USDA

United States Department of Agriculture

Fire Management today

AUGUST 2020 • VOL. 78 • NO. 2

Forest Service Assistance to Ukraine Following the Chernobyl Disaster

The Camp Fire Tragedy of 2018 in California

Optimizing Firefighter Nutrition

and more ...

Fire Management *today*

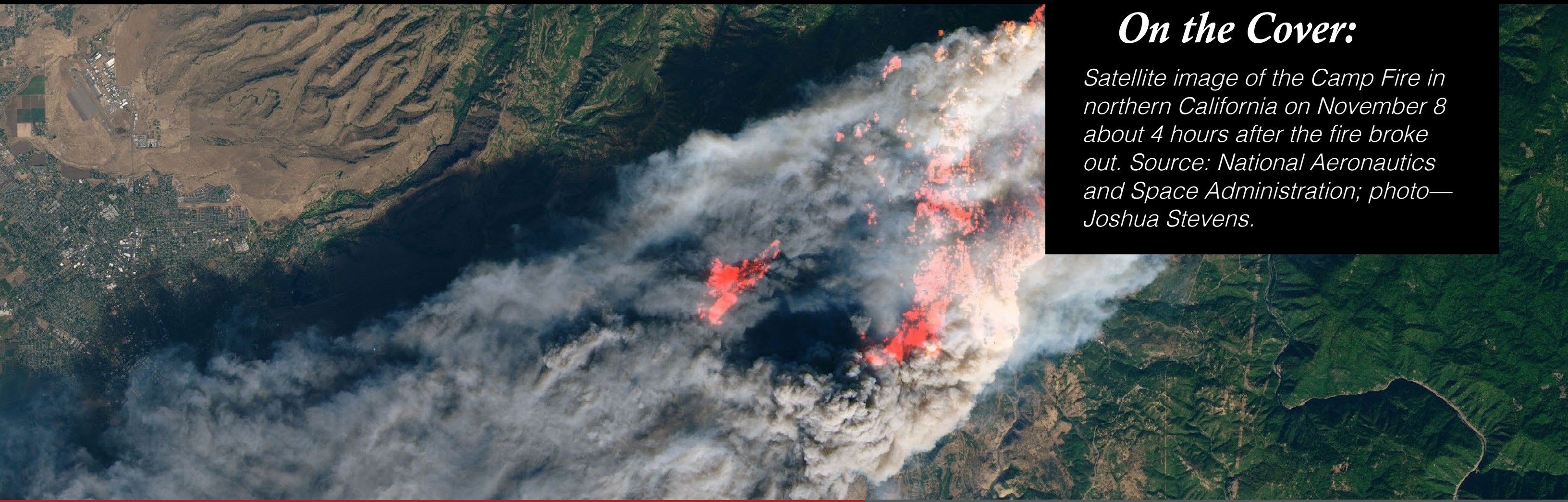
Fire Management Today is published by the Forest Service, an agency in the U.S. Department of Agriculture, Washington, DC. The purpose of ***Fire Management Today*** is to share information related to wildland fire management for the benefit of the wildland fire community. ***Fire Management Today*** is available on the World Wide Web at *https://www.fs.usda.gov/managing-land/fire/fire-management-today.*

Victoria Christiansen, Chief
Forest Service

Shawna A. Legarza, Psy.D., Director
Fire and Aviation Management

Kaari Carpenter, General Manager • Hutch Brown, Editor

AUGUST 2020 • VOL. 78 • NO. 2



On the Cover:

Satellite image of the Camp Fire in northern California on November 8 about 4 hours after the fire broke out. Source: National Aeronautics and Space Administration; photo—Joshua Stevens.

IN THIS ISSUE

AUGUST 2020 • VOL. 78 • NO. 2

Firefighter and public safety is our first priority.

GUIDELINES for Contributors

Responding to Disasters Around the World

By Shawna A. Legarza, Psy.D.
Director, Fire and Aviation Management Forest Service

> **I am proud of the spirit of innovation and discovery in the Forest Service and in the broader wildland fire community.**

This issue of *Fire Management Today* begins with articles related to major disasters—at Chernobyl in Ukraine 34 years ago and in the northern Sierra Nevada of California just 2 years ago. In each case, Forest Service personnel have responded to the effects of the disaster and its implications for the future, and I am proud of the role we are playing in improving firefighter and public safety, both at home and around the world.

In April 1986, the worst nuclear reactor disaster in history occurred at the Chernobyl power plant in Ukraine, near the border with Belarus. Wildfires in radioactively contaminated zones near the Chernobyl reactor can redistribute contaminants in the air, posing health risks to firefighters and the general public. In response, Forest Service International Programs mobilized partners in Ukraine and Belarus as well as in Forest Service Research and Development to assess the potential risks to human health and the environment and work to mitigate the risks.

All this is part of a longstanding program of work that Forest Service International Programs has with partners in the United States and around the world to sustain forests and respond to wildfire-related and humanitarian disasters. Additionally, the Forest Service has had an ongoing relationship with Australia and New Zealand since the 1950s through joint efforts and coordination between the North American Forest Commission's Fire Management Working Group (which includes the United States, Canada, and Mexico) and the Forest Fire Management Group (which includes Australia and New Zealand). Particularly since winter 2019, when the United States sent firefighters and other resources to help Australia during an unprecedented fire year, we recognize the global importance of conservation and the interdependence of people around the world in responding to fire-related challenges.

In November 2018, the Camp Fire was the worst wildfire disaster in the United States since the Cloquet Fire in 1918, with 85 fatalities, nearly 19,000 buildings destroyed, and losses estimated at $16.5 billion. In response, the Forest Service and our interagency wildland fire partners mobilized thousands of firefighters within hours. Despite high winds and extreme fire behavior, tens of thousands of residents were evacuated. Forest Service researchers have joined partners in evaluating the effects of the Camp Fire to highlight the importance of protecting the wildland–urban interface.

Other articles in the issue highlight the historical and ecological context of wildland fire, firefighter nutrition, and smoke management. Innovations in fire equipment and the use of a repurposed military vehicle during a natural disaster round out the issue. I am excited to share with you the great contributions that research is making in helping us rise to fire-related challenges, both here at home and around the world. I am proud of the spirit of innovation and discovery we find today, both in the Forest Service and in the broader wildland fire community—our willingness to learn from experience for the sake of a better future.

Forest Service Assistance to Ukraine Following the Chernobyl Disaster

Rich Lasko, Alan Ager, and Shelia Slemp

In April 1986, the worst nuclear reactor disaster in history occurred at the Chernobyl power plant in Ukraine, about 60 miles (100 km) north of the Ukrainian capital of Kyiv (near the border with Belarus) (fig. 1). An explosion and a 5-day fire released airborne radioactive contamination across large parts of Europe before the accident was finally contained.

In 2005, responding to a request from the National Agricultural University

Rich Lasko, now retired, was the Deputy Director of Fire and Aviation Management for the Forest Service, Washington Office, Washington DC; Alan Ager is a Research Forester for the Forest Service, Missoula Fire Sciences Lab, Rocky Mountain Research Station, Missoula, MT; and Shelia Slemp is the Eastern Europe Program Manager, U.S. Forest Service International Programs, Washington Office, Washington, DC.

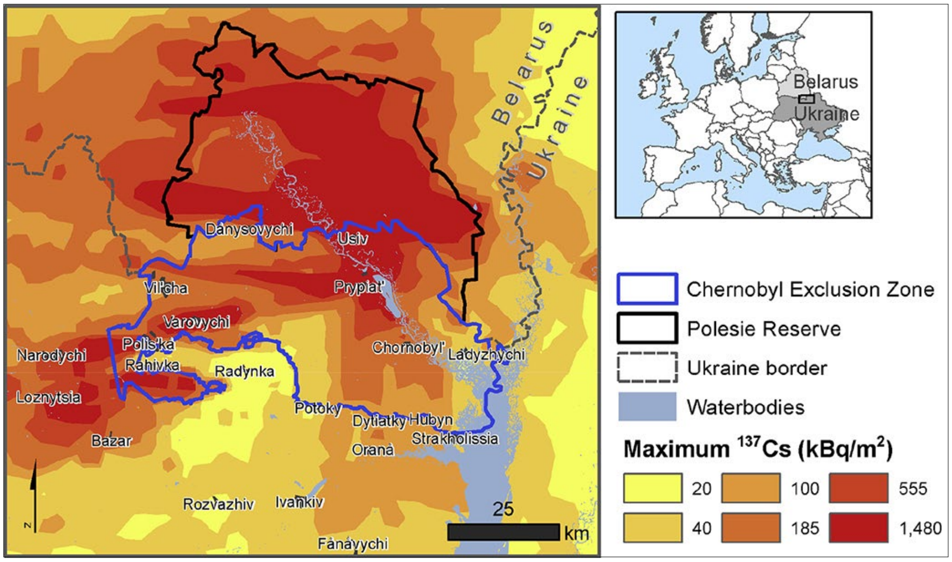


Figure 1—*Location of the Chernobyl nuclear reactor in northern Ukraine. The map shows the extent of radionuclide contamination in 1986, when the accident occurred at the reactor, by radiocesium (^{137}Cs) as well as the Chernobyl Exclusion Zone in Ukraine and the Polesie Radioecological Reserve in Belarus. Both are restricted areas of heavy contamination. (kBq/m^2 = kilobecquerels per square meter, a measure of radioactivity.) Source: Ager and others (2019).*

of Ukraine, specialists from Forest Service International Programs traveled to Ukraine to study natural resource issues and assess whether Forest Service technical assistance might be beneficial. The specialists recognized the potential risks to human health and the environment from wildfires in contaminated forests near Chernobyl, and the Forest Service began technical assistance to mitigate the effects of future wildfires. Forest Service International Programs has a longstanding program of work with partners in the United States and around the world to sustain forests and respond to wildfire-related and humanitarian disasters. The Chernobyl project became part of ongoing Forest Service International Programs work.

