Chichester, England: John Wiley and Sons LTD: 81–96. ■

Estimating Crown Fire Susceptibility for Project Planning

David C. Powell

Fire managers traditionally recognize three types of fire (Pyne and others 1996):

- Ground fires burning in organic materials such as peat;
- Surface fires burning in herbs and other fuels lying on or near the ground surface; and
- Crown fires burning in elevated canopy fuels.

When considering fire effects on vegetation and other ecosystem components, crown fire is acknowledged to be the most severe of the three fire types. Although crown fire is normal and expected for fire regimes III, IV, and V (Schmidt and others 2002), a large amount of crown fire is neither normal nor expected for the dry forests of fire regime I (Agee 1993). (See box on following page for more details on fire regime condition class.)

Because dry forests are affected by crown fire with increasing regularity (Mutch and others 1993) and silvicultural treatments are being planned for the wildland-urban interface where crown fire can seldom be tolerated regardless of fire regime, fire managers need tools to help them evaluate crown fire susceptibility for all forested lands. As expressed by Scott and Reinhardt (2001) "Crown fires result from certain combinations of fuels, weather, and topography." Land managers cannot control weather and topography, but if they could identify

Crown fire in the Blue Mountains, OR, showing the long flame lengths and high fireline intensity typically produced by crown fire. Photo: David Powell, Umatilla National Forest.

Aftermath of a crown fire in the Blue Mountains, OR, showing the impact of crown fire on soils, coarse woody debris and down wood, and other site-level resources. Photo: David Powell, Umatilla National Forest.

David Powell is a silviculturist on the Umatilla National Forest in Pendleton, OR.

areas with high potential for crown fire, the areas could be targeted for application of prescribed fire and thinning, two treatments with demonstrated effectiveness for reducing stand susceptibility to crown fire behavior (Bilgili 2003; Graham and others 2004).

Crown fire susceptibility refers to the potential for crown fire based on inherent stand characteristics such as species composition, forest structure, and tree density. In this context, crown fire susceptibility and crown fire hazard are considered to be interchangeable terms.

Canopy bulk density, a measure of foliage biomass available as crown fire fuel, is "the primary controlling factor of crown fire behavior."

This article relates five common measures of stand density (stand density index, trees per acre, basal area per acre, canopy cover, and equilateral tree spacing) to three categories of crown fire susceptibility (high, moderate, and low). The use of stand density measures to estimate crown fire susceptibility is a practical approach—it is not feasible to directly measure canopy bulk density (CBD), the measure of available crown fuels, except in a research context (Scott and Reinhardt 2001), and these other measures can be collected as part of stand data. In addition, it is easier to relate stand density to CBD than to use indirect estimation techniques relying on hemispherical photography, ceptometers, or spherical densiometers (Keane and others 2005).

Fire Regime Condition Class Definition*

A natural fire regime is a general classification of the role fire would play across a landscape in the absence of modern human mechanical intervention but including the influence of aboriginal burning. The five natural (historical) fire regimes are classified based on average number of years between fires (fire frequency) combined with the severity (amount of replacement) of the fire on the dominant overstory vegetation. These five regime classes include:

- I: 0–35 year frequency and generally low-severity fires replacing less than 25 percent of the dominant overstory vegetation, but can include mixed-severity fires that replace up to 75 percent of the overstory;
- II: 0–35 year frequency and high-severity fires replacing greater than 75 percent of the dominant overstory vegetation;
- III: 35–200+ year frequency, generally mixed-severity fires, but can also include low severity fires;
- IV: 35–200+ year frequency and high severity, replacing greater than 75 percent of the dominant overstory vegetation; and
- V: 200+ year frequency and generally high severity, but may include fires of any severity in this frequency range.

As scale of application becomes finer, these five classes may be defined with more detail, or any one class may be split into finer classes, but the hierarchy to the coarse scale definitions should be retained.

* Definitions are adapted from the Interagency Fire Regime Condition Class (FRCC) Guidebook, Version 1.3.0, June 2008. Available online at <www.frcc.gov> (accessed January 2010). Reference: Hann, W.; Shlisky, A.; Havlina, D.; Schon, K.; Barrett, S.; DeMeo, T.; Pohl, K.; Menakis, J.; Hamilton, D.; Jones, J.; Levesque, M.; Frame, C. 2004. Interagency Fire Regime Condition Class Guidebook. Boise, ID: National Interagency Fire Center. 119 p.

Canopy Bulk Density

CBD, a measure of biomass available as crown fire fuel, is "the primary controlling factor of crown fire behavior" (Graham and others 1999). It is the dry weight of available canopy fuel (including both foliage and small branches) per unit of canopy volume (including spaces between the tree crowns) and is strongly influenced by species composition and stand density (Agee 1996; Keyes and O'Hara 2002); thus, it varies both within and between ecological zones. CBD is usually expressed in kilograms per cubic meter (kg/m^3); it ranges from zero, where there is no canopy, to about 0.4 kg/m^3 (0.25 lbs/ft^3) in very dense forests (Scott and Reinhardt 2002).

To relate CBD to crown fire susceptibility, Agee (1996) analyzed seven stands that had been thinned and later exposed to crown fire during the 1994 Tyee Fire in north-central Washington. He found that crown fire was not sustained in stands where recent thinning had reduced CBD below about 0.10 kg/m^3 (0.006 lbs/ft^3). Conversely, anecdotal evidence from the Southwestern United States demonstrates that stands with CBD exceeding 0.10 kg/m³ (0.006 lbs/ft³) are susceptible to crown fires (Cram and others 2003).

Earlier research from Van Wagner (1977) and Alexander (1988) showed that crown fire is nearly impossible below a CBD of 0.05 kg/m³ (0.003 lbs/ft³), and research from the Lake States suggests that a CBD as low as 0.037 kg/m³ (0.002 lbs/ft³) might be marginally capable of sustaining crown fire under extreme circumstances (Sando and Wick 1972). Analysis of two stands on the Bitterroot National Forest in western Montana concluded that the Sando and Wick threshold value (0.037 kg/m3) might also be relevant to forests of the interior Pacific Northwest (Scott and Reinhardt 2001). Nonetheless, I selected a CBD value of 0.05 kg/m³ (0.003 lbs/ft³) as the lower threshold value for this analysis process.

I used these two thresholds—the CBD above which crown fire is easily sustained (0.10 kg/m³) and the CBD below which crown fire is unlikely (0.05 kg/m³)—as the boundaries for "high" and "low" crown fire susceptibility categories. By default, the "moderate" category then includes all CBD values occurring between the upper and lower thresholds.

Relating CBD to Stand Density

Using the three categories of crown fire susceptibility, CBD can be related to stand density metrics such as stand density index (SDI), trees per acre (TPA), basal area per acre (BAA), canopy cover (CC), and equilateral spacing (ES).

Stand Density Index

SDI expresses the relationship between a number of trees per acre and a quadratic mean diameter (QMD); SDI is indexed to a QMD of 10 inches (25 cm) (Daniel and others 1979, Reineke 1933). Keyes and O'Hara (2002) related Agee's (1996) upper CBD threshold value (0.10 kg/m³ or 0.006 lbs/ft³) to relative density, a percentage of the maximum full-stocking SDI, for the three tree species included in Agee's paper: grand fir, Douglas-fir, and ponderosa pine. Maximum full-stocking SDI values for the three tree species were taken from Cochran and others (1994) and Powell (1999).

The following relative density percentages pertain to the upper CBD threshold of 0.10 kg/m³ (0.006 lbs/ft³):

- Grand fir reaches the upper CBD threshold at an SDI of 200, about 35 percent of its full-stocking SDI of 560.
- Douglas-fir reaches the upper CBD threshold at an SDI of 250, about 66 percent of its full-stocking SDI of 380.
- Ponderosa pine remains below the upper CBD threshold even at its full-stocking SDI of 365.

The following relative density percentages pertain to the lower CBD threshold of 0.05 kg/m³(0.003 lbs/ft³):

- Grand fir crosses the lower CBD threshold at an SDI value of 70, about 12 percent of its full-stocking SDI of 560.
- Douglas-fir exhibits the lower CBD threshold at an SDI value of 100, about 26 percent of its full-stocking SDI of 380.
- Ponderosa pine exhibits the lower CBD threshold at an SDI value of 140, about 38 percent of its full-stocking SDI of 365.

Table 1 shows how the relative density SDI values are related to low, moderate, and high categories of crown fire susceptibility.

Trees per Acre

The TPA metric is an absolute measure of tree density per unit area. To express crown fire susceptibility by using TPA, the SDI values from table 1 were converted into their equivalent TPA values (table 2).

Table 1—*Estimated stand density index (SDI) values for three crown fire susceptibility ratings.*

Cover type group[1]	SDI[2] for each crown fire susceptibility rating[3]		
	Low	Moderate	High
Ponderosa pine	< 141	141–364	> 364
Interior Douglas-fir	< 101	101–249	> 249
Grand fir	< 71	71–199	> 199

[1] Cover type group composition is:
Ponderosa pine: western larch, whitebark pine, lodgepole pine, ponderosa pine
Interior Douglas-fir: Douglas-fir and other species not included in the ponderosa pine or grand fir groups
Grand fir: grand fir, subalpine fir, and Engelmann spruce.
[2] SDI ranges are based on Agee (1996), and Keyes and O'Hara (2002).
[3] Crown fire susceptibility ratings are based on canopy bulk density:
Low: CBD ≤ 0.05 kg/m3 (≤ 0.003 lbs/ft³)
Moderate: CBD 0.06–0.09 kg/m3 (0.004–0.005 lbs/ft³)
High: CBD ≥ 0.10 kg/m3 (≥ 0.006 lbs/ft³)

Table 2—*Estimated trees per acre (trees per hectare) for three crown fire susceptibility ratings.*

Cover Type Group[1]	Diameter Class Category[2]	TPA (T/ha) for each crown fire susceptibility rating[3]		
		Low	Moderate	High
Ponderosa pine	Seed-Sap (< 5" QMD)	< 1,174 (< 475)	1,174–3,057 (475–1,237)	> 3,057 (> 1,237)
	Poles (5–9" QMD)	< 263 (< 106)	263–682 (106–276)	> 682 (> 276)
	Small+ (> 9" QMD)	< 102 (< 41)	102–262 (41–106)	> 262 (> 106)
Interior Douglas-fir	Seed-Sap (< 5" QMD)	< 564 (< 228)	564–1,406 (228–569)	> 1,406 (> 569)
	Poles (5–9" QMD)	< 158 (< 64)	158–390 (64–158)	> 390 (> 158)
	Small+ (> 9" QMD)	< 70 (< 28)	70–172 (28–70)	> 172 (> 70)
Grand fir	Seed-Sap (< 5" QMD)	< 593 (< 240)	593–1,692 (240–685)	> 1,692 (> 685)
	Poles (5–9" QMD)	< 138 (< 56)	138–390 (56–158)	> 390 (> 158)
	Small+ (> 9" QMD)	< 55 (< 22)	55–153 (22–62)	> 153 (> 62)

[1] Cover type groups are described in footnote 1 to table 1.
[2] Average diameter class pertains to an entire forest polygon; QMD is quadratic mean diameter, the diameter associated with a tree of average basal area (Helms 1998). Diameter class is assumed to reflect an average or representative QMD condition for an entire polygon; "seed-sap" refers to the seedling-sapling diameter classes.
[3] Crown fire susceptibility ratings are based on canopy bulk density and described in footnote 3 of table 1.

Because SDI is indexed to a QMD of 10 inches (25 cm), the TPA and SDI values will only be the same when a stand's QMD is 10 inches (e.g., at a QMD of 10 inches, an SDI of 200 is equal to 200 TPA). But for a QMD other than 10 inches, the TPA and SDI values will not be identical. For this reason, the TPA values provided in table 2 are presented for three common size classes. In addition, because the other tables (tables 3–5) are related to TPA in some way, they also include three size classes.

The use of stand density measures to estimate crown fire susceptibility is a practical approach—it is not feasible to directly measure canopy bulk density except in a research context.

Basal Area per Acre

BAA refers to the cross-sectional area of a tree (in square feet) at a specified height on the stem (typically 4.5 feet or 1.4 m above the ground surface); the BAA metric takes the individual tree basal area values and sums them for every tree occurring on an acre to yield a measure of total basal area in ft^2/ac (or m^2/ha). To express crown fire susceptibility by using the BAA metric, it was necessary to convert the TPA values from table 2 into their equivalent BAA values (table 3).

Canopy Cover

CC is a forest density metric used extensively in ecological studies. It is defined as the vertical projection of vegetation foliage onto the ground surface when viewed from above.

Stand density expressed as canopy cover can be estimated from remote

Table 3—*Estimated basal area per acre in ft^2 (basal area per hectare in m^2) for three crown fire susceptibility ratings.*

Cover Type Group[1]	Diameter Class Category[2]	BAA (BA/ha) for each crown fire susceptibility rating[3]		
		Low	Moderate	High
Ponderosa pine	Seed-Sap (< 5" QMD)	< 59 (< 14)	59–149 (14–34)	> 149 (> 34)
	Poles (5–9" QMD)	< 71 (< 16)	71–181 (16–42)	> 181 (> 42)
	Small+ (> 9" QMD)	< 80 (< 18)	80–206 (18–47)	> 206 (> 47)
Interior Douglas-fir	Seed-Sap (< 5" QMD)	< 29 (< 7)	29–68 (7–16)	> 68 (> 16)
	Poles (5–9" QMD)	< 43 (< 10)	43–104 (10–24)	> 104 (> 24)
	Small+ (> 9" QMD)	< 55 (< 13)	55–135 (13–31)	> 135 (> 31)
Grand fir	Seed-Sap (< 5" QMD)	< 30 (< 7)	30–82 (7–19)	> 82 (> 19)
	Poles (5–9" QMD)	< 38 (< 9)	38–103 (9–24)	> 103 (> 24)
	Small+ (> 9" QMD)	< 43 (< 10)	43–120 (10–28)	> 120 (> 28)

[1] Cover type groups are described in footnote 1 to table 1.
[2] Diameter class categories are described in footnote 2 of table 2.
[3] Crown fire susceptibility ratings are based on canopy bulk density and described in footnote 3 of table 1.

sensing information sources, such as satellite imagery or aerial photography, or it can be sampled during field surveys such as stand exams. For polygons created from remote-sensing information, CC (also known as canopy closure, crown cover, or crown closure) is typically the only metric that can reasonably represent stand density because other measures, such as TPA or BAA, cannot be accurately determined from this information.

The CC stand density metric is unique in that it allows us to estimate crown fire susceptibility for historical time periods from old aerial photography. The other stand density metrics are seldom available for historical time periods because stand exams or forestry surveys were uncommon then. Because it is often important to be able to assess how crown fire susceptibility has changed over time, the CC stand density metric is particularly valuable.

Attempts to directly measure CC by using instruments such as a spherical densiometer or moosehorn have often been unsatisfactory (Cook and others 1995), so it is common practice to use mathematical equations to calculate CC (Dealy 1985). To express crown fire susceptibility using CC, I converted the BAA values into their equivalent CC values using Dealy's (1985) equations (table 4).

Equilateral Spacing

A measure of tree spacing is useful when there is a need to evaluate the spatial relationship between adjacent trees in a stand (tree-marking guides often include inter-tree spacing specifications). For older stands, where most of the trees are pole-size or larger, ES is generally thought to be the best measure of tree spacing. To express crown fire susceptibility by using the ES metric, it was necessary to convert the TPA values from table 2 into their equivalent ES values (table 5).