In a previous issue of *Fire Management Today,* Zibtsev and Goldammer (2019) described wildfire issues in Eastern Europe and mentioned Forest Service activities in connection with the Chernobyl disaster. Drawing on Forest Service sources (Ager and others 2019; Hao and others 2006; Lasko 2007, 2016), this article summarizes in additional detail the extent of Forest Service work in connection with the Chernobyl disaster.

RADIATION RISK AND WILDFIRE

Wildfires in radioactively contaminated zones pose health risks to firefighters and the general public in multiple ways. After settling into soils, contaminants are taken up by vegetation. When the vegetation burns, fire releases contaminants from both soils and vegetation into the air, putting firefighters at risk of inhaling radioactive particles (Dvornik and others 2018; Hohl and others 2012).

Wind-driven smoke has the potential to redistribute contaminants for long distances (Evangeliou and others 2016). On surface fires, most radionuclides are redeposited within a few miles of the fire (Zibtsev and Goldammer 2019). However, large crown fires can send convection columns 3 or more miles (5+ km) into the atmosphere, and

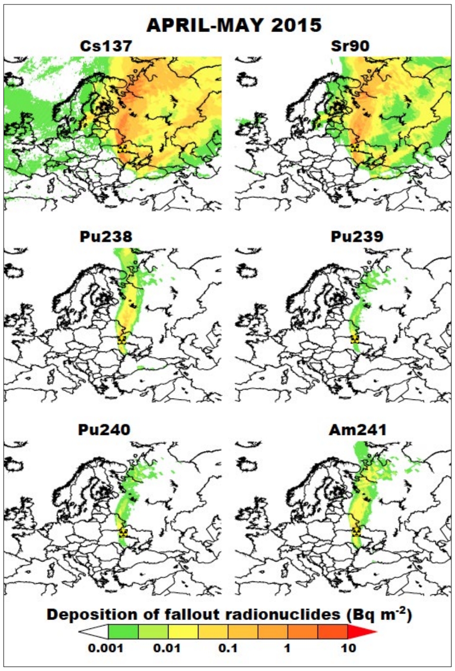


Figure 2—*Radionuclide deposition from wildfires in the Chernobyl Exclusion Zone in spring 2015 reached across much of Europe and deep into Russia. (Bq/m^{-2} = becquerels per meter factored by 2/x.) Source: Evangeliou and others (2016).*

winds can transport the resuspended radionuclides over enormous areas (Evangeliou and others 2016). Several large fires in the Chernobyl Exclusion Zone in 2015 redistributed contaminants to an area ranging from France and the British Isles deep into Russia (fig. 2) (Evangeliou and others 2016).

Radioactive contamination after the Chernobyl disaster was extensive in both Ukraine and Belarus (De Cort and others 1998; Zibtsev and others 2011). In Ukraine alone, more than 2.4 million acres (1 million ha) of coniferous forests were contaminated along the border with Belarus (Zibtsev and Goldammer 2019). Most of the contamination was in an area of about 40,000 square miles (100,000 km^2) near the Chernobyl reactor (fig. 1).

Radionuclide contaminants, including radiocesium (^{137}Cs), strontium (^{90}Sr), plutonium (^{238}Pu, $^{239-240}$Pu, and ^{241}Pu), and americium (^{241}Am), have entered forest litter, the duff layer, mosses, mushrooms, and the understory vegetation (Yablokov and others 2009).

Although much of the radiocesium has entered the mineral soil, radiocesium in the duff layer is especially available to combustion. Radionuclide half-lives range from 31 years (for radiocesium) to 24,065 years (for plutonium 239). The radionuclides release all types of radiation (alpha, beta, and gamma), potentially endangering human health for generations to come.

The main risk of radionuclide resuspension comes from wildfires in the regions of greatest contamination, the Chernobyl Exclusion Zone in Ukraine and the Polesie Radioecological Reserve in Belarus (fig. 1). Both are zones of such heavy contamination that access is severely restricted. Nevertheless, wildfires have been common in both zones; for example, the Chernobyl Exclusion Zone had 1,147 ignitions from 1993 to 2013 (Zibtsev and others 2015)—more than 50 fires on average per year. The ignitions were human caused and can be traced to a wide range of activities, including machinery, arson, and field burning on lands just outside the exclusion zone.

FOREST SERVICE COOPERATION WITH UKRAINE

In 2006, Forest Service technical assistance teams began to prepare assessments and recommendations for mitigating the effects of wildfires in the Chernobyl Exclusion Zone (Hao and others 2006; Lasko 2007, 2016). They reached the following conclusions:

- Facilities, tools, personnel, and equipment in the Chernobyl Exclusion Zone were inadequate for safe and effective wildfire detection and suppression.
- Firefighters lacked the personal protective equipment needed to shield them from exposure to radionuclides during wildfires.
- Fire suppression capacity in the zone was severely tested by the complexity of the large fires of 2015. More investments in personnel, equipment, facilities, and training were urgently needed.

- Reduced forest management in Scots pine (*Pinus sylvestris*) plantations in the Chernobyl Exclusion Zone led to fuel buildups and the need for a long-term strategy for managing vegetation and reducing wildfire risk in contaminated areas.

In response, the Forest Service worked with Ukraine's Agency for Management of the Chernobyl Exclusion Zone and the National University of Life and Environmental Sciences of Ukraine (formerly the National Agriculture University of Ukraine) to improve training, suppression capability, wildfire prevention, and wildfire risk assessment. The projects receive financial support from the USDA Forest Service, the U.S. Agency for International Development, and the U.S. State Department through the U.S. Embassy in Ukraine. Partners in the projects include the Ukraine Ministry of Environment–Protected Areas Management, the Agency for Management of the Chernobyl Exclusion Zone, the State Emergency Services for Ukraine, the Ukrainian State Forest Enterprise "Northern Puscha," the Chernobyl Fire Rescue Unit, the Regional Eastern European Fire Monitoring Center, and the National University of Life and Environmental Sciences of Ukraine. The success of the projects will depend on the partners' ongoing contributions, cooperation, and mutual support.

Wildfires in radioactively contaminated zones pose risk to firefighters, surrounding communities, and agriculture.

FIRE-RELATED TRAINING AND EQUIPMENT

Through various projects, Forest Service specialists worked with counterparts in Ukraine to offer training in wildfire coordination and suppression tactics as well as in fire prevention, public communications, and more. The United States also provided badly needed equipment for wildfire detection and suppression, along with personal protective gear for wildland firefighting.

Abandoned recreational facility in the Chernobyl Exclusion Zone, now overgrown by vegetation. Photo: Rich Lasko, USDA Forest Service.

Wildfire suppression training began in 2012 with an onsite Incident Command System seminar and exercise involving Chernobyl Exclusion Zone emergency managers and Forest Service fire specialists, supported in part by the U.S. Agency for International Development. Continued training in wildland fire management included onsite Incident Command System sessions and tabletop exercises in 2015 and 2016 and a study tour to the United States in 2013 for emergency response personnel to look at all-hazards response operations.

The United States scaled up assistance in 2016 following several large fires in the Chernobyl Exclusion Zone. In 2017, the Forest Service brought 14 Ukrainian firefighters and emergency managers to the United States to observe wildland fire coordination and suppression operations and training methods and to meet with their U.S. counterparts. Ukrainian emergency managers visited emergency coordination centers in both the Eastern and the Western United States to observe the Incident Command System and emergency management practices.

During this same time, the Forest Service supported the installation of seven remotely operated cameras to improve fire detection capabilities in the Chernobyl Exclusion Zone. Forest Service wildfire specialists worked with Ukrainian counterparts to assess other firefighting equipment in or near the zone and to list additional needs, including for firefighter personal protective equipment. The assessment resulted in the delivery of $88,500 worth of firefighter protective gear, water-handling equipment, respirators, and medical supplies to emergency management organizations in the Chernobyl Exclusion Zone.

To date, the Forest Service has provided more than 30 cumulative days of training for over 200 Ukrainian emergency response personnel.

Training included:

- An introduction to basic wildland firefighting,
- An introduction to incident command coordination,
- Strategies for initial and extended attack on wildfires,
- Wildland fire safety,
- Basic fire behavior,
- After-action reviews, and
- Building partnerships with the media and local communities.

In 2018, 11 Ukrainians completed training courses in Montana and Oregon, including Introduction to the Incident Command System (ICS 100), Firefighter Training (S–130), Introduction to Wildland Fire Behavior (S–190), and Human Factors in the Wildland Fire Service (S–180).

In 2019, the Forest Service brought senior leaders from Ukraine to the United States to look at emergency operations centers; the agency is currently supporting training for personnel to set up and manage an emergency operations center for the Chernobyl Exclusion Zone. Seven senior leaders from the Agency for Management of the Chernobyl Exclusion Zone and the State Emergency Services of Ukraine took the National Wildfire Coordinating Group's Gettysburg Staff Ride (L–580), a senior-level leadership course for both wildland and structural firefighters.

SUPPORT FOR SCIENCE AND ASSESSMENT

Forest service researchers have conducted indepth studies on the problem of wildfires in the area contaminated by radionuclides from the Chernobyl disaster. Hao and others (2009) published a paper on smoke dispersion and radionuclides in the area. Lasko (2007, 2016) as well as Ager and others (2015) prepared related reports based on their own extensive research.

In 2007, Forest Service fire specialists gave presentations on the Fire Effects Monitoring and Inventory System to Ukrainian fire specialists and to professors

A comprehensive fire management plan for Chernobyl should integrate fire prevention, fire detection, fire suppression, and vegetation management.

at the National University of Life and Environmental Sciences of Ukraine. Ukrainian scientists were brought to the United States to participate in developing geospatial analysis techniques for assessing landscape conditions in the Chernobyl Exclusion Zone. In 2018, a study was commissioned on how the various Ukrainian agencies with emergency management responsibilities in the Chernobyl Exclusion Zone work together (Nielsen-Pincus and others 2018).