Cautions and Caveats

The five tables in this article do not predict potential crown fire behavior because there is no explicit

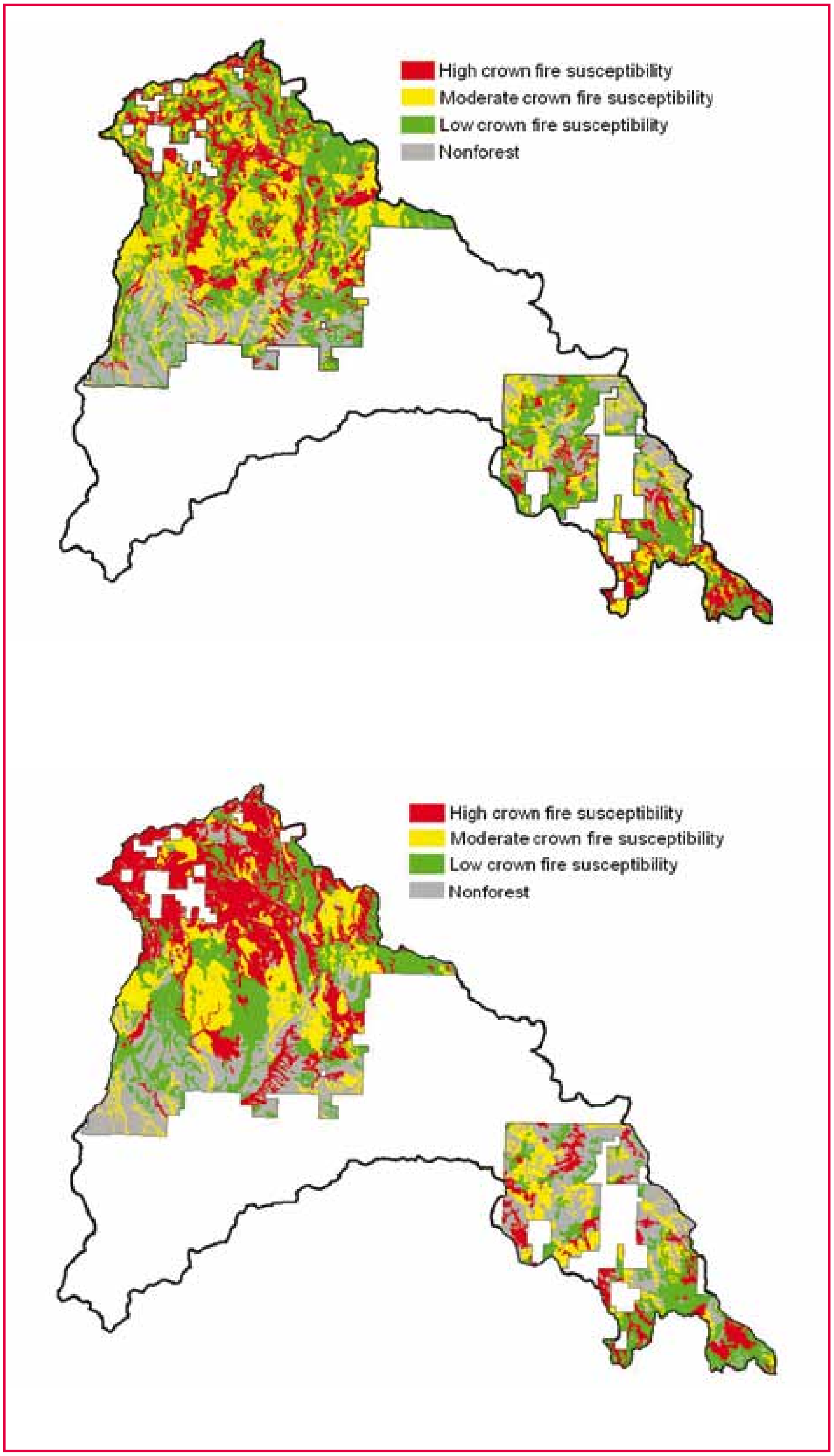

Figure 1—*Existing (upper) and historical (lower) crown fire susceptibility ratings for the Potamus watershed in northeastern Oregon (Forest Service 2004). Because canopy cover could be interpreted from 1939 aerial photography, it was possible to use the rating system in table 4 to estimate historical crown fire susceptibility for more than 78,000 acres of forest land in the Potamus watershed: 42 percent had high crown fire susceptibility, 28 percent had moderate crown fire susceptibility, and 31 percent had low crown fire susceptibility. When evaluating crown fire susceptibility during project planning, it seems that canopy cover is the best stand density measure for comparing existing conditions with reference (historical) conditions.*

consideration of weather, topography, or non-CBD vegetation factors such as canopy base height or foliar moisture content (Reinhardt and Crookston 2003).

Because vegetation databases almost always include more tree species (cover types) than just the three included in Agee's (1996) study, it was necessary to assign additional species to one of Agee's original forest types. These assignments were influenced primarily by crown characteristics: for instance, Engelmann spruce crowns tend to have a similar shape and density as those of grand fir, so Engelmann spruce was assigned to the grand fir cover type group.

Many users believe the stand density values for the ponderosa pine cover type group are too high because they exceed those for the grand fir and Douglas-fir groups. This counterintuitive result reflects tree canopy differences (particularly crown density and length), and it suggests that higher stocking levels of ponderosa pine are required for a specific amount of CBD than for either grand fir or interior Douglas-fir. On average, ponderosa pine crowns have lower density and length than Douglas-fir and grand fir crowns, so it takes more ponderosa pine crowns per acre to reach the same level of CBD as for grand fir or Douglas-fir.*

Except for the ponderosa pine cover type group, the stocking levels associated with the low crown fire susceptibility category are lower than traditional stocking guidelines developed for timber production

*Recent experience on the Umatilla National Forest suggests that more crown fire is actually occurring in ponderosa pine forests than would be predicted from susceptibility ratings for the ponderosa pine cover type group in tables 1–5.

Table 4—*Estimated tree canopy cover (CC) for three crown fire susceptibility ratings.*

Cover Type Group[1]	Diameter Class Category[2]	CC (%) for each crown fire susceptibility rating[3]		
		Low	Moderate	High
Ponderosa pine	Seed-Sap (< 5" QMD)	< 46	46–60	> 60
	Poles (5–9" QMD)	< 49	49–63	> 63
	Small+ (> 9" QMD)	< 51	51–66	> 66
Interior Douglas-fir	Seed-Sap (< 5" QMD)	< 50	50–62	> 62
	Poles (5–9" QMD)	< 56	56–68	> 68
	Small+ (> 9" QMD)	< 60	60–72	> 72
Grand fir	Seed-Sap (< 5" QMD)	< 53	53–68	> 68
	Poles (5–9" QMD)	< 57	57–72	> 72
	Small+ (> 9" QMD)	< 59	59–75	> 75

[1] Cover type groups are described in footnote 1 to table 1.
[2] Diameter class categories are described in footnote 2 of table 2.
[3] Crown fire susceptibility ratings are based on canopy bulk density and described in footnote 3 of table 1.

Table 5— *Estimated equilateral tree spacing in feet (meters) for three crown fire susceptibility ratings.*

Cover Type Group[1]	Diameter Class Category[2]	ES in feet (m) for each crown fire susceptibility rating[3]		
		Low	Moderate	High
Ponderosa pine	Seed-Sap (< 5" QMD)	> 6.4 (> 1.95)	6.4–4.2 (1.95–1.28)	< 4.2 (< 1.28)
	Poles (5–9" QMD)	> 13.8 (> 4.20)	13.8–8.7 (4.20–2.65)	< 8.7 (< 2.65)
	Small+ (> 9" QMD)	> 22.2 (> 6.76)	22.2–13.9 (6.76–4.24)	< 13.9 (< 4.24)
Interior Douglas-fir	Seed-Sap (< 5" QMD)	> 9.4 (> 2.86)	9.4–6.1 (2.86–1.86)	< 6.1 (< 1.86)
	Poles (5–9" QMD)	> 17.8 (> 5.42)	17.8–11.4 (5.42–3.47)	< 11.4 (< 3.47)
	Small+ (> 9" QMD)	> 26.8 (> 8.17)	26.8–17.1 (8.17–5.21)	< 17.1 (< 5.21)
Grand fir	Seed-Sap (< 5" QMD)	> 9.1 (> 2.77)	9.1–5.6 (2.77–1.71)	< 5.6 (< 1.71)
	Poles (5–9" QMD)	> 19.1 (> 5.82)	19.1–11.4 (5.82–3.47)	< 11.4 (< 3.47)
	Small+ (> 9" QMD)	> 30.5 (> 9.30)	30.5–18.2 (9.30–5.55)	< 18.2 (< 5.55)

[1] Cover type groups are described in footnote 1 to table 1.
[2] Diameter class categories are described in footnote 2 of table 2.
[3] Crown fire susceptibility ratings are based on canopy bulk density and described in footnote 3 of table 1.

purposes. For wildland-urban interfaces and other areas where wildfire resilience and a forest structure amenable to low crown fire susceptibility are particularly important, land managers could prescribe residual stocking levels using the "low" category in tables 1–5.

How likely is a crown fire? Here, a firefighter takes a break to get more firing devices from his pack during a night burnout operation on the Blossom Complex, Siskiyou National Forest, OR. Photo: Eli Lehmann, Forest Service, Mount Baker–Snoqualmie National Forest, Concrete, WA, 2005.

References

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

Agee, J.K. 1996. The influence of forest structure on fire behavior. In: Proceedings of the Seventeenth Annual Forest Vegetation Management Conference; 16–18 January; Redding, CA: 52–68.

Alexander, M.E. 1988. Help with making crown fire hazard assessments. In: Fischer, W.C.; Arno, S.F., compilers. Proceedings of the Symposium and Workshop: Protecting People and Homes from Wildfire in the Interior West. Gen. Tech. Rep. INT-251. Ogden, UT: USDA Forest Service, Intermountain Research Station: 147–156.

Bilgili, E. 2003. Stand development and fire behavior. Forest Ecology and Management. 179: 333–339.

Cochran, P.H.; Geist, J.M.; Clemens, D.L.; Clausnitzer, R.R.; Powell, D.C. 1994. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington. Research Note PNW-513. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 21 p.

Cook, J.C.; Stutzman, T.W.; Bowers, C.W.; Brenner, K.A.; Irwin, L.L. 1995. Spherical densiometers produce biased estimates of forest canopy cover. Wildlife Society Bulletin. 23(4): 711–717.

Cram, D.S.; Baker, T.T.; Boren, J.; Edminster, C. 2003. Inventory and classification of wildland fire effects in silviculturally treated vs. untreated forest stands of New Mexico and Arizona. Paper presented at the 2nd International Wildland Fire Ecology and Fire Management Congress; 16–20 November; Orlando, FL. 14 p.

Daniel, T.W.; Meyn, R.L.; Moore, R.R. 1979. Reineke's stand density index in tabular form, in English and metric units, with its applications. Research Report 37. Logan, UT: Utah State University, Utah Agricultural Experiment Station. 16 p.

Dealy, J.E. 1985. Tree basal area as an index of thermal cover for elk. Research Note PNW-425. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 6 p.

Graham, R.T.; Harvey, A.E.; Jain, T.B.; Tonn, J.R. 1999. The effects of thinning and similar stand treatments on fire behavior in western forests. Gen. Tech. Rep. PNW-463. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 27 p.

Graham, R.T.; McCaffrey, S.; Jain, T.B. 2004. Science basis for changing forest structure to modify wildfire behavior and severity. Gen. Tech. Rep. RMRS-120. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 43 p.

Helms, J.A. 1998. The dictionary of forestry. Bethesda, MD: Society of American Foresters. 210 p.

Keane, R.E.; Reinhardt, E.D.; Scott, J.; Gray, K.; Reardon, J. 2005. Estimating forest canopy bulk density using six indirect methods. Canadian Journal of Forest Research. 35: 724–739.

Keyes, C.R.; O'Hara, K.L. 2002. Quantifying stand targets for silvicultural prevention of crown fires. Western Journal of Applied Forestry. 17(2): 101–109.

Mutch, R.W.; Arno, S.F.; Brown, J.K.; Carlson, C.E.; Ottmar, R.D.; Peterson, J.L. 1993. Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystems. Gen. Tech. Rep. PNW-310. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 14 p.

Powell, D.C. 1999. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington: an implementation guide for the Umatilla National Forest. Technical Publication F14-SO-TP-03-99. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 300 p.

Pyne, S.J.; Andrews, P.L.; Laven, R.D. 1996. Introduction to wildland fire. New York, NY: John Wiley & Sons, Inc. 769 p.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agricultural Research. 46(7): 627–638.

Reinhardt, E.D.; Crookston, N.L., technical editors. 2003. The fire and fuels extension to the forest vegetation simulator. Gen. Tech. Rep. RMRS-116. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. 209 p.

Sando, R.W.; Wick, C.H. 1972. A method of evaluating crown fuels in forest stands. Research Paper NC-84. Saint Paul, MN: USDA Forest Service, North Central Forest Experiment Station. 10 p.

Schmidt, K.M.; Menakis, J.P.; Hardy, C.C.; Hann, W.J.; Bunnell, D.L. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. Gen. Tech. Rep. RMRS-87. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 41 p (+CD).

Scott, J.H.; Reinhardt, E.D. 2001. Assessing crown fire susceptibility by linking models of surface and crown fire behavior. Research Paper RMRS -29. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 59 p.

Scott, J.H.; Reinhardt, E.D. 2002. Estimating canopy fuels in conifer forests. Fire Management Today. 62(4): 45–50.

USDA Forest Service. 2004. Potamus ecosystem analysis. Unpublished Report. Pendleton, OR: USDA Forest Service, Umatilla National Forest. 222 p. Available at: <http://www.fs.fed.us/r6/uma/projects/ecosystem/potamus_wa_final.pdf> (accessed December 2009).

Van Wagner, C.E. 1977. Conditions for the start and spread of crown fire. Canadian Journal of Forest Research. 7: 23–34.

Characterizing Hand-Piled Fuels

Clinton S. Wright, Paige C. Eagle, and Cameron S. Balog

The Hand-Piled Fuels Biomass Calculator is available at <http://depts.washington.edu/nwfire/handpiles>.

Land managers throughout the West pile and burn surface fuels to mitigate fire hazard in dry forests. Whereas piling was historically conducted with heavy machinery following commercial harvesting operations, land managers are increasingly prescribing the use of hand piling and burning to treat surface fuels created by thinning and brush cutting. An estimate of the weight of the piled debris to be burned is necessary to assess potential smoke emissions and air quality impacts associated with this practice.

How Much Fuel Is in This Pile?

It is impractical to weigh piled fuels, so methods have been developed to estimate weight from pile dimensions and other characteristics. Data are available for characterizing large, machine-constructed piles (Hardy 1996; Johnson 1984; Little 1982; McNab 1980, 1981; McNab and Saucier 1980), but not hand-constructed piles. Research to quantify the amount of woody debris in machine piles (Hardy 1996) is incorporated into the fire and fuel management decision support software application CONSUME 3.0 (Prichard and others, no date) and the Washington State Department of Natural Resources (DNR) online calculator (Alexander 2007; <http://www.dnr.wa.gov/RecreationEducation/Topics/FireBurningRegulations/Pages/rp_burn_tonnagecalculator.htm>) .

> Tools and applications developed for describing machine piles may overestimate the amount of fuel in hand piles.

Differences in structure and composition between hand and machine piles, however, result in different relationships between pile dimensions, pile volume, and pile weight, so tools and applications developed for describing machine piles are likely to mis-characterize hand piles. To address this issue, we measured and weighed hand piles to document the relationships between easily measured variables and fuel loading and incorporated this information into the Hand-Piled Fuels Biomass Calculator, a

Slash is often piled by hand and later burned as a surface fuel treatment to mitigate potential negative impacts of broadcast burning and to reduce fire hazard. Photo: Ernesto Alvarado, University of Washington, Seattle.

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simple online calculator specifically for characterizing the relationship between hand pile dimensions, volume, and weight.

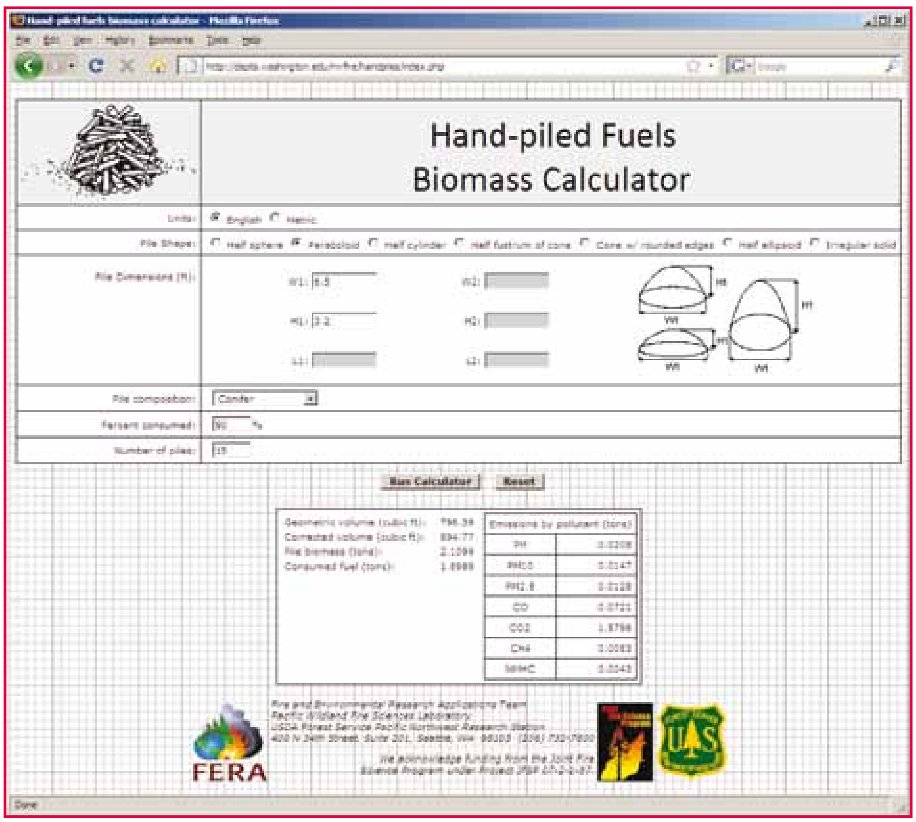
An estimate of the weight of the piled debris to be burned is necessary to assess potential smoke emissions and air quality impacts associated with this practice.