FIRE RISK MODELING

A comprehensive fire management plan for Chernobyl should ultimately describe a coordinated program of fire prevention, fire detection, fire suppression, and vegetation management, thereby integrating actions to meet the wildfire threat in the Chernobyl Exclusion Zone. Risk assessment lays the scientific foundations for the elements of a fire management plan (such as fuel break location, siting of fire suppression resources, and fuel treatment location and prioritization of risk management activities).

In 2015, Forest Service researchers drafted a risk assessment for wildfire impacts in the Chernobyl Exclusion Zone (Ager and others 2015). The risk assessment led to a 2017 workshop in Kyiv under the title "Assessing Wildfire Risk and Exploring Mitigation Strategies for Chernobyl-Affected Landscapes." The workshop included scientists and emergency managers from Ukraine, Belarus, and the United States.

Following the workshop, a study was completed that used a wildfire risk modeling system (Ager and others 2011) to map likely locations of large fires in the vicinity of Chernobyl that have the

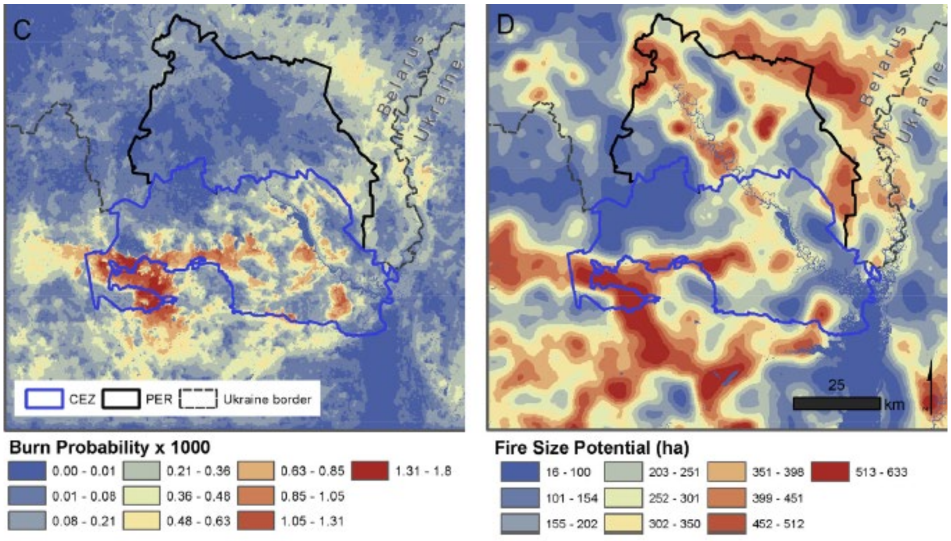


Figure 3—C: *Burn probability. Values represent the likelihood of a fire in a specific location given a single ignition.* **D:** *Fire size potential (in hectares). Hotspots result from a combination of high ignition frequency and large areas of fuel with high spread rates. The map shows where ignitions have the highest potential to generate large fires without considering the likelihood of an ignition. CEZ = Chernobyl Exclusion Zone; PER = Polesie Radioecological Reserve. Although fire size potential is higher in the PER, burn probability is low. High burn probability coincides with high fire size potential in the southern and southwestern parts of the CEZ. Source: Ager and others (2019).*

potential for significant radionuclide resuspension (Ager and others 2019). The study area included the Polesie Radioecological Reserve in Belarus and the Chernobyl Exclusion Zone in Ukraine. Most of the study area was in forests (including degraded Scots pine plantations) or in abandoned farmfields that are now slowly transitioning to mixed conifer–hardwood forest because human activities have ceased.

A key part of this study was understanding how patterns of ignitions contributed to potential radionuclide emissions. The research team created a comprehensive ignition map using a wide range of data sources (fig. 3); they then compared the map to zones of different human activities within the exclusion zones. The ignition data was then coupled with historical weather and fuels data to simulate 10,000 wildfires and generate maps of fire likelihood and potential emissions.

The modeling revealed that potential fire size and emissions were larger in the Belarusian Polesie Radioecological Reserve but that wildfire and resuspension were far more likely in the Ukrainian Chernobyl Exclusion Zone due to lax controls on entry and human activities (fig. 3). By reducing the incidence of human-caused wildfires in the Polesie Radioecological Reserve, Belarus has shown the effectiveness of fire prevention in mitigating the risk of wildfire and the corresponding contaminant resuspension and redistribution.

The research team then used the fire simulation system to examine how fuel breaks, in combination with suppression activities, could reduce fire size and resuspension (fig. 4). Although the Chernobyl Exclusion Zone has a network of fuel breaks, most of them are overgrown because they are not well maintained. The results identified fuel break locations that would be optimal in terms of reducing potential resuspension; such locations corresponded to areas of high ignitions, high potential for large fires, and high levels of radiocesium contamination. The areas at greatest risk were concentrated in the southern and southwestern parts of the Chernobyl Exclusion Zone (fig. 4).

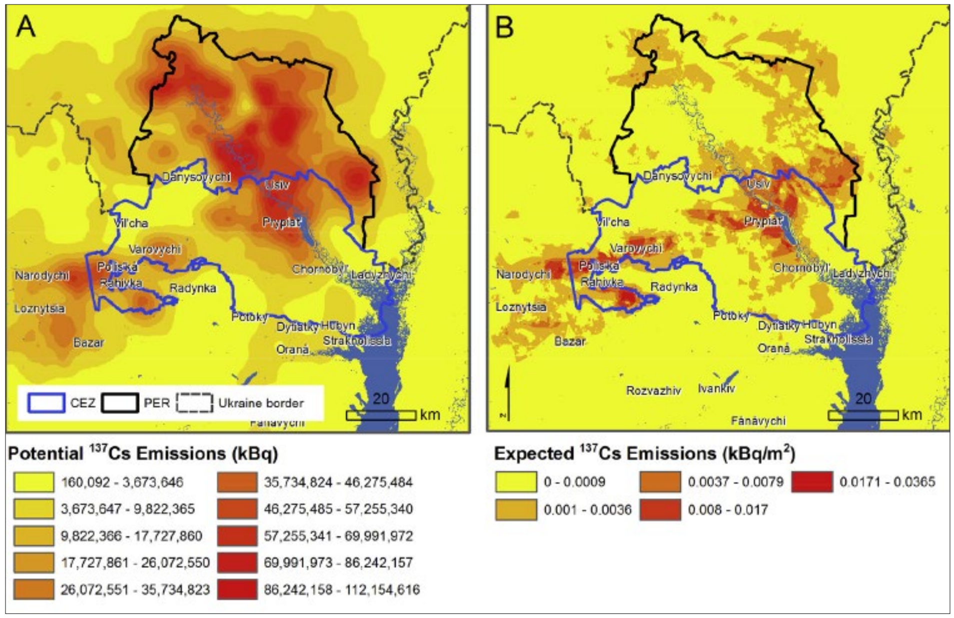


Figure 4—A: *Potential cesium 137 (^{137}Cs) emissions from simulated ignitions and resulting wildfires, based on levels of cesium contamination from the Chernobyl disaster.* **B:** *Expected cesium 137 emissions, based on the likelihood of actual ignitions and resulting wildfires. The highest levels of cesium resuspension and recontamination from wildfires are expected to come from the Chernobyl Exclusion Zone. (kBq/m^2 = kilobecquerels per square meter.) Source: Ager and others (2019).*

FUTURE COLLABORATION ON FIRE MANAGEMENT RESEARCH

Formation of the new Chernobyl Biosphere has raised numerous research needs to help support a comprehensive fire management plan. In November 2019, two new collaborative research projects involving researchers from Ukraine and the Forest Service's Rocky Mountain Research Station were initiated during meetings with Getman Yevgen, Advisor to the Head of the State Agency of Ukraine on Exclusion Zone Management, and Galushchenko Oleksandr, Director of the Chornobyl Radiation and Ecological Biosphere Reserve.

The first of the two projects is a fire danger forecasting system to improve suppression preparedness and response. The system will combine historical ignition patterns with wildfire simulation outputs and climatology to forecast ignition locations and the potential for large fires. The model will include forecasts of suppression hazards related firefighter exposure to radionuclides resuspended in smoke particles.

The second study will examine where the existing fuel breaks need to be hardened to maximize the reduction of large fire spread into contaminated areas. The project will make use of the fire simulation system developed as part of the research described above.

Overall, the proposed research program directly addresses a number of technical gaps outlined in prior recommendations (Zibtsev and others 2015)

Wildfire suppression training began in 2012 with an onsite Incident Command System seminar and exercise.

INTERNATIONAL PRIORITY

Fire-related emissions of radionuclides from the Chernobyl disaster are a social and ecological problem with ramifications for much of Europe and Russia. Solutions will require improvements to risk management systems in the region as well as short-term and long-term mitigation measures in the Chernobyl Exclusion Zone.

Since 2005, Forest Service fire researchers and specialists have worked extensively with counterparts in Belarus and Ukraine to learn from their experience with wildfires in the region (Hao and others 2006; Lasko 2011, 2016). Collaboration has culminated in the risk modeling study described above (Ager and others 2019), which can be used to explore a wide range of fire management scenarios for the contaminated areas.

Moreover, senior leaders from the Agency for Management of the Chernobyl Exclusion Zone and the State Emergency Services of Ukraine worked with Forest Service International Programs to identify needs for improving management of emergency response in the Chernobyl Exclusion Zone. In addition to building out and operationalizing an emergency operations center, future cooperation will include:

- Further training in wildland firefighting tactics,
- Leadership development courses for middle-level and senior-level leaders,
- Introductory training for wildland firefighters from outside the Chernobyl Exclusion Zone who are brought in to support wildland fire management in the zone,
- Communications planning and development of joint information centers,
- Completion of a fire management plan for the zone,
- Fire prevention education, and
- Support for including women in wildland fire management in Ukraine.

Developing a comprehensive fire management plan for the Chernobyl Exclusion Zone would appear to be the logical next step in meeting the potential wildfire threat. The leaders of Ukraine's Agency for Management of the Chernobyl Exclusion Zone believe that such a plan is important. The plan should combine fire prevention measures with better fire detection and steps to improve local capacity for safe and effective initial and extended attack. The plan should also have a fuels management component, including fuel breaks and restored native riparian, wetland, and hardwood forest ecosystems. Forest Service International Programs is ready to support development of the plan.

REFERENCES

Ager, A.A.; Vaillant, N.M.; Finney, M.A. 2011. Integrating fire behavior models and geospatial analysis for wildland fire risk assessment and fuel management planning. Journal of Combustion. 572452:19. DOI: 10.1155/2011/572452.

Ager, A.A.; Finney, M.A.; Lasko, R.J.; Evers, C. 2015. Probabilistic wildfire and fuels risk assessment for the Chernobyl Exclusion Zone. 20 p. Unpublished report. On file with: USDA Forest Service, Rocky Mountain Research Station, Missoula, MT.

Ager, A.A.; Lasko, R.; Myroniuk, V. [and others]. 2019. The wildfire problem in areas contaminated by the Chernobyl disaster. Science of the Total Environment. 696: 133954.

De Cort, G.; Dubois, G.; Fridman, S.D. [and others]. 1998. Atlas of caesium deposition on Europe after the Chernobyl accident. Luxembourg: Office for Official Publications of the European Communities. 63 p.

Dvornik, A.A.; Dvornik, A.M.; Korol, R.A. [and others]. 2018. Potential threat to human health during forest fires in the Belarusian exclusion zone. Aerosol Science and Technology. 52(8): 923–932.

Evangeliou, N.; Zibtsev, S.; Myroniuk, V. [and others]. 2016. Resuspension of radionuclides due to wildfires near the Chernobyl nuclear power plant (CNPP) in 2015: an impact assessment. Scientific Reports. 6: 26062.

Hao, W.; Hutton, D.; Brunello, A. 2006. Technical assistance mission Ukraine. 17 p. Unpublished report. On file with: USDA Forest Service, International Programs, Washington DC.

Hao W.M.; Bondarenko, O.; Zibtsev, S.; Hutton, D. 2009. Vegetation fires and smoke dispersion of radionuclides in the Chernobyl Exclusion Zone. In: Bytnerowicz, A.; Arbaugh, M.J.; Riebau, A.R.; Andersen, C. Wild land fires and air pollution. Amsterdam, The Netherlands: Elsevier: 265–275. Vol. 8. (Krupa, S.V., ed.; developments in environmental science: series).

Hohl, A.; Niccolai, A.; Oliver, C. [and others]. 2012. The human health effects of radioactive smoke from a catastrophic wildfire in the Chernobyl Exclusion Zone: a worst case scenario. Earth Bioresources and Quality of Life. 1: 1–34.

Lasko, R. 2007. Assessment and potential management actions to mitigate effects of forest and grassland fires in Chernobyl Exclusion Zone. 16 p. Unpublished report. On file with: USDA Forest Service, International Programs, Washington DC.

Lasko, R. 2016. Mitigating the effects of wildfire in the Chernobyl Exclusion Zone. 23 p. Unpublished report. On file with: USDA Forest Service, International Programs, Washington DC.

Nielsen-Pincus M.; Jacobs D.; Ager A. 2018. Supporting a network governance approach to management of wildfire and radiation risks in the Chernobyl Exclusion Zone. 2 p. Unpublished report. On file with: USDA Forest Service, International Programs, Washington DC.

Yablokov, A.V.; Nesterenko, A.V.; Nesterenko, V.B.; Sherman-Nevinger, J.D. 2009. Chernobyl: consequences of the catastrophe for people and the environment. New York: New York Academy of Sciences. 345 p.

Zibtsev, S.; Oliver, C.; Goldammer, J.G. [and others]. 2011. Wildfires risk reduction from forests contaminated by radionuclides: a case study of the Chernobyl Nuclear Power Plant Exclusion Zone. 5th International Wildland Fire Conference, May 9–13, Sun City, South Africa.

Zibtsev, S.; Goldammer, J.G.; Robinson, S.; Borsuk, O. 2015. Fires in nuclear forests: silent threats to the environment and human security. Unasylva. 66(243/244): 40–51.

Zibtsev, S.; Goldammer, J.G. 2019. Challenges in managing landscape fires in Eastern Europe. Fire Management Today. 77(1): 48–61.

The Camp Fire Tragedy of 2018 in California

A Forest Service law enforcement officer surveys damage to homes and property on the first day of the Camp Fire in November 2018. The home destruction contrasts with the relatively unburned vegetation nearby. Photo: Tanner Hembree, USDA Forest Service.

The Camp Fire in November 2018 in the Sierra Nevada foothills of northern California was one of the deadliest and most destructive wildfires in U.S. history (Cal Fire 2018; NICC 2018; Reyes-Velarde 2019; WERT 2018). Driven by dry northeasterly winds, the fire swept from the Plumas National Forest in the North Fork Feather River drainage down through large areas of homes in the wildland–urban interface (WUI). Within hours, the fast-moving fire destroyed thousands of homes in Butte County. Unable to evacuate on such short notice, many people were trapped in their cars or homes, and 85 residents lost their lives—the most fatalities in an American wildfire in 100 years (since the Cloquet Fire in Minnesota in 1918).

After 17 days, the fire was finally contained, but not before burning across 153,336 acres (61,334 ha) and reaching the edges of suburban Chico in the Sacramento Valley. The fire also reached the shores of Lake Oroville, the centerpiece of the State Water Project and a critical piece of State infrastructure, supplying water to farms and cities across much of California.

The fire destroyed 18,793 buildings, including 13,972 residences. By comparison, wildfires since 1999 had destroyed 2,701 residences on average each year nationwide (NICC 2018), so the number of residences destroyed by the Camp Fire alone was more than five times the national average for the entire year. Worldwide, the Camp Fire was the single costliest disaster in 2018, with losses estimated at $16.5 billion (Reyes-Velarde 2019).

No single factor can explain great disasters like the Peshtigo Fire of 1871 (Brown 2004; Wells 1968), the Big Blowup of 1910 (Pyne 2001), or the Camp Fire of 2018. The reasons for such disasters range from fire cause and burning conditions to evacuation failures and human vulnerabilities—in this case, home vulnerabilities in the WUI (Kramer and others 2019). All are elements of what has been dubbed the wildland fire system (Christiansen 2018; Spies and others 2014; Thompson and others 2018; USDA Forest Service 2016)—the interplay of social, cultural, institutional, ecological, and other factors that shape the operating environment for wildland firefighters and the living environment in the WUI. This article outlines some of the factors in the wildland fire system in the Sierra Nevada foothills of northern California that led to the Camp Fire disaster.

CAUSE OF THE FIRE

The initial fire start came from a downed powerline on the Plumas National Forest in the North Fork Feather River Canyon near Interstate Highway 70 (St. Johns and others 2018). A utility company employee checking a transmission outage before dawn on November 8 called to report the fire at about 6:30 a.m. The powerline ignition occurred west of the river just upslope from Poe Dam, a hydroelectric facility along the highway east of the river. The only access to the fire was by way of unpaved Camp Creek Road, which parallels the highway across the river on steep slopes upstream from the community of Pulga. The Camp Fire took its name from Camp Creek Road.

The area where the fire started west of the river was mostly private land, and it was all under protection by the California Department of Forestry and Fire Protection (Cal Fire). Fifteen minutes after the fire was called in, an engine captain from Cal Fire arrived

Hutch Brown is the editor of Fire Management Today *and a program specialist for the Forest Service's Office of Communication, Washington Office, Washington, DC.*

Helitanker drawing water from an upper arm of Lake Oroville in the later stages of the Camp Fire. The steep terrain and shrub–pine vegetation are typical of much of the area of the Camp Fire. Photo: Interagency Incident Information System (InciWeb).

to size up the fire and prepare for initial attack. The wind-whipped fire was already 10 acres (4 ha) in size and burning upslope, impossible for an engine to safely reach on the precarious unimproved Camp Creek Road. All that firefighters could immediately do was to warn officials that Pulga and other communities lay in the probable path of the fire.

Powerline ignitions under windy conditions are common in the West. Days before the Camp Fire, expected high winds led to warnings of possible power outages and ignitions from downed powerlines (Baker 2017; Baker and Chediak 2018). The damaged section of powerline that caused the Camp Fire was old, dating to the turn of the 20th century; a storm had toppled five aging transmission towers in the same area in 2012 (Van Derbeken 2018). Officials in California have considered requiring powerlines in high-wind corridors upwind from the WUI to be buried, but maintenance would be more difficult and the costs have seemed prohibitive.

Local landowners and land managers have a long history of active forest management in the area of the Camp Fire.

Most wildfires are not caused by powerlines. From 2000 to 2008, according to Prestemon and others (2013), lightning caused 65 percent of the wildfires on the National Forest System in the West, campfires caused 14 percent, and other human causes (such as smoking, arson, and debris burning) each accounted for 3 percent or less. Powerlines were such a negligible factor that they fell into the category of miscellaneous (10 percent).

Nevertheless, wildfire ignitions involving powerlines have proven disastrous. Cal Fire reported that problems with powerlines and other electrical equipment caused 17 major wildfires in 2017 alone (Meigs 2018). In addition to the Camp Fire, powerline failures sparked the wind-driven Woolsey Fire in 2018 and the Atlas, Nuns, Thomas, and Tubbs Fires in 2017 (Ho and Canon 2018)—fires that collectively burned more than half a million acres, taking 29 lives and destroying more than 11,800 structures. The same high winds that are likely to damage powerlines are also likely to fan sparks into flames and then drive a fire for miles under drought conditions, threatening lives and homes. Low-probability, high-consequence events associated with wildfire ignitions from overhead powerlines are part of the wildland fire system in the West.