The equations in the calculator are based on measurements of the dimensions, volume, and weight of 121 hand piles composed primarily of coniferous (n=63) and shrub/hardwood (n=58) material located in Washington and California. Equations using pile dimensions, shape, and type allow users to more accurately estimate the volume and weight of hand piles for regulatory reporting and smoke-management planning (Wright and others 2010).

Calculating Emissions

Calculating emissions from pile burning is a five-step process:

1. Measure pile dimensions and calculate pile volume;
2. Assess the pile composition (conifer or shrub/hardwood debris);
3. Calculate the weight of fuel in the pile using equations that relate pile volume to pile weight;
4. Calculate consumable fuel weight (pile weight × percentage of expected consumption = consumable fuel weight); and
5. Apply an emission factor (consumable fuel weight × emission factor = emissions) to estimate potential emissions.



The online calculator allows the user to estimate the volume and weight of hand-piled fuels according to the shape selected and the entered dimensions. Potential emissions of different pollutants are calculated based on the calculated weight, emission factors, and user-specified consumption proportions.

Pile volume and fuel weight

A potentially large portion of the error associated with estimating pollutant emissions from fire is related to difficulties and inaccuracies in characterizing fuel weight or loading (Peterson and Sandberg 1988). In the calculator, users select a geometric shape that best represents their pile or piles and enter the measured dimensions required for that pile shape. These inputs are used to calculate the volume of the pile based on specific geometric formulas. Pile volume determined from pile dimensions and geometric formulas (geometric pile volume) is not perfectly correlated with true pile volume, so the calculator applies an empirically derived adjustment to the geometric volume, resulting in a more accurate estimate. Adjusted or true pile volume is then used as a predictor to estimate pile weight for different pile types (that is, piles composed primarily of coniferous debris or piles composed primarily of shrub and hardwood debris).

Estimating Consumable Fuel

CONSUME 3.0 assumes that 90 percent of piled fuels are consumed during a burning operation based on observations of 75–95 percent consumption reported by Hardy (1996). Hardy observed consumption in machine pile burns; no studies that we know of have documented the fuel consumption when hand piles are burned, although we expect hand piles to burn in a manner similar to machine-piles, in which most, if not all, of the piled debris is consumed. Users can adjust the estimated percentage consumption when hand piles are burned under conditions that are expected to reduce fuel consumption, such as in wet or snowy conditions.

Adjusting Emission

The amount of soil that is mixed into a pile when it is constructed affects the amount of smoke that is produced during burning. Soil contamination reduces combustion efficiency and effectively increases the emissions of airborne pollutants that are produced for each increment of fuel that is consumed. Machine piles can contain significant quantities of mineral soil depending upon the soil conditions at the time of piling and the skill of the equipment operator who constructed the pile. Hand piles, on the other hand, are virtually free of soil contamination and, therefore, burn more efficiently, producing fewer pollutants for each increment of fuel that is consumed. Hardy (1996) provides emission factors for total particulate matter (PM), particulate matter less than 10 micrometers in mean diameter (PM_{10}), and particulate matter less than 2.5 micrometers in mean diameter ($PM_{2.5}$) from the burning of piled fuels with differing levels of combustion efficiency related to differing levels of soil contamination. Using a combustion efficiency of 0.91 for "clean" piles yields emission factors of 13.5, 15.5, and 21.9 pounds of emissions per ton of fuel consumed (6.75, 7.75, and 10.95 kg per metric ton) for $PM_{2.5}$, PM_{10}, and PM, respectively. Assuming that 70 percent of consumption occurs during the flaming phase of combustion and that 15 percent occurs during each of the smoldering and residual phases of combustion, emission factors for carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), and nonmethane hydrocarbons (NMHC) are 152.0, 3,327.4, 11.2, and 9.0 pounds per ton (76.0, 1,663.8, 5.6, and 4.5 kg per metric ton), respectively (Prichard and others, no date). Multiplying fuel weight consumed by the above-listed emission factors yields the weight of pollutant emissions.

> Looking ahead, we would like to improve this tool so that users will have a single resource for characterizing piles of any type.

Looking Ahead

We designed the initial version of this online calculator specifically for estimating the volume and weight of hand-piled fuels. This tool complements CONSUME 3.0 and the Washington DNR calculator that address machine-piles. It enables fire managers and air-quality regulators to more accurately estimate fuel consumption and emissions for hand piles. Looking ahead, we would like to improve the functionality of this tool by integrating the algorithms for estimating machine pile weight, consumption, and emissions into a future version so that users will have a single resource for characterizing piles of any type.

References

Alexander, M.E. 2007. How much fuel is in that pile or windrow? Fire Management Today 67(3): 12–27.

Hardy, C.C. 1996. Guidelines for estimating volume, biomass and smoke production for piled slash. Gen. Tech. Rep. PNW-364. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 17 p.

Johnson, V.J. 1984. How shape affects the burning of piled debris. Fire Management Notes 45(3): 12–15.

Little, S.N. 1982. Estimating the volume of wood in large piles of logging residue. Administrative Report PNW-1. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 7 p.

McNab, W.H. 1980. A technique for inventorying volumes and weights of windrowed forest residues. Research Paper SE-215. Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station. 8 p.

McNab, W.H. 1981. Inventorying windrowed logging residues. Gen. Tech. Rep. SO-34. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station, pp. 234–237.

McNab, W.H.; Saucier, J.R. 1980. Estimating quantities of windrowed forest residues: a management tool for increased biomass utilization. Georgia Forest Research paper No. 11. Macon, GA: Georgia Forestry Commission, Research Division. 4 p.

Peterson, J.L.; Sandberg, D.V. 1988. A national PM10 emissions inventory approach for wildfires and prescribed burning. In: Mathai, D.V.; Stonefield, D.H., eds., Transactions: PM10: implementation of standards: an APCA/EPA International Specialty Conference; February 22–25, 1988, San Francisco, CA, pp. 353–371.

Prichard, S.J.; Ottmar, R.D.; Anderson, G.K. no date. Consume 3.0 User's Guide. Seattle, WA: USDA Forest Service, Pacific Northwest Research Station. Available online at: <http://www.fs.fed.us/pnw/fera/research/smoke/consume>. 234 p.

Wright, C.S.; Balog, C.S.; Kelly, J.W. 2010. Estimating volume, biomass, and potential emissions of hand-piled fuels. Gen. Tech. Rep. PNW-805. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 23 p.

The Results of a Brief Web-Based Questionnaire on Wildland Fire Smoke

A.R. Riebau and D.G. Fox

From October 2009 through February 2010, fire management and other professionals with interest and experience in fire smoke issues were asked to complete a short online questionnaire as part of a smoke science plan development effort by the Joint Fire Science Program, sponsored by the U.S. Department of the Interior (DOI) and U.S. Department of Agriculture (USDA). Five hundred and fifty-four individuals answered the questionnaire. Although some of the results might have been anticipated, there are differences in responses between this and previous needs assessments; one example is that, although many respondents saw regulatory restrictions increasingly impacting the ability of fire managers to apply prescribed fire (a common perception since at least the late 1970s), there are also new concerns that the public's perceptions of fire may also increasingly limit its use. Finally, the questionnaire results and written comments highlight a perceived fundamental tension between the need for fire to maintain ecosystem health and air quality regulations to protect public health.

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Almost all respondents indicated that they expect increasing air quality regulatory pressure on smoke as a pollutant.

Gauging Concern for Smoke Issues

Since at least the U.S. 1977 Clean Air Act Amendments, there has been concern that air quality regulations and smoke from prescribed fires could collide in conflicting legal requirements, vested interests, overly bureaucratic interpretations of regulations, lack of appreciation for ecosystem health and public health, and fumbled communication. Although there has been friction over the issue, air quality and forest management have avoided a national showdown. There may be a number of reasons for this happy circumstance, but it can be rightfully said that the fire community's support of smoke research has produced tools to ameliorate potential conflicts. The Joint Fire Science Program (JFSP) has been very supportive of fire smoke research and has funded more than 34 studies on the topic, much of this funding based on results from needs assessments. In 2007, JFSP conducted 2 workshops to identify new smoke research areas at both regional and national levels, resulting in 11 recommendations. Some recommendations were clearly within the research scope of JFSP and others addressed technology or procedural needs. In 2009, it was determined that these 11 recommendations were not sufficient to guide future smoke research investments. As a result, JFSP commissioned the development of a smoke science plan, a framework to focus smoke research for the next 5 years. As a foundation for this, a brief Web-based questionnaire was developed to gauge current perceptions of wildland fire smoke as an issue, what research topics are perceived as highest need, and what value people placed on the 11 recommendations of the preceding JFSP smoke roundtables.

Distributing the Questionnaire

The use of a Web-based questionnaire is not unique to development of the JFSP smoke science plan. An earlier Web-based questionnaire was used to complete a smoke research needs assessment in 1999 (Riebau and Fox 1999). This questionnaire was brief (12 questions) and took only about 10 to 15 minutes to complete. A link to the questionnaire was distributed by email to about 150 individuals beginning in early October 2009. Recipients were asked to complete the questionnaire themselves and to send the link on to others they knew that might have useful input. Although, at first, response was light, subsequent email reminders fed the momentum of the survey, with 554 people responding before the Web-link was deactivated at the end of February 2010. Well over two times the number of people completed the questionnaire than were initially emailed. This, itself, may reflect a grass-roots interest in the issues of fire smoke and the future actions of the JFSP. (Readers should note, however, that the questionnaire was not designed to meet scientific social sciences survey standards. The questionnaire results and following conclusions are based on the authors' interpretation of the volume and patterns of response to the questionnaire.) Due to the size of the response to the questionnaire and strength of convictions expressed, we believe that the results should be shared.

Results of the Questionnaire

Who Responded

The questionnaire's first two questions asked for the respondent's employer and primary job function. Respondents to the questionnaire were offered 31 choices to identify their employer and 12 choices to describe their job category. These job categories and employer choices were developed from our personal experience in fire smoke (more than 50 years between the authors) and our understanding of the audience for the Joint Fire Science Program. As the questionnaire was voluntary (not required by employers, for example), it was not possible to set targets for a required number of responses from a specific type of employer or specific job category. There were also respondents from different job categories than those defined that the authors considered meaningful to the results.

Twenty-six people responded from outside of the United States, while the remaining 528 were from within the United States. The greatest number of respondents work for Federal Government agencies, primarily for the Forest Service. There was some representation from most USDA and DOI agencies, many of which are significant clients for JFSP research products. Among job classifications, the largest group (190 respondents) defined themselves as fire managers or firefighters. Table 1 presents the breakdown among the largest groups and position classifications. This represents, to our knowledge, the largest and widest response to a wildland fire smoke questionnaire to date.

> It may be that a new dialogue is needed between those who advocate education and social sciences investigations on fire and those who advocate air quality and health science concerned with fire smoke.

The Importance of Wildland Fire Smoke

The question "How important is wildland fire smoke?" has been addressed in published literature, conference proceedings, and in unpublished internal government documents. Questionnaire respondents generally agreed that smoke factors are important now and will become more important in the next decade. (Out of 554 people, only 6 stated that smoke would become a less important issue in the next decade.) When asked to rate smoke as a general issue on a scale of 1 to 10 (10 being "critical"), 111 people rated smoke as 10, 85 people rated smoke as 9, 139 people rated smoke as 8, and only 6 people rated smoke as 1 ("safe to ignore"). Thus, 60 percent of respondents see smoke as one of the top three issues relating to natural resources or environmental concerns. Sixty-nine percent of respondents stated the reason for this was increasing regulatory pressure by both Federal and State governments, while 47 percent felt that smoke would adversely impact public health. When asked what might make smoke less important (or ameliorate smoke concerns), 72 percent of respondents said that increased public awareness about smoke might do so. Respondents were allowed space for short written comments within the questionnaire. Two views (expressed in different ways) appeared repeatedly: (1) smoke does impact public health and no amount of public education about smoke would make people accept serious health threats from smoke; and, conversely, (2) if the public understood the reasons for prescribed fire (in particular), they would accept any resulting smoke without hesitation.

Smoke Research Priority

One important question in developing a JFSP smoke science plan is the priority of smoke research. Eighty-four percent (450) of the respondents stated that more research should be done on smoke in the United States by universities, governments, and nongovernment agencies (NGOs). When

Table 1—*Employers and job functions of respondents to the Joint Fire Science Program Smoke Science Plan development activity Web-based questionnaire.*

Employer	Scientist (researcher)	Fire Manager or Firefighter	Air Quality Manager or Specialist	Natural Resources Manager
USDA Forest Service	22	94	16	8
DOI Fish and Wildlife Service	0	34	0	3
DOI National Park Service	2	16	1	5
DOI Bureau of Land Management	0	21	0	0
U.S. Environmental Protection Agency	4	0	2	0
National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA)	3	0	0	0
U.S. State and Local Agencies	2	18	20	18
International Respondents	12	4	1	2
U.S. Universities	22	1	0	1
Other	5	20	3	20

asked how much of a $100,000 research budget they would spend on smoke, 30 percent of the 550 people who answered the question stated they would spend half or more of the budget on smoke research and 21 percent stated that they would spend a quarter of the budget. Less than 12 percent of respondents stated that they would not spend any of the $100,000 on smoke research and only 6 percent stated they would spend it all on smoke. Of the respondents who did not recommend spending all the available $100,000 on smoke, we asked what other wildland fire research topics had higher priority for research in their opinion (fig. 1). The 2 most important research issues identified from the 12 choices given were social issues and fire (48 percent or 259 respondents) and fire fuels management (45 percent or 242 respondents). Running a close third place to these two topics were fire ecology and climate change and fire, tied at 41 percent (220 respondents) each. Interestingly, 99 respondents still listed smoke as most important and 17 of the respondents chose to skip the question. Respondents were given the opportunity to write short comments to this question, and the comments submitted supported the tabular results. There was an interesting feature to the responses in that fireline professionals were most supportive of social research concerning fire (61 percent of the fire managers and fire fighters who responded to the question), research scientists put most emphasis on climate change fire research (51 percent), and air quality managers rated climate change and then smoke research as highest priority (45 percent for climate change and 42 percent for smoke).

> There was a clear division on the balance between the need for fire in ecosystems and the protection of the public from unhealthy smoke concentrations.

Joint Fire Science Program Smoke Roundtables

In 2007, smoke roundtables involving invited specialists produced 11 recommendations for future fire research needs (SRA 2007). Only about 14 percent of respondents to the questionnaire stated that they were fully aware of the roundtables and their results. Forty-nine percent stated that they had no knowledge of the roundtables whatsoever.

Respondents were asked to rate each of the roundtable recommendations as high, medium, or low usefulness or need, with an opportunity to state whether they found that the recommendation wasn't useful or was impossible to understand. (The recommendations were not all strictly smoke research topics, as some suggestions—such as holding annual summits to share information and names of responsible people in agencies concerning smoke—might best be approached as topics for government agency policymaking or operations.)

Fire managers who responded were supportive of a campaign to educate schoolchildren about the need for fire (54 percent of them ranked this as high) but ranked climate change issues and fire as low (climate change regulations: 44 percent; greenhouse gases: 42 percent; and climate change regulation effect on fire management prognostication: 37 percent). Air quality managers who work for the Forest Service, the U.S. Environmental Protection Agency, or State and local governments rank the roundtable recommendation for a national emissions inventory for fire smoke as high (61 percent), a campaign for school education as medium (41 percent), and climate change regulation receiving the most ticks for a low ranking (48 percent).

Researchers and scientists who responded also ranked fire emissions inventory their numerically highest choice of the roundtable recommendations (49 percent), but more of them ranked the campaign for school education about fires as low than any other choice (37 percent). International respondents to the questionnaire ranked the two emissions inventory roundtable recommendations (for general pollutants and greenhouse gases) as high (61 percent and 39 percent, respectively) but considered the campaign for school education about fire as equal in usefulness to a greenhouse gas inventory (also about 39 percent); the roundtable recommendation with lowest international respondent ranking was that of holding local "summits" to exchange information about fire smoke (39 percent as low and 12 percent as not useful at all).