TOPOGRAPHY AND CLIMATE

The wildland fire system is also shaped by topography and climate, which influence burning conditions. Elevations in the footprint of the Camp Fire range from about 400 feet (120 m) near the city of Chico to about 1,500–2,500 feet (460–760 m) in the foothill communities of Paradise and Magalia and about 5,000 feet (1,520 m) on the peaks and ridges of the Plumas National Forest to the east.

The area is cut by canyons oriented from north/northeast to south/southwest (fig. 1), with canyon walls rising by as much as 2,000 feet (610 m) from where the fire started in the North Fork Feather River Canyon. Smaller canyons break the topography in the fire area to the west, including deep valleys carved by the West Branch Feather River, Little Butte Creek, and Butte Creek. Together, the three smaller canyons bracket the city of Paradise on a broad, gently sloping ridge; chaparral-filled arroyos break up the ridge, which has many cul-de-sacs with homes overlooking defiles. The broken topography, steep slopes, and orientation of the canyons are all conducive to extreme fire behavior under drought conditions, especially in high easterly winds.

The vegetation in the area of the Camp Fire ranges from grasses and scattered live oaks in the lower foothills (up to about 1,000 feet (305 m)) to chaparral and open pine–oak woodlands in the upper foothills (up to about 2,000 feet (610 m)) and coniferous forests in the mountains to the east (BCCFPA 2015). Hot and dry summers are followed by cool and wet winters, with rising levels of seasonal precipitation as elevations rise from west to east.

Fire return intervals in the area range from about 5 to 50 years, depending on elevation and fuel type. Previous fires covered 70 percent of the area of the Camp Fire since 1960 and 60 percent since 1987 (WERT 2018). In 2008 alone, two wildfires—the 23,334-acre (9,334-ha) Humboldt Fire and the 59,440-acre (23,776-ha) Butte Lightning Complex Fire—covered almost half of the area of the Camp Fire (Gafni 2018).

From 2000 to 2018, California experienced three increasingly severe droughts (2001–05, 2007–2010, and 2011–18) (NIDIS 2019). In 2018, the U.S. Drought Monitor showed Butte County as “abnormally dry” for the summer and fall (NDMC 2019), with no significant rainfall since June due to a delayed onset of the rainy season (Swain 2018). Drought conditions were compounded by hot dry winds locally known as Jarbo winds (Simon 2018). In autumn, the jet stream often dips into the Great Basin, pushing winds up the face of the Sierra Nevada Front and down the other side, where they descend like a waterfall over the western Sierra slopes. Warming as they sink, the Jarbo winds further dehydrate vegetation already parched by a hot and dry summer.

Firefighters holding part of the southeastern perimeter of the Camp Fire (division D, near Lake Oroville) on November 20, 2018. The photo gives some idea of the rugged topography in the area of the fire. Photo: Interagency Incident Information System (InciWeb).

High winds whipped the fire through landscapes of all types, regardless of fuels treatments and defensible space.

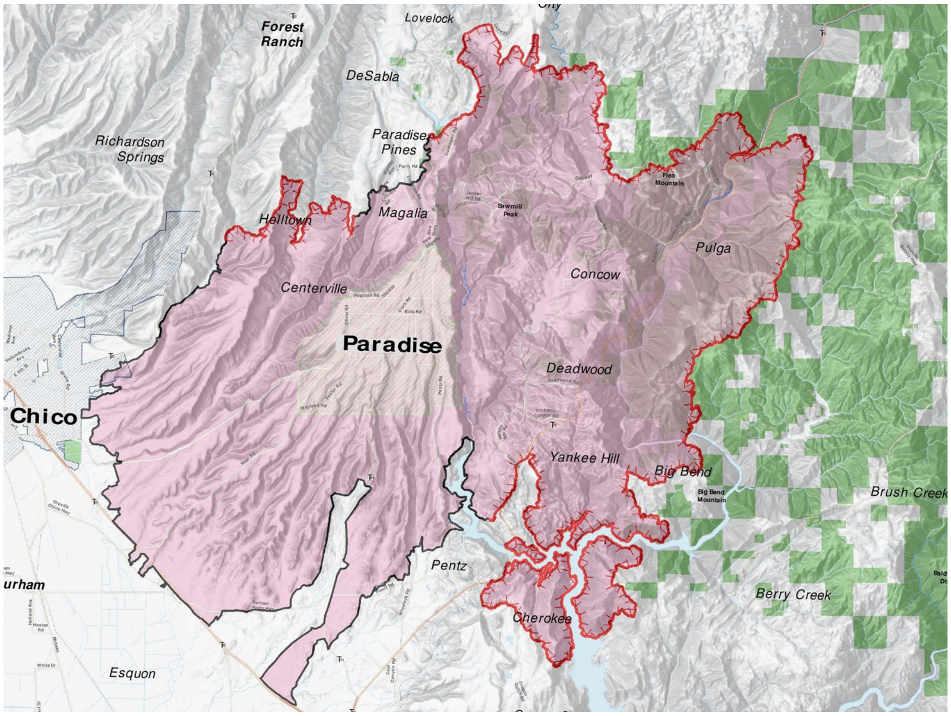


Figure 1—*Map of the Camp Fire perimeter on November 15, 2018, a week after ignition. The fire originated near Pulga (upper right) and swept southwest through Paradise to the outskirts of Chico (center left), driven by high northeasterly winds. Gray shading demarcates the rugged topography, including the West Branch Feather River Canyon (center, oriented north/south) on the eastern edge of Paradise. (Pink is the area burned, red is actively burning fire, green is the Plumas National Forest, and blue is Lake Oroville.) Source: Interagency Incident Information System (InciWeb).*

In 2018, the Jarbo winds arrived in the first week of November, blowing from the northeast at sustained speeds of about 30 miles per hour (48 km/h), with gusts of up to 50 miles per hour (80 km/h). The National Weather Service promptly issued a Red Flag Warning, which it extended into the second week of November (Moleski 2018). When the Camp Fire broke out on November 8, it was whipped by hot northeasterly winds that drove the fire downhill across parched slopes and into the WUI.

On the first day of the fire, responders faced conditions reminiscent of a hurricane.

In short, wind-driven fires are common in autumn in Butte County, where the topography and climate give rise to fire-adapted vegetation types across seasonally dry landscapes with frequent large fires. The Jarbo winds create "firesheds" (areas of fire risk around communities (USDA Forest Service 2018)) that reach from the national forests of the northern Sierra Nevada across the Sierra foothills and into the Sacramento Valley. Firesheds associated with high easterly winds (regionally known as Jarbo, Diablo, or Santa Ana winds) are typical of the wildland fire system across much of California, as is the risk of extreme fire behavior in a drought.

ACTIVE FOREST MANAGEMENT

Aware of the danger, officials in Butte County took steps to prepare. Butte County has an active fire safe council, and it had a detailed community wildfire protection plan for 2015–20 (BCCFPA 2015). The plan listed 14 values to protect, starting with a WUI that has (or had) "over 30,000 structures." Other values at the top of the list also pertain to the built environment, including public infrastructure, hydroelectric facilities, and historic buildings.

Most of the built environment in Butte County is in or near the Sacramento Valley, where more than two-thirds of the county's population of about 230,000 lives. However, tens of thousands of residents live in the foothills, either in rural areas or in the WUI, which takes two forms: intermix and interface (BCCFPA 2015). In the intermix, homes are scattered in wildlands; in the interface, homes are in compact bedroom communities that adjoin areas of wildland vegetation (Martinuzzi and others 2015). Most of the Butte County WUI is intermix, although Paradise and Magalia (with populations of about 27,000 and 11,000, respectively, at the time of the fire) are largely interface. Paradise is (or was) Butte County's second largest city (after Chico) and Magalia its fourth largest (after the county seat of Oroville).

The community wildfire protection plan for Butte County divided the county into "battalions" for fire protection, with cooperators including Cal Fire, Federal land managers, private timberland owners, and county and municipal fire departments. Priorities included active forest management, such as "shaded fuelbreak projects" (wildland vegetation thinned to remove ladder fuels while leaving most trees intact) and reforestation projects in previously burned areas. Appendixes to the plan at the time of the Camp Fire listed 142 fuels-related projects in Butte County, including:

- 20 active or ongoing fuels or prescribed fire treatments,
- 48 completed fuels treatments,
- 12 maintained fuels treatments, and
- 62 planned fuels or prescribed fire treatments.

The projects were mostly intended to protect particular communities, including Concow, Magalia, Paradise, and Yankee Hill. Eighty projects were either completed or underway at the time of the Camp Fire.

In addition, local landowners and land managers have a long history of active forest management in Butte County. Most of the area burned by the Camp Fire—about 85 percent—is private land, and Sierra Pacific Industries and other timber companies own large tracts of timber in the county (BCCFPA 2015). According to Cal Fire's Butte Unit (2016), Butte County has 200,000 acres (80,000 ha) of commercial timberland and generates 40 million board feet (94,400 m^3) of timber per year, making timber one of the county's 10 most valuable agricultural products.

In its first few hours, the Camp Fire burned through areas of private timberland with scattered blocks of Federal land (BCWC 2005; EII 2019). Much of the private timberland had been salvage logged or selectively harvested following the large fires of 2008 (EII 2019), including projects in collaboration with the Butte County Fire Safe Council to protect the communities of Concow and Yankee Hill (BCFSC 2018a). For their part, Federal land managers had launched a hazardous fuels project on 1,510 acres of scattered treatments following the fires of 2008 to protect the communities of Concow, Magalia, Paradise, and Yankee Hill (USDA Forest Service/BLM 2011).