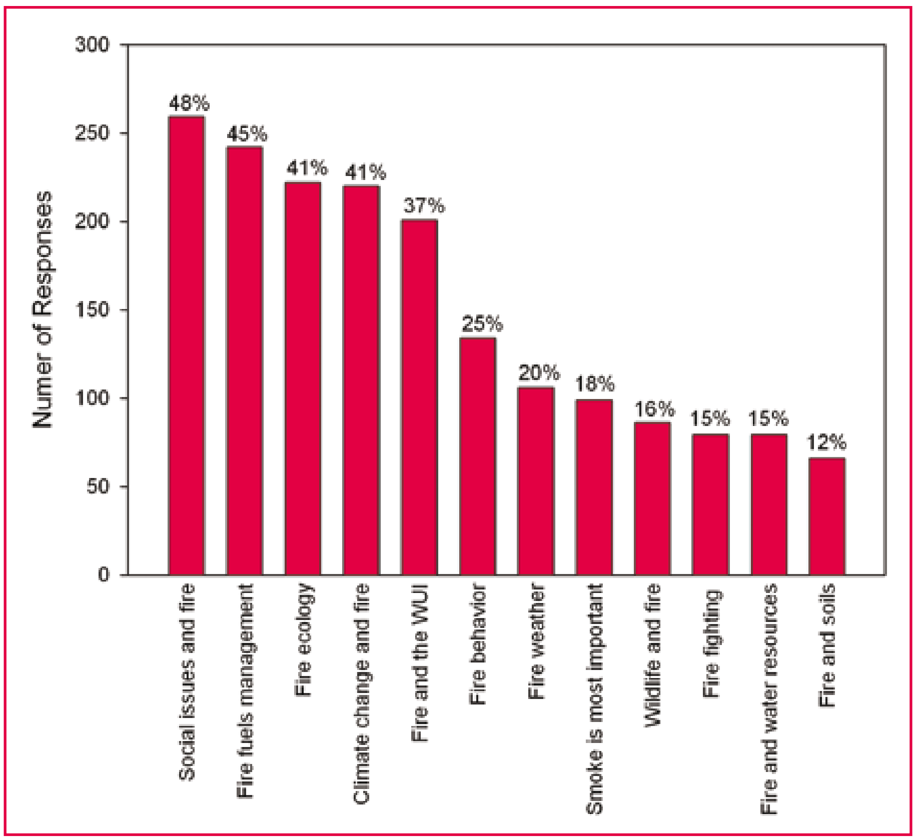

Figure 1—*Research priorities chosen from 537 people who completed the Joint Fire Science Program Smoke Science Plan questionnaire. Responses answer the question "What issues concerning fires are more important research topics than smoke?" WUI stands for wildland–urban interface.*

Interestingly, of the 11 recommendations, the 2 that directly mentioned climate change and fire got the most marks for low or no usefulness by the entire group of respondents. Although the roundtable recommendations were presented without explanation due to space limitations on the questionnaire, very few respondents checked a box indicating they could make no sense of the recommendations (on average about 2 percent) or didn't think the recommendations on average were useful at all (about 6 percent of respondents). Among smoke research topics, the responses to the questionnaire concerning the roundtable recommendations support (1) fire emissions inventory, (2) fire smoke impacts to health of populations, (3) a field experiment(s) for smoke model performance evaluation, and (4) climate change smoke issues. Such topics for smoke research investments have been identified by others (Bytnerowicz and others 2009) and thus have some confirmation of these results outside of the smoke roundtables and the questionnaire.

Two Important Viewpoints

While many written comments were received, an interesting overall pattern in them emerged. In general, fire and natural resources managers (especially those from U.S. agencies) believe that education on the need for fire as an ecosystem process will lower the concerns of the public about smoke.

Researchers and air quality managers in general (from the comments they wrote) disagreed and stated that it is unlikely the public could be educated or informed in a manner that would make them accept potential adverse impacts to their health from smoke. Some comments on either side of this divide were almost vehement; it may be that a new dialogue is needed between those who advocate education and social sciences investigations on fire and those who advocate air quality and health science concerned with fire smoke. A simplistic way to harmonize these two views may be to balance the health of ecosystems and the health of human populations in an as-yet undiscovered, generally satisfying manner.

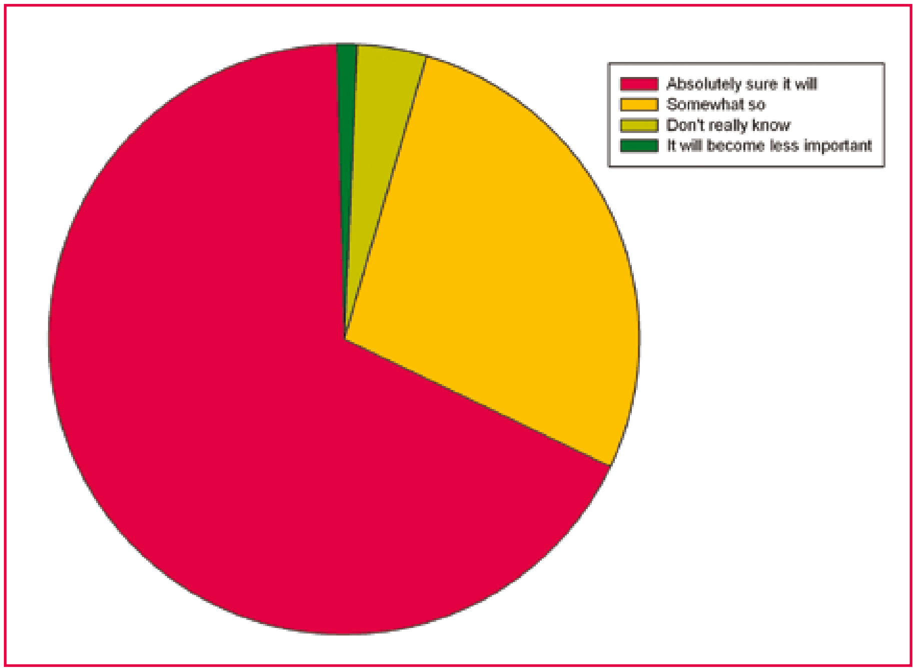

Figure 2—*Sixty-seven percent (67%) of all respondents (554) to the Joint Fire Science Program Smoke Science Plan questionnaire say that smoke from prescribed fires will become a more important issue in the next decade. Responses answer the question "Do you think fire smoke will become a more important issue to society in the next 10 years?"*

Conclusions

It was both gratifying and perhaps even a bit surprising that the questionnaire drew so many people to respond and that the questionnaire was forwarded by so many individuals to their colleagues. A conclusion we draw from this is that smoke from prescribed fires is an important issue that many respondents said would surely become more important in the next decade (fig. 2).

A majority of the respondents also voted that the United States should spend more research funds for smoke research, and a majority indicated that about 25 percent of fire research funding should address the smoke issue. The JFSP smoke roundtable recommendations were not well known to the questionnaire respondents, but a significant number of respondents expressed that the recommendations had value, although to varying degrees, relating closely to the respondents' work duties. Fire managers who responded indicated that education of the public about the ecological and emergency response needs for fire management would ultimately lessen controversy about wildland fire. Air quality managers didn't necessarily agree that this was so. Almost all respondents indicated that they expect increasing air quality regulatory pressure on smoke as a pollutant, with some written responses very gloomy about the future of prescribed fire in the light of perceived more stringent regulations. There was also a clear division between respondents on the balance between the need for fire in ecosystems and the protection of the public from unhealthy smoke concentrations. Some extremes in expressed views were that the public should just accept smoke or be educated enough to accept that burning to improve ecosystem health should trump concerns for their own health. Another extreme was that fire and resulting smoke must be stopped at whatever cost if there was danger to public health from smoke intrusion.

It is clear that the debate over wildland fire smoke is far from over. Readers of this paper who have been involved in the issue of smoke, from either air quality or fire management perspectives, will not find the results reported here surprising. It is clear that conflicts between smoke production and air quality regulations are still seen as threatening the application of prescribed fire, just as they have in earlier decades. Of course, a common concern of respondents is whether or not future regulations related to climate change will somehow preclude all prescribed burning, favoring (as expressed by some respondents) the requirement to turn all excess fire fuels in all U.S. forest ecosystems into boiler fuels or biofuels. Although such a concern may at first appear novel, climate change regulations and fire smoke concerns have been discussed since the 1980s and perhaps earlier. That such dire circumstances have not occurred as yet, in our estimation, demonstrates the usefulness of past smoke science, modeling and models, collegial relations between all parties, and continuing thoughtful attention to the issue.

More information on the questionnaire and its results may be downloaded at <http://www.ninepointsouth.com.au>. Readers are reminded that the questionnaire was not a scientifically designed survey and should approach its results with that understanding.

Acknowledgement

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References

Bytnerowicz, A.; Arbaugh, M.J.; Anderson, C.; Riebau, A.R. 2009. Integrating fire research and air quality: Needs and recommendations. In: Wildland Fires and Air Pollution. Oxford, United Kingdom: Elsevier. Developments in Environmental Science, Vol. 8: 585–602.

Riebau, A.R.; Fox, D. 2001. The new smoke management. International Journal of Wildland Fire. 10 (3–4): 415–427.

Riebau, A.R.; Fox, D.G. 1999. Technically Advanced Smoke Estimation Tools (TASET): Needs Assessment and Feasibility Investigation. Joint Fire Science Program. Washington, DC: USDA Forest Service, Wildlife, Fisheries, Watershed, and Air Research. 80 p.

The Society of Research Administrators International (SRA). 2007. Joint Fire Science Program Smoke Management and Air Quality Roundtables Research Needs Assessment. Internal Joint Fire Science Program Document. 18 pps.

Thompson, G. P.; Pouliot, G. 2007. Wildland Fire in the National Emissions Inventory: Past Present and Future. Slide presentation. Available online at: <http://weather.msfc.nasa.gov/conference/aq_presentations/Day%202%20afternoon%20pdf/Wildland_Fire_EI_PPF_NASA_AQTeam_2007_TGP.pdf> (accessed June 2010). ■

How Big Was Dodge's Escape Fire?

Martin E. Alexander

Several published accounts exist of how smokejumper foreman Wag Dodge survived the 1949 Mann Gulch Fire in northwestern Montana by setting an "escape fire" in cured grass fuels, the most notable among them being Norman Maclean's 1992 book *Young Men and Fire*. Two other smokejumpers survived by reaching a rockslide. Sadly, 12 smokejumpers and a local fireguard perished in their attempt to try and outrun the rapidly spreading grass fire in steep terrain.

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In a recent paper (part of a project dealing with survival zones for wildland firefighters), Alexander and others (2009a) critically examined the question of how big an area was burned off before Dodge was overrun by the main advancing fire front. They also addressed the issue of how tall the flames of the advancing fire front were that initially met and ultimately swept around the area burned out by Dodge's escape fire.

The contents of the paper prepared by Alexander and others (2009b) were first presented at the 10th Wildland Fire Safety Summit sponsored by the International Association of Wildland Fire held in April 2009 in Phoenix, AZ, and, again, as an invited presentation at the Pacific Northwest Fire Operations Safety Conference held in March 2010 in Portland, OR.

For a copy of the paper, including an associated presentation at, visit <http://fire.feric.ca/36702008/36702008.asp>.

References

Alexander, M.E.; Baxter, G.J.; Ackerman, M.Y. 2009a. Is a wellsite opening a safety zone for a wildland firefighter or a survival zone or neither? In: Masters, R.E.; Galley, K.E.M.; Despain, D.G., eds. The '88 Fires: Yellowstone and Beyond. Tall Timbers Miscellaneous Publication No. 16. Tallahassee, FL: Tall Timbers Research Station: 110.

Alexander, M.E.; Ackerman, M.Y.; Baxter, G.J. 2009b. An analysis of Dodge's escape fire on the 1949 Mann Gulch Fire in terms of a survival zone for wildland firefighters. In: Proceedings of 10th Wildland Fire Safety Summit; 2009 April 27–30; Phoenix, AZ. Birmingham, AL: International Association of Wildland Fire. 27 p. CD-ROM. ■

Firefighters Visit Seattle Schools: Recruiting Realizes Results

Renee Bodine

About 22 South Lake High School students crowded into the tiny room listening quietly to Gerald Williams describe what it is like to be a Forest Service firefighter. "I don't want to sugar-coat this. This is hard, grueling work. You dig all day," he said. He described fuel breaks and explained a controlled burn, digging lines, and how to fight a wildfire in the middle of nowhere. They liked the pictures he showed of what could be their office next summer: tents staked outdoors with fixed-wing airplanes and a helicopter in the background. "We ask you to show up, ready to work, have a strong work ethic, and be in shape," he said. Students asked questions about physical training, travel, fire camp, and money.

Most of the kids Williams recruits are from the city. "The learning curve is incredible. Imagine never having been in a forest environment, never even taking a walk in the woods, then learning the business of fighting fires," Williams said. Richard Tavares, who has worked several summers for Williams on the fireline, helped present to his former classmates and neighborhood friends. He shared his experiences: camping outdoors for the first time, trying to sleep through a thunderstorm, and standing on the edge of the Grand Canyon and feeling like he was on the top of the world. Williams explained that having a former student from the community helps his recruiting efforts and gives kids a first-hand perspective on working as a firefighter for the Forest Service.

Renee Bodine is a public affairs officer on the Mt. Baker-Snoqualmie National Forest in Everett, WA.

Gerald Williams, supervisor of Mt. Baker Initial Attack Fire Crew, instructs students during basic firefighter training, or "guard school." Photo: Renee Bodine.

Williams starts in early spring recruiting at local area high schools and colleges. Williams' approach is systematic. For the last 6 years, he's started early in the year coordinating with Seattle schools, counselors, teachers, the International District, tribes, the National Association for the Advancement of Colored People, and women's groups. Williams schedules back-to-back presentations throughout Seattle in early spring. "Finding highly motivated recruits who can take orders, handle hard labor, who enjoy the outdoors, takes extra effort," described Williams. He brings his computer and helps those interested in applying to navigate through their first experience with Avue.

Williams has been successful filling the six to eight vacancies on his initial attack crew with diverse candidates every year since he started. His additional recruits round out other fire and recreation crews on the Mt. Baker-Snoqualmie National Forest, and the excess candidates go to other forests in the Pacific Northwest Region. After presenting to 60 students at 6 Seattle schools and 2 in Burlington this year, he identified 20 who were serious about going to work for the Forest Service.

"Gerald is successful because he is passionate about what he does: fire and outreach to diversity. He does the job, and the candidates respond

Williams' 2010 guard school graduates pose with Thomas Taylor, assistant supervisor, after completing on-the-ground firefighter training. The Mt. Baker Initial Attack Fire Crew takes pride in diversity. Photo: Renee Bodine.

to that," said Tony Engel, fire management officer for the Mt. Baker-Snoqualmie National Forest.

When school gets out and the recruits start firefighter training, Williams immediately sets the tone for the season. He's building a team—when they deploy to fight a fire, they will be together 24 hours a day, 7 days a week, eating, working, and resting. "Under these conditions, compatibility, camaraderie, understanding, communication, and crew pride are an absolute necessity," noted Williams.

Williams says his hope is that all members of his crew get a sense of accomplishment out of being firefighters and working as part of a team. "It helps that I hire the best of the best, highly motivated people," explained Williams. "It is a hard, but rewarding job."

For more information about the Mt. Baker-Snoqualmie type 2 initial attack firefighters, contact Gerald Williams or go to <http://www.fs.fed.us/r6/mbs/fire/mbs-ia>. ■

A High-Quality Fuels Database of Photos and Information

Clinton S. Wright, Paige C. Eagle, and Diana L. Olson

The Digital Photo Series is available at <http://depts.washington.edu/nwfire/dps>.

Photo series and their associated data provide a quick and easy way for managers to quantify and describe fuel and vegetation properties, such as loading of dead and down woody material, tree density, or height of understory vegetation. This information is critical for making fuel management decisions and for predicting fire behavior and fire effects. The Digital Photo Series (DPS) is a user-friendly, Web-based application that displays data and images from all 16 currently published volumes of the Natural Fuels Photo Series (NFPS) (42 different photo series for a total of 438 sites). The database format of DPS enables searching, downloading, customized site generation, and side-by-side comparison of data and images. DPS follows the published volumes in both content and presentation.

Clint Wright is a research forester with the Forest Service, Pacific Northwest Research Station, Pacific Wildland Fire Sciences Laboratory, Seattle, WA. Paige Eagle is a Web designer and programmer with the College of Forest Resources, University of Washington, Seattle. Diana Olson was a forester with the Forest Service, Pacific Northwest Research Station, Pacific Wildland Fire Sciences Laboratory, and is now the project manager for the Fire Research and Management Exchange System (FRAMES) project in the College of Natural Resources, University of Idaho, Moscow.

The Natural Fuels Photo Series

Accurate, complete, detailed fuels data are critical for fire management planning and implementation, but are often lacking, insufficient, or difficult to obtain for many geographic areas or ecosystems. Developed to address the need for high-quality fuels information, the NFPS is a printed compilation of georeferenced data and photographs that displays conditions and fuel loadings in a wide variety of forest, woodland, shrubland, and grassland ecosystem types (Ottmar and others 2009).

The NFPS is built on a well-established tradition and methodology (see Blank 1982, Fisher 1981a, Maxwell and Ward 1980a, and others). At the inception of the NFPS project in the mid-1990s, conventional printing was the most effective way to distribute the images and data in a concise, economical, intuitive, and user-friendly package. Technological changes enabled us to enhance the utility of the NFPS by making it available in an electronic format.