In short, much of the area in the path of the Camp Fire was under active management. Postfire photos show a mix of landscapes in the area initially burned (EII, n.d.), many with signs of logging and reforestation, such as the blackened remains of brush and small trees. Through the timber industry and an active fire safe council involving partnerships with timberland owners, Federal land managers, and nongovernmental organizations, the wildland fire system in Butte County had a well-developed institutional framework for active forest management. Overall, the area of the Camp Fire was a good test case for the efficacy of active forest management in creating space for firefighters to stop a wildfire from burning into homes and communities.

EXTREME FIRE BEHAVIOR

The astonishing speed of the Camp Fire gave firefighters no time to deploy. The high Jarbo winds whipped the fire through landscapes of all types, regardless of fuels treatments and defensible space, rendering any fuels treatments or other forms of active management useless for fire control. As a hotshot superintendent on the Camp Fire explained upon witnessing the wind-driven fire on its first day, fuels treatments are irrelevant on a fire that spots 2 miles (3.2 km) ahead through a blizzard of embers (Kasler 2018) (fig. 2).

After starting at about 6:30 a.m. on November 8, the fire spread so fast that the Butte County sheriff quickly ordered the evacuation of Pulga; other evacuation orders soon followed, and evacuations remained the top priority for responders on the fire's first few windy days. In less than an hour, the fire swept out of the North Fork Feather River Canyon and through the footprint of the 2008 Butte Lightning Complex Fire. It crossed Concow Road (at elevations of up to about 4,000 feet (1,200 m)) by about 7:40 a.m., sweeping through the community of Concow within little more than an hour from its start.

The wind-driven fire swept on toward the West Branch Feather River Canyon across from Paradise and Magalia, at elevations of up to 2,000 feet (610 m) (fig. 1). About 600 feet (180 m) deep and a quarter mile (0.4 km) wide, the canyon had stopped previous large fires from reaching the town of Paradise, but not this time. High winds blew billions of embers across the canyon and into the communities of Paradise and Magalia, starting spot fires.

The first fires were reported in Paradise at 7:51 a.m. and in Magalia at 8:45 a.m. (Moriarty and others 2018), about 2 hours after the fire's start. The spot fires quickly combined into a fire front; shortly after 10 a.m., the main fire crossed Pentz Road (the easternmost of three main north/south thoroughfares) and burned into Paradise.

In short, the Camp Fire swept across about 10 miles (16 km) in its first 4 hours, burning straight downhill from the ridges overlooking the fire's point of origin to reach elevations thousands of feet lower. Such rapid downhill fire spread is highly unusual; Ken Pimlott, the Chief of Cal Fire, said that the fire spread downslope at the phenomenal rate of one football field (about 1.3 acres (0.5 ha)) per second (Gabbert 2018). On its first day alone, the Camp Fire roared downhill across about 70,000 acres (28,000 ha), almost half of the total area it would ultimately burn (InciWeb 2018a, 2018b).

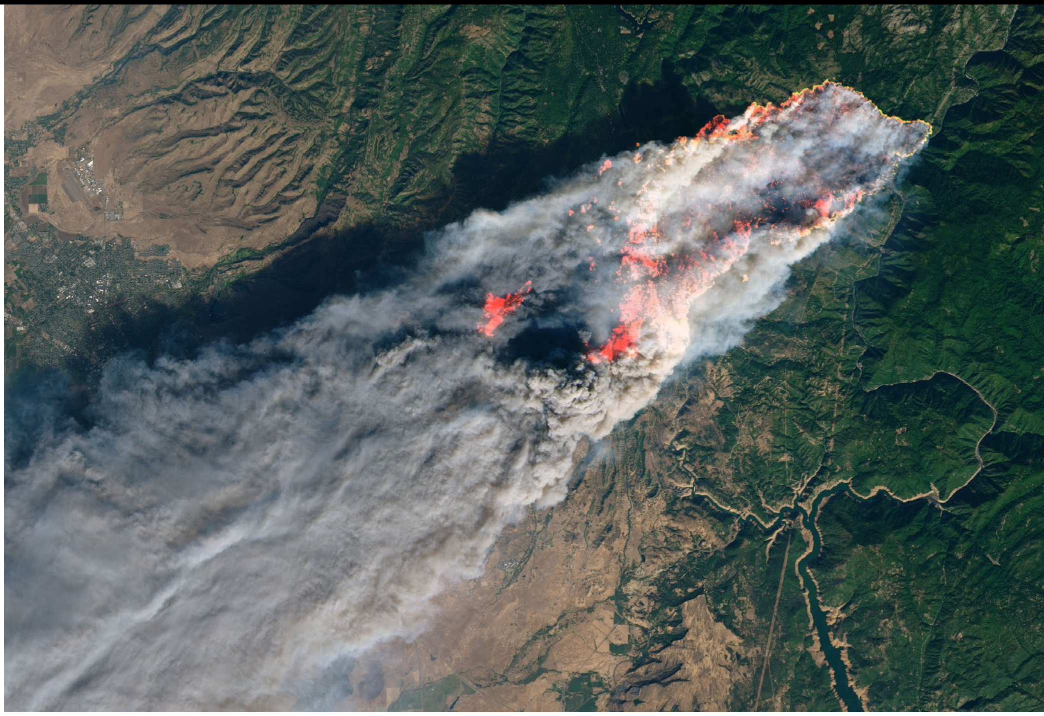


Figure 2—*LANDSAT 8 image of the Camp Fire on November 8 at about 10:45 a.m., a little more than 4 hours after the fire broke out. The point of origin is the "speartip" (upper right) in the North Fork Feather River Canyon near the community of Pulga. High northeasterly winds are blowing the fire through an area of fuels treatments and actively managed timberlands into the community of Paradise, where the main fire front appears (center right). Flying embers have already ignited an area well downslope (center left). (At upper left are the suburbs of Chico; at lower right is Lake Oroville.) Source: NASA (2018); photo—Joshua Stevens.*

The fire moved so quickly that it left signs of low-intensity burning. Postfire watershed studies showed that 82 percent of the area within the Camp Fire perimeter had low or very low to nonexistent soil burn severity (WERT 2018). Conifers in closed forest stands were often scorched without burning; trees held green needles after the fire passed. Obstructed by closed stands, the fiery winds tended to pour instead through relatively open areas. The flashy fuels in cutover and reforested areas, such as brush and small trees, tended to completely burn, but canopy burning in closed forest stands was relatively rare (Johnson 2018; EII 2019, n.d.).

THE BUILT ENVIRONMENT

The Camp Fire behaved in the same way when it reached homes and communities, spread mainly by embers. Trees and their foliage offered few crevices for the embers to lodge in, but homes and properties in the WUI certainly did. When it entered the bedroom communities of Paradise and Magalia, the Camp Fire favored artificial fuels, spreading from home to home through radiant heat or flurries of new embers blown by the winds. Postfire photos show unburned trees surrounding homes reduced to ashes; like its rural and WUI intermix counterparts, the WUI interface forest canopy rarely burned.

Butte County homeowners had plenty of warning. In 2005, a fire management plan from Cal Fire for the northern Sierra Nevada cautioned that the "greatest risk" came from an "east wind fire" (St. John and others 2018)—which is exactly what happened. The plan specifically warned of "a high potential for large damaging fires and loss of life and property" in the town of Paradise. In its community wildfire protection plan, the Butte County Fire Safe Council noted the danger to homes in the WUI from "a blizzard of embers" finding "a receptive fuel bed on or near a structure" (BCCFPA 2015)—again, exactly what happened.

In 2008, in an effort to mitigate such dangers, California adopted a new building code for high-fire-hazard zones across the State (Cal Fire 2012). The new standards were for building design, vent meshes, double-paned windows, roofing and decking materials, and other building features to make homes in the WUI more fire resistant (Quarles 2018; Valachovic 2018). The new code also required a 100-foot (30-m) zone of defensible space around the home, in accordance with Firewise specifications (Prudhomme 2018). Butte County subsidized such firesafe practices through several programs (BCCFPA 2015):

- A Home Visit Program, offering free expert advice on improving a home's chances of surviving a wildfire;
- A Chipping Program, offering to chip brush and slash from tree trimmings; and
- A Residents Assistance Program, offering help to residents who were physically or financially unable to maintain defensible space around their homes.

The Butte County Fire Safe Council also sponsored local fire safe councils and at least five Firewise communities in the Sierra Nevada foothills (BCCFPA 2015).

Despite such institutional improvements to the wildland fire system, the Camp Fire exposed glaring vulnerabilities in the Butte County WUI, borne out by a broader study of wildfire damage to homes in the WUI interface across California in recent decades (Kramer and others 2019) (see the sidebar). Few homeowners could afford the expense of retrofitting their homes according to State guidelines, and relatively few went to the effort of clearing a defensible space around their homes. Moreover, many homes in the Sierra Nevada foothills are built on canyon rims for the views. The brush-filled defiles became chimneys for the Camp Fire, turning many homes on canyon rims into flaming infernos.

Homes built with fireproof materials away from slopes and free from flammable debris on or near the structure were most likely to survive the Camp Fire (Kaplan and Sellers 2018; Valachovic 2018). According to a postfire analysis (Kasler and Reese 2019), homes built in accordance with the new California guidelines stood a much better chance of surviving the Camp Fire than older homes. Of 350 single-family homes built after 2008 in the path of the Camp Fire, 51 percent survived, compared to only 18 percent of the 12,100 homes built before 2008.

Yet even the newer homes stood only a fifty-fifty chance of survival. Most homes in the path of the Camp Fire burned, even in Firewise communities. In Paradise—which includes the Firewise neighborhood of Paradise Ridge—roughly 9 in 10 residences were destroyed overall (Bartolone 2019; NFPA, n.d.). If the WUI in Butte County contained about 30,000 structures before the Camp Fire (BCCFPA 2015), then the fire destroyed more than 60 percent of them.

Evidently, the wildland fire system in the Sierra Nevada foothills has firesheds so dangerous that neither Firewise measures nor active forest management will furnish better than even odds of a home surviving a blaze like the Camp Fire. "It looks like another case where you've got billions and billions of embers riding with the wind," observed fire historian Stephen J. Pyne (Simon 2018). "It only takes one ember to take out a house or a hospital. If there's any point of vulnerability, all those embers will find it."

FIRE MANAGEMENT RESPONSE

The wildland fire system in the United States has outstanding Federal, State,

Fire Damage Heaviest in Areas With Few Wildland Fuels

Based on Hodgins (2019).

In California, the State with more building destruction by wildfire than all other States combined, scientists have found something surprising (Kramer and others 2019). Over nearly 3 decades (1985–2013), half of all residences destroyed by wildfire were in areas with relatively few of the grasses, shrubs, and trees that are thought to fuel fire in the wildland–urban interface (WUI).

The interface part of the WUI—bedroom communities with clusters of homes and relatively little wildland vegetation—made up only 2 percent of the total area burned by wildfires in California but had 50 percent of the homes destroyed. The study, published in the International Journal of *Wildland Fire,* is available at *https://www.nrs.fs.fed.us/pubs/58348.*

The Federal definition of the WUI includes the interface (developed areas with little or no wildland fuels but close to a large patch of wildland vegetation) and the intermix (areas where scattered homes intermingle with wildland vegetation) (Martinuzzi and others 2015). Both are separate from rural areas (agricultural and silvicultural lands where the number of homes is less than one per 40 acres).

"Our findings show that WUI areas do experience the vast majority of all losses, with 82 percent of all buildings destroyed," said Miranda Mockrin of the Forest Service's Northern Research Station, one of the study's authors. "We were surprised to find 50 percent of all buildings lost to fire in the interface portion of the WUI, however. Many risk reduction plans focus on natural vegetation fueling

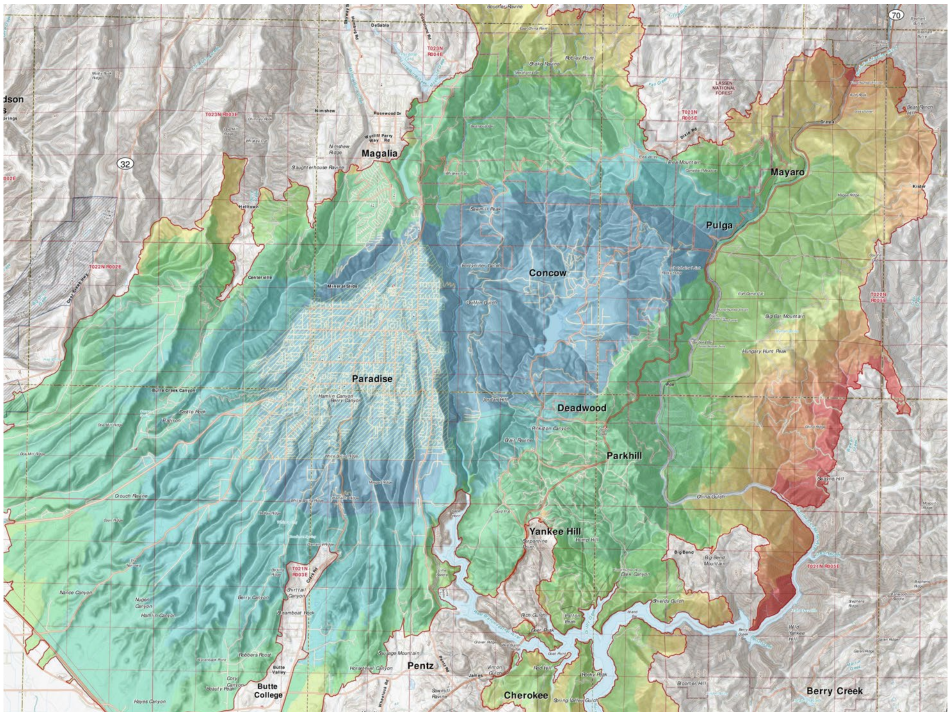


Figure 3—*Camp Fire progression, final map. From its point of origin in the North Fork Feather River Canyon on November 8 (blue "speartip," upper right), the fire spread on its first day (shades of blue) downslope through Concow, Paradise, and lower Magalia, driven by high northeasterly winds. By the end of its fifth day (shades of green), the fire covered most of the area it would ultimately burn. For the next 2 to 3 weeks, the fire spread mostly to the east (shades of yellow, orange, and red) before full containment on November 25. Source: Interagency Incident Information System (InciWeb).*

Tribal, and local fire organizations, and they work together as a community through cooperative agreements. The first incident report for the Camp Fire (from the evening of November 9) noted 59 hand crews, 303 engines, and hundreds of other resources already on the fire, for a total of 2,303 personnel—all within 48 hours of the fire start (InciWeb 2018a).

On the fire's first few windy days, direct attack was difficult or impossible. The first priorities were evacuation and structure protection, especially of public buildings and other points of assembly for the thousands of people who had fled their homes. Butte County had designated public assembly points—schools, churches, town halls, and so on—where residents could shelter in place, protected by firefighters.

The vast majority of the area of the Camp Fire burned on the fire's first 5 days (fig. 3, area of blue/green). Most of those 125,000 acres (50,000 ha) burned on the first day (fig. 3, blue), when the fast-moving fire was driven downslope by fierce Jarbo winds. On subsequent days (fig. 3, green), the fire reached the outskirts of Chico, where control lines held. The fire also spread to the north and south and started making uphill runs on the Plumas National Forest to the east. In a few places, such as a small reservoir near Magalia, firefighters were able to exploit prior fuels treatments to establish and hold local firelines.

Most subsequent fire spread (fig. 3, yellow/orange/red) came during uphill runs at higher elevations on the eastern flanks of the fire. Resource deployments peaked on November 17 (about 2 weeks after the fire start), with 5,624 personnel on the fire, including 102 hand crews.

By the evening of November 20, with the fire 75 percent contained, the worst was over (InciWeb 2018a). Firefighters were holding firelines on the fire's entire perimeter as well as extinguishing hotspots and felling hazard trees. Two days later, with rain helping to put out remaining hotspots, the fire was 95 percent

fire; but in the interface WUI, we have to consider finer grained fuels such as wood piles, propane tanks, and cars."

"It seems like every fall there is a new record-setting fire in California, with three of the five most destructive fires in State history having burned in the last 5 years and the deadliest California fire (the Camp Fire) burning in 2018," said Anu Kramer of the University of Wisconsin–Madison, another author. "These fires are fueled by the homes themselves, landscaping, and other manmade fuels that are seldom included in the fire models that are used to predict these fires. Our work highlights the importance of studying and mitigating the fuels in these interface WUI areas in California where most of the destruction is occurring."

In addition to Mockrin and Kramer, the study was co-authored by Volker Radeloff of the University of Wisconsin–Madison and Patricia Alexandre of the University of Lisbon in Portugal.

A Forest Service law enforcement officer inspects community wreckage in the wake of the Camp Fire. The main fuels in the WUI interface were artificial: homes, vehicles, and the associated structures and residential vegetation. Photo: Tanner Hembree, USDA Forest Service.

contained. On November 25, the Camp Fire was declared fully contained.

Overall, the fire management response was a success. On the first day of the fire, responders faced horrendous conditions—high winds, low visibility, flying embers and spot fires all around, and the urgency of mass evacuations and structure protection. Yet responders mobilized by the thousands within hours, putting hundreds of engines and other resources on the fire, and they successfully defended all public assembly points and saved many homes and other buildings from burning.

More importantly, tens of thousands of residents in the Butte County WUI owe their lives to the courage and skill of the responders who helped them evacuate or protected them from the flames. Despite the extreme fire behavior, no firefighter entrapments occurred, and firefighter injuries on the fire were limited to three, all on the first day.

EVACUATING THE WUI INTERFACE

Evacuations of Magalia and Paradise were less successful. The Butte County Fire Safe Council had posted detailed disaster preparedness plans for the WUI based on the Ready, Set, Go! formula (BCFSC 2018b; Lutz 2018). The plans included evacuation instructions in the event of a wildfire, along with maps of evacuation routes and public assembly points (fig. 4). The maps showed what routes to take and where people could gather to shelter in place.

Development in the WUI interface communities of Magalia and Paradise had left many homes on culdesacs with limited access and egress, so traffic in an emergency could easily snarl. Moreover, Paradise had only three main thoroughfares leading to highways in the Sacramento Valley (fig. 4), with a fourth escape route (Skyway) leading north through Magalia. All four evacuation routes were two-lane roads. Even with both lanes used for evacuation, the four routes were not enough to evacuate tens of thousands of residents all at once.