The Digital Photo Series

Fire and fuels management requires extensive fuel and vegetation data, like those included in the NFPS, to effectively plan management activities, including the application of prescribed fire and mechanical fuels treatment. Development of new fire- and natural resource-based software applications that require fuel and stand information as inputs further highlight the need for electronically accessible data.

The objective of the DPS project was to create a user-friendly, intuitive software application that could be accessed online or run locally and would be capable of displaying site-level data and images in a format that is familiar to users of the printed volumes of the NFPS. The result is a Web-based application that provides better access to and enhanced functionality of NFPS fuels data and images. The digital form of NFPS data provides users with the ability to view data and images across series and volumes,

> Photo series provide quick and easy ways for managers to quantify and describe fuel and vegetation properties.

to query the database by various criteria (e.g., cover type, fuelbed category, species composition, or Bailey's ecoregion), to compare the fuels on sites side-by-side, and to build and save user-defined fuelbeds. The DPS complements book versions of the data, and NFPS data can be extracted from the DPS in a number of commonly used formats. The reporting feature allows users to print reports or to save data to a variety of mainstream digital file formats (text, spreadsheet, and XML).

Development and Design

DPS developers surveyed users of the NFPS books and the wider user community to determine what features they wanted to see in the DPS and to ensure that the technology requirements (particularly those employed by Federal land management agencies), interface design, and output specifications met the needs of fire and fuels managers and planners.

Developers scanned film images at a high resolution, and data from 438 photo series sites were consolidated and standardized in a relational database. The DPS application consists of a user-friendly interface that is accessed through a Web browser (such as Microsoft Internet Explorer or Mozilla Firefox).

In the absence of an Internet connection, a stand alone version of the DPS (utilizing the desktop server emulator MicroWeb) can be used to run the Web site from a local computer hard drive. Once the standalone version of DPS is installed, the user can start and use the application with their Web browser to mimic the online version. An installation CD is available upon request from the Pacific Wildland Fire Sciences Laboratory[1].

A Quick User Guide

The DPS homepage (fig. 1) is organized into tabbed Web pages, allowing a user to navigate to photo series sites in a variety of ways:

- Retrieve sites of interest by selecting the "Site search" tab (fig. 2). Select a specific site or sites by clicking on the map or by selecting geographic (State, Bailey's ecoregion, and/or landowner) and/or ecological criteria (e.g., cover type, species, and fuel and stand structural attributes) from the drop-down menus below the map. Clicking on the "Get sites" button will display all of the photo series sites that meet the selection criteria.
- Select the "Site browser" tab to view an expandable navigation tree (fig. 3) that includes all 438 sites organized by volume.
- Create and save custom sites with the controls on the "Custom site builder" page (fig. 4); data tables can be combined to create custom sites that are more representative of a specific land management unit or a desired management state. Custom sites created in this way can be saved and shared between DPS users.

The user can access application documentation, a more detailed introduction, and a description of the differences between the DPS and published volumes of the NFPS under the "DPS Help" tab on the far right of any screen. DPS Help includes instructions for navigating the DPS (including descriptions of the site search, site browser, and custom site builder tabs), perform-

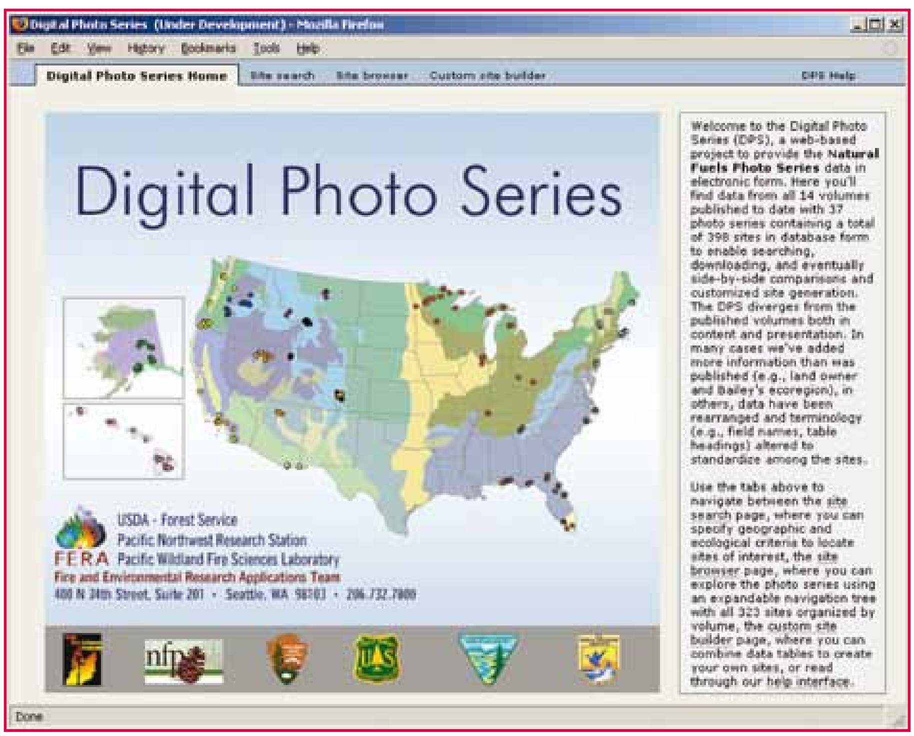

Figure 1—*DPS home page. This page can be accessed directly or through a link on the home page for the Fire and Environmental Research Applications team (<http://www.fs.fed.us/pnw/fera>).*

[1] Request CD versions of the Digital Photo Series by telephone (206-732-7827) or email (cwright@fs.fed.us).

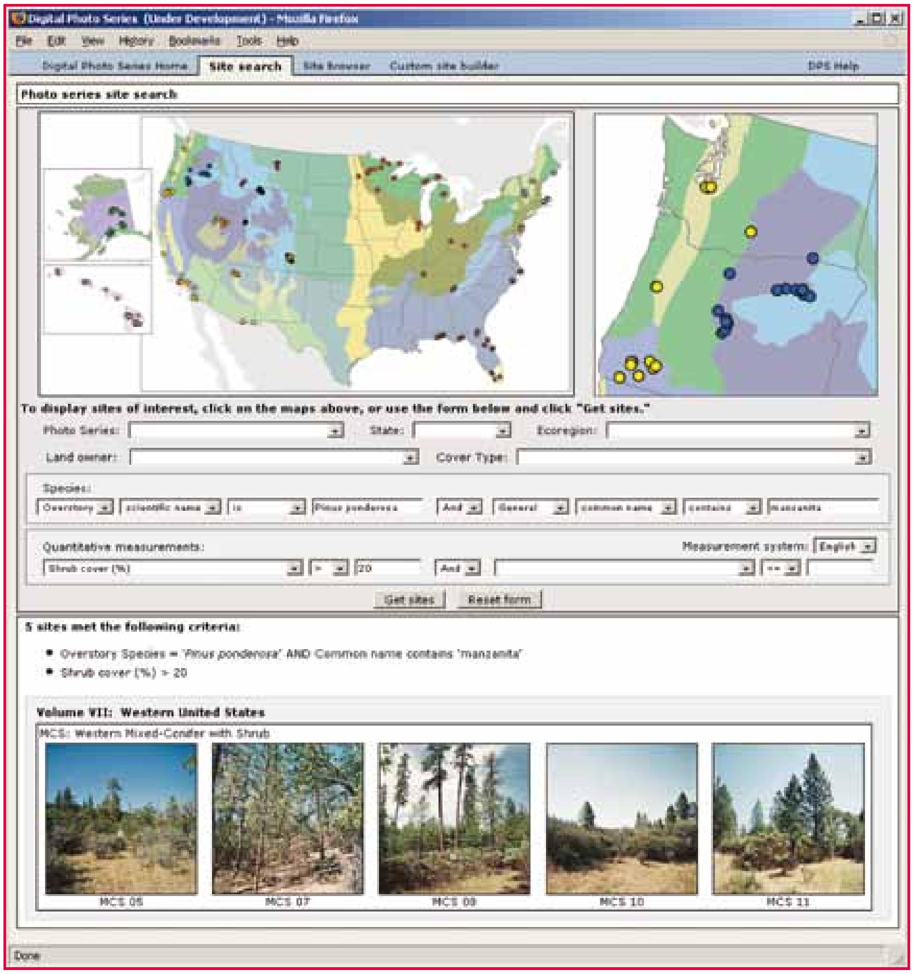

Figure 2—*Site search page for DPS. Sites can be selected by any combination of map selection and query building criteria. In the example shown, all sites with ponderosa pine in the overstory, manzanita presence, and shrub cover >20 percent were selected from the 438 sites that form the current DPS database. The species search function allows users the flexibility to search for all species or just overstory species by full or partial scientific or common names. Users can select an individual photograph to view a larger image and detailed site-level information.*

ing tasks (e.g., downloading and interpreting data files, viewing larger photographs, etc.), and running the stand alone MicroWeb version of DPS. Links to all of the documentation included in the printed NFPS volumes are available in the DPS at the bottom of every site-level page; it is very important to check this documentation to ensure proper interpretation and use of the data for each series.

The DPS diverges slightly from the published volumes of the NFPS in content and presentation. In many cases, information was added to DPS that was not originally published in the NFPS (e.g., landowner information and Bailey's ecoregions); in others, data were rearranged and terminology (e.g., field names and table headings) was standardized among sites. DPS also offers a choice of measurement units: the DPS default is English units (the original NFPS units), but users can toggle between English and metric units.

Future Development

Enhancements to the DPS will be released as they are developed, with input coming from current users of the NFPS books, fire and fuels planners, managers, and scientists. For example, we would like to allow data from the DPS to be easily extracted and formatted to interface with existing and future fire and fuel-management software packages (e.g., Fuel Characteristic Classification System, BehavePlus, FOFEM, and Consume 3.0).

At present, the DPS offers wide-angle photos for each site; we are hopeful that, in coming years, users will be able to view stereoscopic images on a computer screen. Data from other published photo series (e.g., Blonski and Schramel 1981; Fischer 1981b, 1981c, 1981d; Koski and Fischer 1979; Maxwell and Ward 1979, 1980b; Ottmar and Hardy 1989a, 1989b; Reeves 1988; Scholl and Waldrop 1999; Weise and others 1997), or other photographically documented fuels sources could also be added to the DPS.

DPS is robust, easy to use, and can readily accept new data as they become available.

Summary

The DPS is robust, easy to use, and can readily accept new data as they become available. The DPS effectively complements printed versions of the NFPS by extending the usefulness of NFPS data. Enhanced functionality includes the following:

- Data characterizing all of the vegetation and fuels, not just the down woody and surface fuels in an ecosystem, are viewable and available as printed or saved reports.

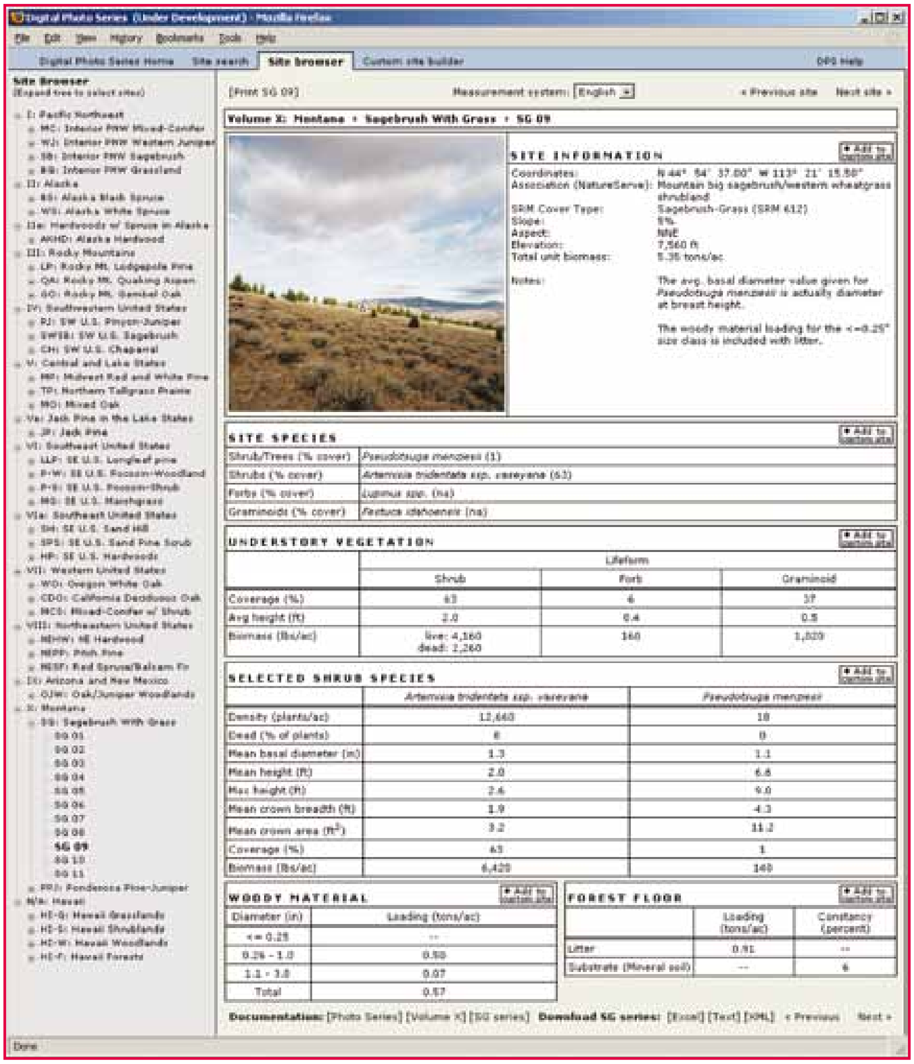

Figure 3—*Example of site-level data displayed by DPS. Data content and page display vary dynamically based on the type and amount of data collected at the different sites. The contents of DPS can be browsed much as in the printed volumes by using the navigation tree (left side of page) or by selecting the previous or next site in a series (lower and upper right of page). Data can be displayed in English or metric units and can be printed (top left of page) or exported to a Microsoft Excel, text, or XML file (bottom of page). Species are listed with their scientific names; hovering the cursor above a name will display the accepted common name. Documentation describing the NFPS in general and the volume or series in particular can be viewed using the links at the bottom of the page.*

- As a free, Web-based tool, DPS provides fire management and academic instructors with data and images for a wide variety of ecosystems.
- Users are able to draw on data and images from all published volumes simultaneously. Among other uses, the ability to query across locations and ecosystems allows users familiar with one ecosystem or fuel type to compare them with other, less familiar types.
- DPS is expandable, allowing it to accept new NFPS images and data as they are developed. Future versions may also incorporate data from other published photo series or photodocumented fuels inventories.

Acknowledgments

Numerous individuals contributed to the successful completion of the DPS: Alynne Bayard, Lara Kellogg, Mike Tjoelker, Jeff Kelly, Joe Restaino, Jon Dvorak, Aarin Sengsirirak, Paul Campbell, Frank Archuleta, Ann McCauley, Noah Carlson, Felicia Mehl, Zhen Zhu, and Veronica Mendoza. John Szymoniak helped us distribute our development survey to Federal fire and fuels professionals. The mansucript was improved by reviews from Ernesto Alvarado, Ellen Eberhardt, and David L. Peterson. The authors acknowledge funding from the Joint Fire Science Program under Project JFSP 04-4-1-02.

References

Blank, R.W. 1982. Stereo photos for evaluating jack pine slash fuels. Gen. Tech. Rep. NC-77. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station. 23 p.

Blonski, K.S.; Schramel, J.L. 1981. Photo series for quantifying natural forest residues: southern Cascades, northern Sierra Nevada. Gen. Tech. Rep. PSW-56. Berkeley, CA: USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. 145 p.

Fischer, W.C. 1981a. Photo guides for appraising downed woody fuels in Montana forests: how they were made. Res. Note INT-299. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 12 p.

Fischer, W.C. 1981b. Photo guide for appraising downed woody fuels in Montana forests: grand fir-larch-Douglas-fir, western hemlock, western hemlock-western redcedar, and western redcedar cover types. Gen. Tech. Rep. INT-96. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 53 p.

Fischer, W.C. 1981c. Photo guide for appraising downed woody fuels in Montana forests: interior ponderosa pine, ponderosa pine–larch–Douglas-fir, larch–Douglas-fir, and interior Douglas-fir cover types. Gen. Tech. Rep. INT-97. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 133 p.

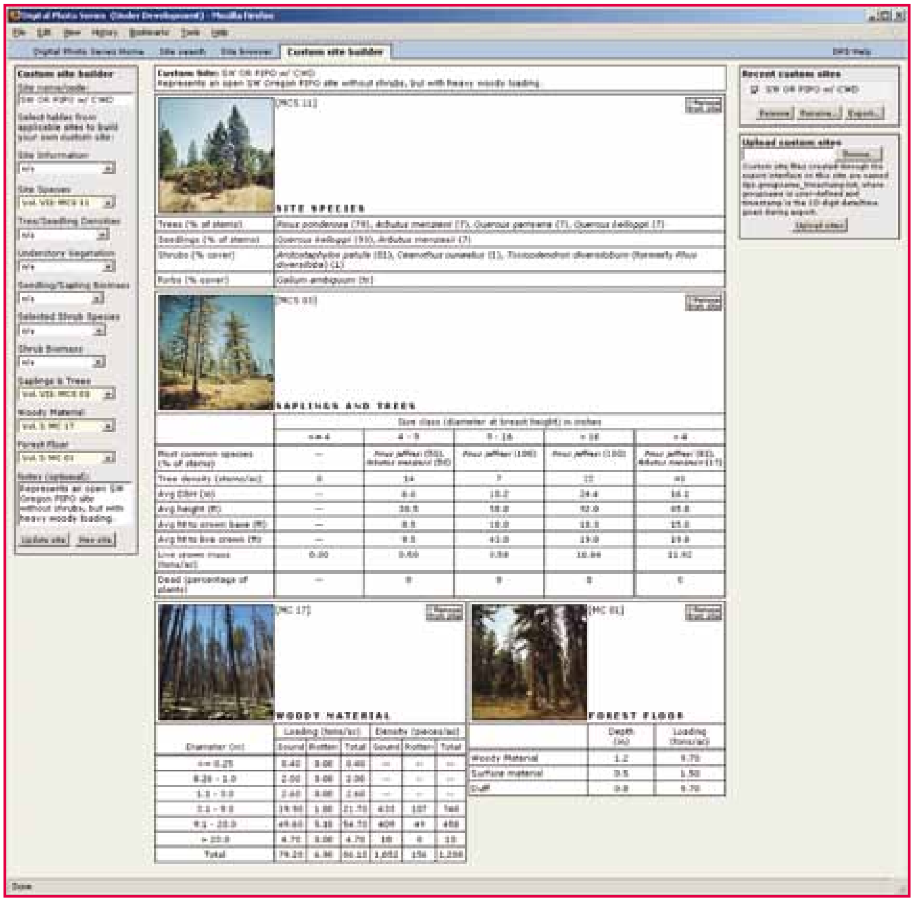

Figure 4—*Custom site builder page in DPS. Custom sites can be developed when users feel that the characteristics of their site are best represented by several different sites in DPS. In the example shown, the species composition and overstory structure are represented by two different sites in the mixed-conifer with shrub (MCS) series from Volume VII (Ottmar and others 2004). Woody material loading and forest floor characteristics are represented by two different sites in the mixed-conifer with mortality (MC) series from Volume I (Ottmar and others 1998). Medium-sized thumbnail images accompany the data for each site selected. Users can append short descriptions to their custom sites, save the resulting file to their computers, and share the file with colleagues.*

Fischer, W.C. 1981d. Photo guide for appraising downed woody fuels in Montana forests: Lodgepole pine, and Engelmann spruce–subalpine fir cover types. Gen. Tech. Rep. INT-98. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 143 p.

Koski, W.H.; Fischer, W.C. 1979. Photo series for appraising thinning slash in north Idaho: western hemlock, grand fir, and western redcedar timber types. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 50 p.

Maxwell, W.G.; Ward, F.R. 1979. Photo series for quantifying forest residues in the Sierra mixed conifer type, Sierra true fir type. Gen. Tech. Rep. PNW-95. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 79 p.

Maxwell, W.G.; Ward, F.R. 1980a. Guidelines for developing or supplementing natural photo series. Res. Note PNW-358. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p.

Maxwell, W.G.; Ward, F.R. 1980b. Photo series for quantifying natural forest residues in common vegetation types of the Pacific Northwest. Gen. Tech. Rep. PNW-105. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 230 p.

Ottmar, R.D.; Hardy, C.C. 1989a. Stereo photo series for quantifying forest residues in coastal Oregon forests: second-growth Douglas-fir–western hemlock type, western hemlock–Sitka spruce type, and red alder type. Gen. Tech. Rep. PNW-231. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 67 p.

Ottmar, R.D.; Hardy, C.C. 1989b. Stereo photo series for quantifying forest residues in the Douglas-fir-hemlock type of the Willamette National Forest. Gen. Tech. Rep. PNW-258. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 63 p.

Ottmar, R.D.; Vihnanek, R.E.; Wright, C.S. 1998. Stereo photo series for quantifying natural fuels. Volume I: mixed-conifer with mortality, western juniper, sagebrush, and grassland types in the interior Pacific Northwest. PMS 830. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 73 p.

Ottmar, R.D.; Vihnanek, R.E.; Wright, C.S.; Olson, D.L. 2004. Stereo photo series for quantifying natural fuels. Volume VII: Oregon white oak, California deciduous oak, and mixed-conifer with shrub types in the Western United States. PMS 839. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 75 p.

Ottmar, R.D.; Wright, C.S.; Prichard, S.J. 2009. A suite of fire, fuels, and smoke management tools. Fire Management Today. 69(2): 34–39.

Reeves, H.C. 1988. Photo guide for appraising surface fuels in east Texas: grass, clearcut, seed tree, loblolly pine, shortleaf pine, loblolly/shortleaf pine, slash pine, longleaf pine, and hardwood cover types. Nacogdoches, TX: Center for Applied Studies, School of Forestry, Stephen F. Austin State University. 89 p.

Scholl, E.R.; Waldrop, T.A. 1999. Photos for estimating fuel loadings before and after prescribed burning in the upper coastal plain of the southeast. Gen. Tech. Rep. SRS-26. Asheville, NC: USDA Forest Service, Southern Research Station. 25 p.

Weise, D.R.; Gelobter, A.; Haase, S.M.; Sackett, S.S. 1997. Photo series for quantifying fuels and assessing fire risk in giant sequoia groves. Gen. Tech. Rep. PSW-GTR-163. Albany, CA: USDA Forest Service, Pacific Southwest Research Station. 49 p.

Modeling Post-Fire Soil Erosion

Esther Godson and John D. Stednick

With the expansion of the wildland–urban interface, social pressures have increased to reduce potential wildfire threats to human life and property and minimize the negative environmental effects of fire (Pierson and others 2001; Elliot and Robichaud 2001; Parsons 2003; Pyne 2004; Stephens 2005; Stephens and Ruth 2005; Carroll and Cohn 2007). Because fire often results in changes in soil properties, reducing nutrient content and promoting soil erosion, sedimentation, and lower surface water quality (Neary and others 1999; Cannon 2001; Ice and others 2004), Federal and State land management agencies often focus on post-fire soil erosion control as a first step in post-fire site rehabilitation.

Computer-driven prediction models of post-fire soil erosion can aid site prioritization for erosion control measures (Robichaud and others 2003; Covert and others 2005) and incorporation of geographical information system (GIS) data has made these models useful watershed management tools (Renschler and others 1999; Flanagan and others 2000; Elliot and Foltz 2003; Miller and others 2003; Cochrane and Flanagan 2005). The Watershed Erosion Prediction Project (WEPP) and the geospatial interface for WEPP (GeoWEPP) are two process-based erosion models developed for forested environments (Flanagan and Livingston 1995; Elliot and Hall 1997; Elliot and others 2000a, 2000b; Renschler 2001, 2003). Such models predict post-fire soil erosion potential and help resource managers prioritize areas for site rehabilitation (Moody and Martin 2000; Elliot and Robichaud 2001).

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> Fire often results in changes in soil properties, reducing nutrient content and promoting soil erosion, sedimentation, and lower surface water quality.

Site rehabilitation efforts are often limited by funding, time, available information, and staff resources (USDA 1995; Robichaud and others 2000; Beeson and others 2001; Robichaud and others 2003). Furthermore, post-fire management decisions often lack detailed information about which areas are at highest risk of soil erosion and where to assign erosion control treatments for watershed rehabilitation. Fire and site characterization by fire crews during suppression efforts could address this information gap and provide information to resource managers immediately after fire containment for better post-fire management decisions.

Bridging Suppression and Rehabilitation Efforts

Initial attack incident organizers (IAIOs), pamphlets used by Forest Service initial attack forces, are used to track fires and collect information on fire suppression efforts. IAIOs can contain site-specific information, such as fuel type, fire character, fire spread potential, threatened resources, and weather conditions (NWCG 2006). IAIOs are maintained for all wildfire incidents (types 5, 4, and 3) until the fire is declared out or until it becomes more complex (type 2 or 1), at which point the use of a higher level incident action plan is required.

The site-specific information gathered by on-the-ground personnel could serve to increase the accuracy of fire severity classification, which currently is based on remote sensing imagery, and post-fire erosion potential models, which are based on soil and topography data. The addition of an IAIO field for fire severity could serve this need.

INITIAL ATTACK FIRE SIZE-UP
IC to Dispatch for Wildfires

Incident Name: ____________	**Date:** ____________
Estimated Size: ____________	**Time:** ____________
Approximate Location: ____________	**Datum: NAD83**
Incident Number: ____________	**Lat/Long: DD____MM____SEC** ______
	UTM: E________N ______
Incident Commander ____________	**Legal: T_____R_____S_____¼** _____
Qualifications ____________	**Estimated # Personnel to Control** ______
Home Unit ____________	____________
	Estimated Equipment Needed ______
CAUSE: H L INV Needed? ______	____________
IF HUMAN Need: Temp____RH ______	**Special Needs** ____________
	____________
Today's ERC of Unit ____________	**Today's BI of Unit** ____________

Character **% Active** ____________
smoldering crowning
creeping spotting
running

Estimated Size ____________
spot 1 acre
¼–½ acre 1–5 acres
½–¾ acre 6–25 acres

Estimated Wind ____________
0–5 20+
5–20 variable

Wind Direction ____________
down canyon north
up canyon south
down slope east
up slope west
variable

Fuel Type ____________
grass snag
brush/sage log/duff
re-prod p. pine
heavy timber Doug-fir
logging slash alpine fir
thin slash lodgepole

Adjacent Fuel ____________
grass snag
brush/sage log/duff
re-prod p. pine
heavy timber Doug-fir
logging slash alpine fir
thin slash lodgepole

Aspect ____________
flat south
north southwest
northeast west
east northwest
southeast ridgetop

Slope (Percent) ____________
flat 20–40
0–20 40+

Position on Slope ____________
ridge top lower 1/3
upper 1/3 valley/canyon bottom
middle 1/3 flat or rolling

Elevation ____________

Remember to give dispatch regular updates.

Management Factors

Values/Improvements ____________
Close proximity
Distance from values

Potential Fire Size ____________
<1000 acres
1000–5000 acres
>5000 acres

Barriers (e.g., old burns) ____________
Few
Moderate
Numerous

Fuel Continuity ____________
Continuous Fuels
Abundant Breaks
Limited Fuel Breaks

Potential Duration ____________
Short Term
May persist until WX change
Long Term

Sample page from an initial attack incident organizer for the Forest Service Intermountain Region (Region 4) showing fire size-up fields.

Revisiting Fires on the Payette

The Payette National Forest took part in a proof-of-concept study to assess the potential use of the IAIOs as a site-specific data source for WEPP and GeoWEPP to aid in prioritization of post-fire watershed rehabilitation sites. The study objectives were to model post-fire soil erosion using IAIO data fields, determine erosion model sensitivity to erosion factors, and propose future amendments to IAIO input in prioritizing rehabilitation efforts to limit soil erosion.

We compiled IAIO data for fire incidents from 2000 to 2004 on the Payette National Forest, located in west-central Idaho. The forest averages 150 fires per year, with a 20-year mean annual burn area of 50, 418 acres (20,403 ha); 70 percent of the fires are less than 0.25 acres (0.1 ha) in size. The study focused on the New Meadows Ranger District, where lower elevation, dry grasslands transition to forested uplands (Schnur 2009). The New Meadows Ranger District averages 20 wildfires per year, burning an average of 8,000 acres (3,237 ha) (Buescher 2004).

> Models of post-fire soil erosion can aid site prioritization for erosion control measures.

Putting IAIO Data to Use

We used the April 2005 version of WEPP and the March 2005 version of GeoWEPP (ArcX 2005.1) to model soil erosion. Input requirements for GeoWEPP included a 10-meter digital elevation model (DEM) and soils, land cover, land management, and climate data. We developed a GIS point layer of the IAIO fire locations and incorporated the IAIO fields wildfire location (latitude and longitude), fuel type, fire character, and fire spread potential into the model.

The fire character and fire spread potential fields from the IAIOs were used to produce a fire severity rating. We assumed that a fire with high spread potential and an extreme fire character would remove a majority of the overstory and ground vegetation, and thus rated it as high severity. This correlation is not always direct, as fire duration and residence time also influence fire severity; however, fire severity is often quantified by the amount of canopy cover removed (Neary and others 1999; Robichaud 2000; Parsons 2003). For purposes of modeling, the percentage of canopy cover removal for low-, moderate-, and high-severity wildfire was defined as 25, 45, and 90 percent, respectively, using Disturbed WEPP parameters as a guide (Flanagan and Livingston 1995; Renschler 2001).

Erosion Models for the Payette

We loaded the IAIO data in the soil erosion model to predict soil erosion rates and conducted a model sensitivity analysis of predicted rates using wildfire severity, soil texture (from the Disturbed WEPP soil categories), and slope as variables. Soil types were determined from land cover maps, slopes were input from the DEM, and fire severity was based on fire character and fire spread potential from the IAIO.

We used two erosion simulation methods: the watershed method and the flowpath method. The conventional watershed level method outputs sediment yields and distribution maps from representative hillslopes, including stream channel routing within the watershed; this method assesses the off-site impact on sediment yield. The user can set a threshold of concern and then map the sediment yield, showing areas where sediment production exceeds the level of concern.

The flowpath method differs from the watershed method in that it simulates and merges soil loss along all possible flowpaths for every pixel within the watershed. Soil loss is simulated for every flowpath individually, merged, and weighted by contributing area and length. The flowpath method (although more time-consuming to model) represents a more detailed assessment of soil loss and more accurately predicts on-site erosion impacts (Flanagan and others 2000; Renschler 2003; Elliott and others 2006; Schnur 2009).

> Fire and site characterization by fire crews during suppression efforts could provide information to resource managers immediately after fire containment for better post-fire management decisions.

The model was run with IAIO data for a total of 62 fires: 38 fires of low severity, 15 of moderate severity, and 9 of high severity (Schnur 2009). We then compared the model outputs for watershed and flowpath soil erosion using Student's paired t-test (SAS 2006).

Relating Erosion and Fire Severity

Predicted soil erosion rates increased with fire severity in both simulation models (watershed and flowpath). For the watershed method, the mean soil erosion rate for low-severity fires was 13.3 Mg/ha/yr (11,900 lbs/ac/yr), while soil losses following moderate- and high-severity fires were ecologically similar: 63.6 and 69.4 Mg/ha/yr (56,800 and 62,000 lbs/ac/yr), respectively (table 1). For the flowpath method, the mean soil erosion for low-severity fires was 21.4 Mg/ha/yr (19,100 lbs/ac/yr), compared to 78.2 and 115.7 Mg/ha/yr (69,800 and 103,000 lbs/ac/yr) for moderate- and high-severity fires, respectively. Differences in the potential soil erosion rates from watershed and flowpath models were statistically significant only for fires of low severity.

Several factors could have influenced the model's sensitivity to the increase of fire severity from low to moderate. The model's sensitivity to fire severity suggests that canopy cover change strongly influences model output (Miller and others 2003). This raises the question as to whether there is a threshold of canopy cover removal beyond which other factors become more important in predicting erosion.

The model was found to be less sensitive to slope, although predicted soil erosion increased about 25 Mg/ha/yr (22,000 lbs/ac/yr) for every 10-percent increase in slope (Schnur 2009). The IAIOs include slope classes of 0–20 percent, 20–40 percent, and over 40 percent. Smaller slope class intervals would improve estimates of potential soil erosion.

The model was notably less sensitive to soil texture than to slope. We assigned four different soil textures to the modeling runs: clay loam, silt loam, sandy loam, and loam. The sandy loam and loam soil textures had the greatest effect on model output: a difference of 0.67 Mg/ha/yr (600 lbs/ac/yr) in soil erosion was predicted between the two fire severities (low and high) modeled in areas with the sandy loam texture. Additional soil information would not necessarily improve prediction of soil erosion potential.

Table 1—*Summary statistics and Student's paired t-test results for watershed and flowpath methods' soil loss estimates, 2-year annual average in Mg/ha/yr (lbs/ac/yr) for all fires, according to wildfire severity.*

Fire Severity	Sample Size	Soil Loss	Mean	Std. Dev.	Minimum	Maximum	p-Value (α = 0.05)
Low	38	Watershed	13.3 ± 3.2 (11,800 ± 2,800)	20 (18,000)	0 (0)	111 (99,000)	0.01
		Flowpath	21.4 ± 4.4 (19,000 ± 3,900)	27 (24,000)	0 (0)	110 (98,000)	
Moderate	15	Watershed	63.6 ± 13.9 (56,700 ± 12,000)	51 (46,000)	1 (890)	186 (166,000)	0.20
		Flowpath	78.2 ± 15.5 (69,800 ± 14,000)	60 (54,000)	0 (0)	182 (162,000)	
High	9	Watershed	69.4 ± 19.9 (61,900 ± 18,000)	60 (54,000)	0 (0)	154 (137,000)	0.08
		Flowpath	115.7 ± 33.0 (103,000 ± 29,000)	99 (88,000)	3 (2,700)	286 (255,000)	

Summary and Recommendations

Results from this proof-of-concept study suggest that IAIO data can be used in the GeoWEPP model to estimate post-fire soil erosion potential. Using this methodology, land managers can better identify and prioritize site rehabilitation and make efficient post-fire decisions.

Modeling efforts pointed to a few issues to be addressed in future use of GeoWEPP and IAIO data. Output from the watershed and flowpath methods of modeling of soil erosion differed significantly for low severity fires only, but potential ecological differences between model outputs suggest that additional research is needed to recommend one method over the other. Because estimated soil erosion rates were sensitive to soil slope, we recommend that IAIOs have smaller slope class intervals for more accurate modeling and use of fine scale GIS data.

Based on the sensitivity analysis, we recommend that an additional data entry field for fire severity be included within the IAIO, accompanied by a description of each classification, similar to the fuel type descriptions. This would help improve rating consistency and decrease subjectivity. A field guide for classifying fire severity would be a useful supplement to the IAIOs to provide ready classification guidance for use by suppression forces.

We also recommend that future modeling include additional factors. To better anticipate site-specific effects, further investigation should include the roles of off-site erosion and stream connectivity to post-fire conditions in the fire area. The next step in site prioritization would be to incorporate these considerations in the post-fire management strategy and decision process.

Results from this proof-of-concept study suggest that IAIO data can be used in the GeoWEPP model to estimate post-fire soil erosion potential.

Literature Cited

Beeson, P.C.; Martens, S.N.; Breshears, D.D. 2001. Simulating overland flow following wildfire: Mapping vulnerability to landscape disturbance. Hydrological Processes. 15: 2917–2930.

Buescher, C. 2004. Annual Fire Report, Payette National Forest. McCall, ID: USDA Forest Service, Payette National Forest. 19 p.

Cannon, S.H. 2001. Debris-flow generation from recently burned watersheds. Environmental and Engineering Geoscience. 7(4): 321–341.

Carroll, M.S.; Cohn, P.J. 2007. Community impacts of large wildland fire events: consequences of actions during the fire. In: Raish, C., ed. People, Fire, and Forests: A Synthesis of Wildfire Social Science. Corvallis, OR: Oregon State University Press: 104–123.

Cochrane, T.A.; Flanagan, D.C. 2005. Effect of DEM resolutions in the runoff and soil loss predictions of the WEPP watershed model. Transactions of the American Society of Agricultural Engineers. 48(1): 109–120.

Covert, S.A.; Robichaud, P.R.; Elliot, W.J.; Link T.E. 2005. Evaluation of runoff prediction from WEPP-based erosion models for harvested and burned watersheds. Transactions of the American Society of Agricultural Engineers. 48(3): 1091–1100.

Elliot, W.J.; Foltz, R.B. 2003. The challenges in developing the WEPP cumulative effects model. In: Proceedings of the 2nd Forest Engineering Conference, Vaxjo, Sweden: 55–58.

Elliot, W.J.; Hall, D.E. 1997. Water erosion prediction project (WEPP) forest applications. Gen. Tech. Rep. INT-365. Moscow, ID: USDA Forest Service, Intermountain Research Station. 14 p.

Elliot, W.J.; Miller, I.S.; Glaza, B.D. 2006. Using WEPP technology to predict erosion and runoff following wildfire. Paper No. 068011. In: Annual International Meeting, American Society of Agricultural and Biological Engineers; Portland, OR. 11 p.

Elliot, W.J.; Robichaud, P.R. 2001. Comparing erosion risks from forest operations to wildfire. In: The International Mountain Logging and 11th Pacific Northwest Skyline Symposium, Seattle, WA: 78–89.

Elliot, W.J.; Scheele, D.L.; Hall, D.E. 2000a. The Forest Service WEPP Interfaces, Paper No. 005021. In: Annual International Meeting, American Society of Agricultural Engineers; Milwaukee, Wisconsin. St. Joseph, Michigan: American Society of Agricultural Engineers. 8 p.

Elliot, W.J.; Scheele, D.L.; Hall, D.E. 2000b. Disturbed WEPP (Draft 02/2000): WEPP interface for disturbed forest and range runoff, erosion and sediment delivery. Available at: <http://forest.moscowfsl.wsu.edu/fswepp/docs/distweppdoc.html> (accessed February 2010).

Flanagan, D.C.; Livingston, S.J. 1995. WEPP User Summary. NSERL Report No. 11. West Lafayette, IN: National Soil Erosion Research Laboratory.

Flanagan, D.C.; Renschler, C.S.; Cochrane, T.A. 2000. Application of the WEPP model with digital geographic information. In: Proceedings of the 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospects and Research Needs. Banff, Alberta, Canada. 15 p.

Ice, G.A.; Neary, D.G.; Adams, P.W. 2004. Effects of wildfire on soils and watershed processes. Journal of Forestry. 102: 16–20.

Miller, J.D.; Nyhan, J.W.; Yool, S.R. 2003. Modeling potential erosion due to the Cerro Grande Fire with a GIS-based implementation of the revised universal soil loss equation. International Journal of Wildland Fire. 12: 85–100.

Moody, J.A.; Martin, D.A. 2000. Initial hydrologic and geomorphic response following a wildfire in the Colorado Front Range. Earth Surface Processes and Landforms. 26(10): 1049–1070.

Neary, D.G.; Klopatek, C.C.; DeBano, L.F.; Folliott, P.F.1999. Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management. 122: 51–71.

National Wildfire Coordinating Group (NWCG). 2006. Incident Organizer. Boise, ID: National Wildfire Coordinating Group.

Parsons, A. 2003. Burned area emergency rehabilitation (BAER) soil burn severity definitions and mapping guidelines. Unpublished draft. Placerville, CA: USDA Forest Service, Eldorado National Forest. 8 p.

Pierson, F.B.; Robichaud, P.R.; Spaeth, K.E. 2001. Spatial and temporal effects of wildfire on the hydrology of a steep rangeland watershed. Hydrological Processes. 15: 2905–2916.

Pyne, S.J. 2004. Pyromancy: reading stories in the flames. Conservation Biology. 18(4): 874–877.

Renschler, C.S. 2001. GeoWEPP: the geo-spatial interfaces for water erosion prediction project (WEPP). Available at: <http://www.geog.buffalo.edu/~rensch/geowepp>. (accessed March 2010).

Renschler, C.S. 2003. Designing geo-spatial interfaces to scale process models: the GeoWEPP approach. Hydrological Processes. 17: 1005–1017.

Renschler, C.S.; Cochrane, T.A.; Harbor, J.; Diekkruger, B. 1999. Regionalization methods for watershed management: hydrology and soil erosion from point to regional scales. In: Stott, D.E.; Mohtar, R.H.; Steinhardt, G.C., eds. Selected Papers From the 10th International Soil Conservation Organization Meeting: Sustaining the Global Farm. West Lafayette, IN: Purdue University and the USDA Agricultural Research Service, National Soil Erosion Research Laboratory: 1062–1067.

Robichaud, P. 2000. Forest fire effects on hillslope erosion: what we know. Watershed Management Council Networker. 9(1). Available at: <http://www.watershed.org/?q=node/329> (accessed March 2010).

Robichaud, P.; MacDonald, L.; Freeouf, J.; Neary, D.; Martin, D.; Ashmun, L. 2003. Postfire rehabilitation of the Hayman Fire. In: Graham, R.T., tech. ed. Hayman Fire Case Study. Gen Tech Rep. RMRS-114. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 293–314.

Robichaud, P.R.; Beyers, J.L.; Neary, D.G. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. Gen. Tech. Rep. RMRS-63. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 85 p.

SAS. 2006. SAS Enterprise v. 4.1. SAS Institute Inc.

Schnur, E. 2009. Using initial attack incident organizers in prediction of postfire soil erosion potential. Master's thesis. Fort Collins, CO: Colorado State University. 77 p.

Stephens, S.L. 2005. Forest fire causes and extent on United States Forest Service lands. International Journal of Wildland Fire. 14(3): 213–222.

Stephens, S.L.; Ruth, L.W. 2005. Federal forest-fire policy in the United States. Ecological Applications. 15(2): 532–542.

United States Department of Agriculture (USDA). 1995. Burned area emergency rehabilitation handbook. FSH 2509.13. Washington DC: USDA Forest Service. ■

Using Trail Cameras To Understand Fire Behavior

Karen Ridenour and Rich Gray

Each year in Texas, wildfire events impact many small rural communities. On Thursday, April 9, 2009, Texas experienced an outbreak of wildfires in 12 North Texas counties. In Montague County, where 7 fires burned independently of each other, 36,408 acres (14,734 ha) of agriculture land, 86 homes, and 4 lives were lost. A case study team was sent to examine the economic, agricultural, and community impacts to the area, and the factors affecting home loss during this fire event.

Observing Fire From Within

While collecting data for the case study, several homeowners indicated that they had acquired images of the fire within the fire perimeter from game cameras placed around their property. The cameras provide a firsthand view of the fire movement within the cameras' sight range. The study team recognized that such images could have great value in fire analysis.

Existing equipment can capture high-quality images, collect data, and produce scientific fire outputs for examination; however, this information comes at an extremely high cost. McMahon and others (1986) discuss using a low-cost video imagery analysis system to measure fire behavior in both lab and field experiments. Nelson and Adkins (in preparation) studied rates of spread, flame lengths, and fireline intensity relationships in controlled conditions on small-scale fires. Clark and others (2005) used digital video imagery to analyze the convective-scale motion in the plane viewed by the camera and then develop a computational technique to derive quantitative estimates of the convective motion within a grass fire from the digital video imagery. The latter studies yielded valuable information regarding fire behavior, but each cost thousands of dollars. This cost makes the technology unattainable to most land managers and fire analysts.

By using trail cameras, researchers and professionals can gain a unique view of fire activity during an event at a low, affordable cost.

Trail cameras are a logical complement to equipment already being used to study fire behavior. Researchers have used buried electronic data loggers and surface thermocouples to capture temperature dynamics during prescribed fires, yielding information on heat outputs and rates of spread. Equipment cost is about $300 per firelogger (Grace and others 2005). Trail cameras can capture images at an affordable cost to complement firelogger data. The cameras that captured fire photos in this study ranged in price from $80 to $100.

Land managers establish objectives prior to conducting a prescribed burn. Afterward, they can determine the success or failure to meet objectives but generally cannot observe how these objectives are met during the burn. Regarding the threat to homes in the wildland–urban interface (WUI), understanding fire behavior and effects that take place within different ecosystem types can encourage builders to develop fire-resistant building techniques for homes in areas of high risk.

Monitoring Fire Conditions

The timber fuels throughout Montague County were composed of mixed hardwoods, including blackjack oak (*Quercus marilandica*), post oak (*Quercus stellata*), and, in some places, hickory (*Carya* spp.) and elm (*Ulmus* spp.). Dead oak leaves are sizeable and create a deep layer of burnable biomass on the forest floor. These dead leaves increase ember production and spotting ahead of the fire front. The undergrowth in some parts of the study area was so matted with greenbrier (*Smilax bona-nox*), a thorny vine, that almost impenetrable "roughs" were formed. Greenbrier can overwhelm the lower canopy of hardwood forests and create elaborate vine communities on hardwood trunks. With each series of photos, visual inference of the fire that took place in specific

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post oak areas emerged. Upon early examination of images, some inferences could be made with regard to fire behavior in the post oak–grass understory ecosystem.

Fire researchers and managers routinely map and model fire spread as a linear progression. Most homeowners believe that, when a fire moves through an area, there is a spike in temperature of a short duration. The trail cameras provided a microsite viewpoint that revealed not a spike but an arc in ambient air temperatures. Ambient

Images taken by a game camera during a wildfire on April 9, 2009, on the property of Dan Cordonnier. Photos: Dan Cordonnier.

temperatures at one trail camera were elevated to 116 °F (47 °C) for 6 minutes. The fireloggers located at ground level measured an extreme temperature spike of more than 1,000 °F (537 °C) for several seconds but then logged a drop in ambient temperatures similar to that recorded by the trail cameras. The trail cameras revealed that elevated temperatures occurred throughout the vertical profile of the landscape and not just at ground level: not only as radiant

Images taken by a game camera during a wildfire on April 9, 2009, on the property of Robert Lindsey. Photos: Robert Lindsey.

> The trail cameras revealed that elevated temperatures occurred not only as radiant heat, but as a heated air mass affecting the fire environment, potentially promoting re-burning of fuels after the fire front had passed.

heat, but as a heated air mass affecting the fire environment, potentially promoting re-burning of fuels after the fire front had passed. This heated air mass contributed to long-duration burning in 100- and 1,000-hour fuels. These fuels exhibited complete consumption due to radiant and convective heat as well as residual burning, which reflected dry fuel conditions in the heavy down and dead fuels represented in the images.

The massive heat given off by the fire created extreme heat pulses that increased the ambient air temperature by as much as 32 °F (18 °C) in a matter of minutes; the temperatures remained elevated above the initial ambient air temperature for 60 minutes. A different trail camera located a mile (1.6 km) away on the same property produced a similar long-duration heating arc following fire passage.

Local remote area weather stations validated initial ambient air temperatures recorded by the trail cameras throughout the burn area. Typically, onsite weather data is collected at the flank or back of the fire but does not include data from the center point of fire activity; trail cameras could be used to provide onsite fire weather information as well as images in the most extreme area of the fire.

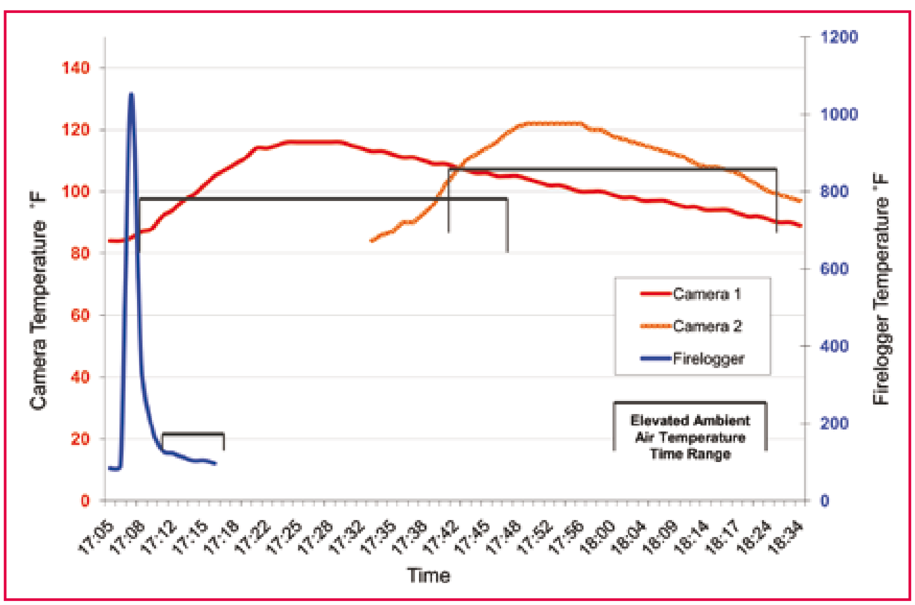
Rethinking Fire Modeling

Assumptions built into existing fire models do not accommodate the temperatures and prolonged duration of the fire environment observed in this study. For example, BEHAVE, a fire modeling program commonly used to predict wildland fire behavior, has a maximum dry bulb temperature parameter of 110° F (43 °C) for determining fine dead fuel moisture, which contributes to such fire behaviors as reaction intensity and rates of spread. Observed temperatures exceeded that maximum, requiring an examination of this and other parameters.

As land managers plan prescribed burns and model expected fire behavior, real-time observations could aid in defining objectives and obtaining desired outcomes. Planners should consider the increase and duration of temperatures in the environment, and models could be adjusted to reflect this temperature exposure to vegetation. Trail cameras could be placed in predetermined locations prior to a prescribed burn and used to observe flame lengths and the residence time of fire in a particular area in order to calibrate BEHAVE runs. These trail cameras could also be used to evaluate how prolonged heat duration affects management objectives and how the fire affects targeted vegetation even after passage of the fire front.

Fire Behavior and Fire Protection

When examining homes in the WUI, the customary tactic is to protect homes from fire only until the fire front passes. Given that a secondary fire danger remains, fire managers need to re-examine tactical decisions in pretreating or protecting homes, retreating when safety becomes an issue, but



Ambient air temperatures recorded on game cameras and surface fire temperatures recorded on research fireloggers for a wildland fire in Montague County, TX, on April 9, 2009. Although the firelogger captures the extreme temperature spike of more than 1,000 °F (537 °C), the trail cameras reveal longer duration, elevated ambient air temperatures.

Position of camera. Photo: Karen Ridenour, Texas Forest Service, 2009.

then re-engaging the fire after the front passes to prevent the delayed ignition of homes exposed to prolonged elevated temperatures. Ember production, for instance, is routinely noted in literature as a major source of home loss in the WUI. Images from the trail cameras reveal the showering of embers into both receptive and nonreceptive fuels, and large fuels located in dirt can be seen burning as a result of fallen embers, not flame contact.

Each trail camera presents a unique series of images; this information can be used to make visual inferences that would not be possible otherwise. As current fuel models project only average temperatures, the data from trail cameras can be used to compare modeled and real-time data. Rates of spread in different surface fuels, such as grass or leaf litter, could be examined by this low-cost method. After wildfire events, data from these trail cameras could provide reference photos of fire behavior to verify rates of spread, ember production, and flame length in the area. Also, these trail cameras would help managers determine if prescribed fire objectives had been achieved by looking at vegetation impacts based on observed time of heat duration and fire intensity. Further investigation could improve management of valued ecosystems as well as creation of defensible space around homes and communities and implementation of other activities recommended by Firewise programs.

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References

Clark, T.L.; Reeder, M.J.; Griffiths, M.; Packham, D.; Krusel, N. 2005. Infrared observations and numerical modelling of grassland fires in the Northern Territory, Australia. Meteorology and Atmospheric Physics. 88(3–4): 193–201.

Grace J.; Owens, A.; Allain, L. 2005. Firelogger user's manual. USGS Open-file Report 2005-1212. Lafayette, LA: U.S. Geological Survey National Wetlands Research Center. Version III. 24 p. Available online at: http://www.nwrc.usgs.gov/about/web/OFR2004-1212.pdf (accessed June 2010).

McMahon, C. K.; Adkins, C. W.; Rodgers, S. L. 1986. A video image analysis system for measuring fire behavior. Fire Management Notes. 47(1): 10–15.

Nelson, Ralph M., Jr.; Adkins, Carl W. In preparation. Flame characteristics of wind-driven fires in surface fuels. Submitted to Canadian Journal of Forest Research. ■

Failure To Communicate: Improving Radio Discipline on the Fireline

By Ken Frederick and Mike Tuominen

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It has become one of the most memorable lines in the history of American cinema: "What we've got here is failure to communicate." That line, from the 1967 film *Cool Hand Luke*, aptly and ironically describes a serious issue in radio communication on wildfires and other incidents: too much radio traffic. Rather than facilitating communication, too much of a good thing actually causes problems.

Overabundant radio communication isn't just an annoyance; it can have serious consequences in all areas of fire suppression. Leaders in fire and aviation management—particularly supervisors at the crew level—should be mindful of radio discipline and encourage good radio use and etiquette.

Defining "Radio Discipline"

Radio discipline is the adherence to codes of use and behavior (both formal and informal) associated with communication using handheld, mobile, and base radios. Radio discipline falls into three general areas:

- Avoidance of offensive, derogatory, or disrespectful language in radio transmissions;
- Avoidance of radio use that reflects panic, anger, or other behaviors associated with a loss of professional composure; and
- Avoidance of pointless traffic in radio transmissions—communication that is irrelevant or only marginally relevant to the job at hand.

These aren't the only issues involved with radio communication. Operations and communications specialists cite several other common issues: scanning more channels than can meaningfully be understood, overriding another person's radio traffic, competition for frequencies, failure to clear frequencies during emergencies, and difficulty enforcing standards of behavior related to radio use. This article focuses specifically on the overabundance of radio traffic, its ramifications on the fireline, and how leadership can respond to this issue.

Constant radio transmission is likely to diminish a person's ability to mentally sort, track, and act on information in a dynamic environment.

Handheld radios are indispensible tools in wildland fire suppression. Photo: National Interagency Fire Center.

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Causes of Too Much Radio Traffic

Buck Wickham is a long-time fire management officer, operations section chief, and firefighter on the Coconino National Forest in northern Arizona. He recalls an instance that demonstrates how communication was handled prior to the widespread use of radios:

> At the start of my career in the early 1970s, I worked at a remote guard station in central Arizona. One time, two 80-year-old gents came to visit my guard station, as they had worked there decades ago. As we visited, we got to discussing how things used to be. They recalled in the old days, they would climb a tree after lightning and if they saw a fire, they would naturally head over to it. When they arrived, they would assess the fire, and if they could handle it, they would pile up some green limbs and set them on fire. This individual smoke column would send the message to everyone else back at the guard station that they had the fire in hand and didn't need any help. I asked them what they would do if they needed help. They just looked at each other and told me, "Son, if we needed help everyone knew because the smoke column from the main fire got big!" It shows that we have come a long way.

Fireline supervisors discuss tactics while working on a large fire in the Pacific Northwest. Division/group supervisors use multiple radio frequencies to coordinate operations on their divisions. Photo: National Interagency Fire Center.

Technological advances have indeed come a long way. Handheld radios are far more advanced than their distant cousins of a generation ago. "One of the newest technologies is multiband radios," said Mike Tuominen, who works at the National Interagency Fire Center (NIFC) in Incident Communications Operations. "A single radio can now operate on multiple *bands*, not just multiple frequencies. In terms of communication capability, this means we've gone from a sedan to a sports car in just the past couple of years." But one of the downsides of the availability of technology is occasionally having too much radio traffic. What has caused this?

First, the increase in radio chatter is a reflection of our culture and society. Our world is saturated with instant communication. Cell phones, texting, instant messaging, social networking Web sites, and other communication technologies drive this phenomenon. People expect to communicate rapidly, constantly, and without restraints. As younger firefighters enter the ranks, they bring these expectations with them.

The second causal factor relates to the sheer number of radios being used in wildland fire. Twenty years ago, hand crews normally shared 3 radios among the 20-person crew. Now, the typical type 2 hand crew often has six to eight radios. Hotshot crews carry an average of 11 radios among the crew, and some hotshot crews supply all 20 crewmembers with a radio, according to the National Interagency Incident Communication Division (NIICD) at NIFC. This abundance of radios has naturally led to an increase in the volume of radio traffic.

Third, placing a radio in a firefighter's hands is essentially an authorization to use it. It is, however, counterintuitive to give someone use of a tool like a radio while telling him or her at the same time to restrict his or her use of that tool. Merely *having* a tool helps create the *need* to use the tool.

Consequences of Overabundant Radio Traffic

The problem of overabundant radio traffic is not new. The 1998 Firefighter Safety Awareness

Study pointed out the same problem: "The intended result [of increased radio communication] is to increase the flow of important information through interaction, *without the unintended result of flooding the available radio communication frequencies and interfering with critical messages*" (NIFC 1998; emphasis added).

Overabundant radio traffic clogs the airwaves and can force necessary communication to wait in line or become lost amid the cacophony.

Too much chatter relates to several significant problems. First, constant radio transmission is likely to diminish a person's ability to mentally sort, track, and act on information in a dynamic environment. Researchers have studied how talking on a cellular telephone affects a person's ability to sustain his or her attention in a dynamic visual environment (Kunar and others 2008). They concluded that the cognitive processes necessary to converse over a telephone overshadowed the cognitive processes needed to evaluate, compare, and draw inferences about a dynamic situation (in the study cited: while driving). The parallels between talking on a telephone while driving and talking on a radio while supervising multiple tasks in a wildfire environment are apparent. Acting as a lookout, directing water or retardant drops, and supervising direct line construction are examples of firefighting activities that require a high level of focus and attention. Research suggests that this focus and attention can be impaired by excessive radio conversation.

A firefighter uses a driptorch to burn out fuels inside a section of fireline. Clear radio communications are essential to coordinate complex suppression tactics like burnouts. Photo: National Interagency Fire Center.

Firefighting pilots are especially cognizant of the distractions caused by too much radio traffic. Overabundant radio traffic can pose special challenges for pilots flying a firefighting mission without a copilot, observed Mark Bickham of the Bureau of Land Management's National Aviation Office. In addition to safely flying the aircraft, solo pilots have to communicate with dispatch, air attack, other tactical aircraft, and ground contacts on up to three radios. "It's important for ground personnel to communicate with pilots using *clear* and *concise* speech," Bickham emphasized.

Overabundant radio traffic clogs the airwaves and can force necessary communication to wait in line or become lost amid the cacophony. For example, one analysis of radio traffic transcripts from training exercises and actual emergencies found that up to 12 percent of radio messages went unacknowledged (Timmons 2007). In many instances, messages to the incident commander went unacknowledged—presumably, because the messages were not heard. This is a significant safety issue because, when the lives of firefighters or the public may be in danger, critical information must be communicated by radio.

Furthermore, crowded airwaves tend to trigger unrealistic pressure for additional frequencies on incidents. Frequencies are finite resources and simply may not be available. U.S. Department of Agriculture and U.S. Department of the Interior land management units with fire management responsibilities number in the hundreds, yet these units together have only 208 permanently allotted frequencies. “Radio frequencies are intangible, so it’s understandable that people don’t think of them as they do a more tangible firefighting resource, like airtankers and hotshot crews,” added Tuominen. “Sometimes every available frequency is being used.”

Some crews attempt to work around overcrowded frequencies on incidents by using their home unit radio frequencies on assignments, especially for intercrew communication. “What many people don’t realize,” said Stephen Jenkins, director of the NIICD, “is that they don’t own their home unit frequencies.” Radio frequencies are assigned and authorized throughout the country by either the Federal Communications Commission or the National Telecommunications and Information Administration. Units are authorized to use their “home” frequencies *only* on their home unit. That frequency might be in use in dozens of other localities in the country. “Not only is using a ‘home unit’ frequency in another part of the country illegal, it can cause serious communication and safety problems,” Jenkins noted.

Improving Radio Use Habits

A number of approaches exist for alleviating problems in radio discipline, etiquette, and use. One thing that will *not* be done is to start taking away radios. Handheld radios offer far more benefits than problems, and no one is suggesting the removal of radios as a response to radio discipline issues. Still, leadership can take some positive steps to improve radio use:

A member of the Eldorado Hotshots directs aerial support. When speaking with pilots, targets should be described clearly and concisely. Photo: National Interagency Fire Center.

1. Effective preseason training in radio etiquette and use helps prevent problems on incidents. Kyle Cannon is a fire management officer on the Okanogan-Wenatchee National Forest in central Washington State. As a former interagency hotshot crew superintendent, Cannon has dealt with radio discipline issues on many occasions. “We found that carefully addressing radio etiquette and use issues before fire season was a good approach,” he said. “Most hotshot crews have a good reputation and senior crew members don’t want the crew’s reputation tarnished by improper radio communication by newer members of the crew. Once everyone knew what our crew’s standards were, much of the accountability for proper radio use occurred within the crew.”
2. Describing complex situations and locations over the radio can be aided by practice. “Clearly and concisely describing a target location to a pilot flying above a fire is not always easy,” said Mark Bickham. “But it’s a skill that can be improved by practicing in a simulated environment.”
3. Education on radio discipline can and should occur at incidents. Briefings before shifts present a good opportunity to address issues like overabundant or irrelevant radio traffic. “At each briefing, I mention the need for brevity and thinking ahead in radio communications,” said Paul Glazer, a communications unit leader and National Park Service telecommunications manager in Arizona. “I have a saying that’s sort of my mantra: ‘On the radio, if you have nothing to say…don’t say it.’ After a few days of repeating that phrase at morning briefings, all I have to say is, ‘If you have nothing to say…’ and the firefighters will finish my sentence.” Similarly, safety officers can use a few minutes at briefings to outline procedures for keeping frequencies clear during emergencies.

4. Glazer pointed out another important aspect of radio discipline: radio users need to think through what they want to say well ahead of keying the microphone. This point is made succinctly in a recent U.S. Fire Administration report: "Prior to transmitting a message, firefighters should collect their thoughts and format the message in their head" (USFA 2009). Time is wasted—and confusion is created—when people talk over the radio without saying what they need to say.
5. Messages about radio discipline and etiquette can also be published in the incident action plan, posted on bulletin boards, and placed in dining areas at the incident command post. Simple and direct methods of getting the message to firefighters are useful because, if they understand why radio discipline is important, firefighters will be much more apt to use self-discipline to curb poor or unnecessary radio use.
6. In some cases, operations section chiefs have removed crews from assignments for serious violations of radio etiquette. Though punitive measures are almost always a last resort, leaders should maintain meaningful accountability for improper radio use.
7. After-action reviews are another means of reinforcing good radio etiquette, especially if a crew witnessed an egregious example of poor radio use on an incident. Facilitated learning is a good method of ingraining positive behavior.

People expect to communicate rapidly, constantly, and without restraints. As younger firefighters enter the ranks, they bring these expectations with them.

A division/group supervisor conducts a briefing prior to a shift on the fireline. Briefings offer opportunities to reinforce radio discipline principles with firefighters. Photo: National Interagency Fire Center.

Conclusion

The radio communication system used for incident management across the United States is world-class. Its technological capability, ease of use, and exceptional effectiveness add up to a fantastic tool. This system reflects the interagency commitment to excellence in fire management. However, the system's effectiveness can be degraded by poor radio use habits. Good radio etiquette and discipline should be practiced by fire crews, supervisors, and leaders on the fireline for a safe and productive firefighting environment.

References

Hutchins, S.G.; Timmons, R.P. 2008. Radio interoperability: Addressing the real reason we don't communicate well during emergencies. Paper presented at the 12th International Command and Control Research and Technology Symposia; 19–21 June; Newport, RI.

Kunar, M.A.; Carter, R.; Cohen, M.; Horowitz, T.S. 2008. Telephone conversation impairs sustained visual attention via a central bottleneck. Psychonomic Bulletin and Review. 15(6): 1135–1140.

National Interagency Fire Center (NIFC). 1998. Firefighter Safety Awareness Study; Phase III: Implementing Cultural Changes for Safety; Chapter 3: Organizational Culture. Boise, ID: National Interagency Fire Center, p. 73.

Timmons, R.P. 2007. Interoperability: Stop blaming the radio. Homeland Security Affairs. III(1): 7.

United States Fire Administration. 1999. Improving firefighter communications. Special report USFA-TR-099. Washington, DC: U.S. Department of Homeland Security. 17 p.

2010 Photo Contest

Deadline for submission is 6 p.m. eastern time, Wednesday, December 1, 2010

Fire Management Today (FMT) invites you to submit your best fire-related images to be judged in our photo competition. Entries must be received by close of business at 6 p.m. eastern time on Wednesday, December 1, 2010.

Awards
Winning images will appear in a future issue of *FMT* and may be publicly displayed at the Forest Service's national office in Washington, DC.

Winners in each category will receive the following awards:
- 1st place: One 20- by 24-inch framed copy of your image.
- 2nd place: One 16- by 20-inch framed copy of your image.
- 3rd place: One 11- by 14-inch framed copy of your image.
- Honorable mention: One 8- by 10- inch framed copy of your image.

Categories
- Wildland fire
- Aerial resources
- Wildland-urban interface fire
- Prescribed fire
- Ground resources
- Miscellaneous (fire effects, fire weather, fire-dependent communities or species, etc.)

Rules
- The contest is open to everyone. You may submit an unlimited number of entries taken at any time, but you must submit each image with a separate release/application form. You may not enter images that were judged in previous *FMT* contests.
- You must have the authority to grant the Forest Service unlimited use of the image, and you must agree that the image will become public domain. Moreover, the image must not have been previously published in any publication.
- *FMT* accepts only digital images at the highest resolution using a setting with at least 3.2 mega pixels. Digital image files should be TIFFs or highest quality JPGs. Note: *FMT* will eliminate date-stamped images. Submitted images will not be returned to the contestant.
- You must indicate only one category per image. To ensure fair evaluation, *FMT* reserves the right to change the competition category for your image.
- You must provide a detailed caption for each image. For example: *A Sikorsky S-64 Skycrane delivers retardant on the 1996 Clark Peak Fire, Coronado National Forest, AZ.*
- You must submit with each digital image a completed and signed Release Statement and Photo Contest Application granting the Forest Service rights to use your image. For a copy of the release, see http://www.fs.fed.us/fire/fmt/release.pdf.

Disclaimer
- A panel of judges with significant photography and publishing experience will determine the winners. Their decision is final.
- Images depicting safety violations, as determined by the panel of judges, will be disqualified.
- Life or property cannot be jeopardized to obtain images.
- The Forest Service does not encourage or support deviation from firefighting responsibilities to capture images.
- Images will be eliminated from the competition if they are obtained by illegal or unauthorized access to restricted areas, show unsafe firefighting practices (unless that is their expressed purpose), or are of low technical quality (for example, have soft focus or camera movement).

To help ensure that all files are kept together, e-mail your completed release form/contest application and digital image file at the same time.

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