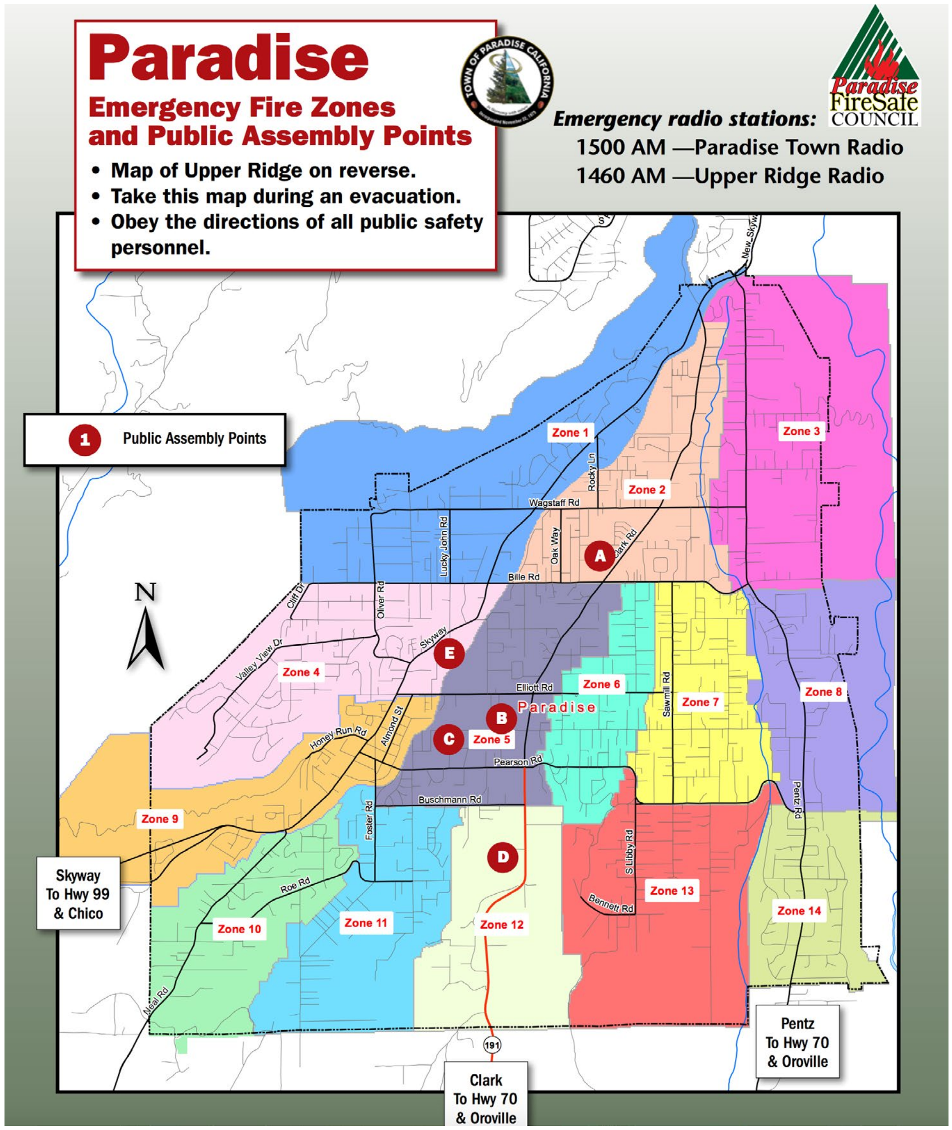


Figure 4—*Emergency evacuation map for Paradise, CA. Evacuations were ordered consecutively for zones as the Camp Fire approached but with so little time between the evacuation orders that the effect was simultaneous. The three evacuation routes going south (Skyway, Clark Road, and Pentz Road) became clogged with vehicles; Skyway going north was longer and little used except by Magalia residents. Unable to leave town, many people took refuge at the five public assembly points. Source: BCFSC (2018a).*

To avoid traffic jams, officials had divided Paradise and Magalia into zones for staggered evacuations (fig. 4). However, the Camp Fire spread so fast that the plans failed and the evacuations became practically simultaneous (Moriarty and others 2018). The traffic snarled and stopped, with people leaving their cars and fleeing on foot. At least nine fire victims were found trapped in their cars.

Other victims were found in their homes. County officials issued evacuation orders through emails, phone calls, and texts, in addition to social media and loudspeakers (Elias and Ronayne 2018). But many calls and emails were never received, and cell phone service went down. The fire moved too fast for emergency responders to go house to house, so many people simply stayed put, not recognizing the danger until too late. Thousands of people took refuge at public assembly points (Elias and Ronayne 2018), both planned and improvised (Moriarty and others 2018), where they were protected by firefighters. Yet the fire still claimed 85 lives.

Evacuation plans and routes proved to be a major weakness in the wildland fire system for Butte County and a major reason for the extensive loss of life on the Camp Fire. A better system is needed for communicating the urgency of evacuation in an emergency. Moreover, the broken topography in the area of the Camp Fire and a legacy of uncoordinated development in the WUI limit options for rapid evacuation to escape any fast-moving fire. Additional escape routes and better neighborhood access and egress are needed, but physical, social, and economic constraints stand in the way.

THE WILDLAND FIRE SYSTEM

In the foothills of the northern Sierra Nevada (and elsewhere across the Nation), social license and economic incentives (including homeowner insurance) have allowed for development in firesheds that can be highly dangerous, lovely and amenable though they might usually be (Bramwell 2014; Pyne 2015). Such factors, along with aging powerlines in firesheds with seasonal high winds—and a warming climate that is escalating fire danger during fire seasons that are increasingly year round—came together to make the Camp Fire one of the worst wildfire disasters in American history.

Part of the wildland fire system in Butte County and elsewhere across the Nation is active forest management to protect the WUI. Although fuels treatments can allow firefighters to establish control lines to protect homes and communities from a wildfire, they proved useless on some of the largest California wildfires in 2017–18 (CCI 2018). The 2017 Thomas Fire, like the 2018 Woolsey Fire, was whipped by Santa Ana winds through chaparral, burning through multiple prescribed fire footprints to reach homes and communities (CCI 2018). The North Bay fires of 2017 (Atlas, Nuns, and Tubbs) were driven by high winds that carried blizzards of embers across highways and other open terrain into the WUI interface (CCI 2018). The homes then ignited each other, just as they did on the Camp Fire. Treating wildland fuels would have made no difference, just as it made no difference in the behavior of the Camp Fire on its first day.

Evacuation plans and routes failed for many residents in the path of the Camp Fire.

In many areas, including Butte County, hazardous fuels programs can be an effective part of the wildland fire system (BCFSC 2018a; Tubbesinga and others 2019), particularly if strategies for timing and placing treatments can improve through the use of new tools, such as scenario investment planning (USDA Forest Service 2018). But fuels treatments can be irrelevant under some circumstances, such as Red Flag Warnings of high Jarbo (or Santa Ana) winds in a drought.

In fact, 50 percent of the homes destroyed by wildfires in California from 1985 to 2013 were in interface parts of the WUI, bedroom communities with little or no wildland vegetation in them (Kramer and others 2019); another 4 percent were in non-WUI urban areas like Berkeley and Santa Rosa, CA, destroyed by the 1991 Oakland Hills Fire and 2017 Tubbs Fire, respectively. As in Paradise and Magalia, the fuels were mainly the homes themselves, along with the associated structures, vehicles, and residential vegetation. Instead of focusing on the areas most at risk, most fuel models and treatment plans are tailored to intermix parts of the WUI, where the risk to lives and homes is lower (Kramer and others 2019).

In short, active forest management alone cannot resolve the myriad issues associated with fire risk in the WUI. What counts is the entire wildland fire system in all of its complexity (Spies and others 2014), with all of its interacting parts. If the combination is dysfunctional, disaster will result, just as it did on the fateful first day of the Camp Fire.

Camp Fire Success Story

On November 12, 4 days after the fire started, the evening incident report was the first to strike an optimistic tone, noting that "firefighters were successful in many areas of the fire today" (InciWeb 2018a). By then, firefighters were able to exploit fuels treatments in some places (BCFSC 2018a).

In one place on the fire's northern flank, the Forest Service had partnered with the Sierra Nevada Conservancy and the Butte County Fire Safe Council to fund a timber sale on 176 acres (71 ha) of land. In combination with mastication (mulching) of ground fuels, the treatment had opened up mixed-conifer stands near Paradise Lake (a small reservoir near Magalia) while reducing ladder fuels. Firefighters were able to get into the treated area to control the fire, keeping it from reaching the reservoir.

Butte County officials subsequently took visitors to tour the site as a success story.

Visiting the fuels treatment at Paradise Lake in the wake of the Camp Fire on November 26, 2018—and visibly shaken by the tragedy—were (from left to right) Forest Service Chief Vicki Christiansen, Pacific Southwest Regional Forester Randy Moore, and Secretary of Agriculture Sonny Perdue. Photo: Jim Mackensen, USDA Forest Service.

Under the influence of a changing climate, the parts of the wildland fire system might be reconfiguring and interacting in new ways, particularly in California. The California fires of 2017–18 might be the harbinger of a new kind of wildland fire environment, with fires behaving in ways not seen since the 19th and early 20th centuries, when wildfires often burned into towns. As Stephen J. Pyne observed (Simon 2018):

> *We're seeing urban conflagrations, and that's the real phase change in recent years … what's remarkable is the way they're plowing over cities, which we thought was something that had been banished a century ago.*

Is California on the cusp of an emerging "new normal," with a new kind of fire?

ACKNOWLEDGMENTS

I would like to thank Russ Briggs, Susan Cook-Patton, and Duncan McKinley for taking time from their busy schedules to review and comment on a longer draft of the article. I would also like to thank Bill Lange and Lily Whiteman for calling the paper by Kramer and others (2019) to my attention, including a Forest Service online writeup about it (Hodgins 2019). Russell D. Briggs is the director of the Division of Environmental Science at the College of Environmental Science and Forestry, State University of New York, Syracuse, NY; Susan Cook-Patton is a forest restoration scientist on the Carbon Science Team for The Nature Conservancy, Arlington, VA; William Lange is a senior advisor to the Deputy Chief for National Forest System for the Forest Service, Washington Office, Washington, DC; Duncan McKinley is a program specialist for the Forest Service, Office of the Chief, Washington Office, Washington, DC; and Lily Whiteman is a program specialist for Knowledge Management and Communications, Forest Service, Research and Development, Washington Office, Washington, DC. As author, I am solely responsible for any errors.

LITERATURE CITED

Baker, D.R. 2017. Underground power lines don't cause wildfires. But they're really expensive. San Francisco Chronicle. 21 October. https://www.sfchronicle.com/bayarea/article/Underground-power-lines-don-t-cause-wildfires-12295031.php. (30 May 2019).

Baker, D.R.; Chediak, M. 2018. PG&E decided not to cut power as winds raged before California wildfire. Insurance Journal. 28 November. https://www.insurancejournal.com/news/west/2018/11/28/510260.htm. (30 May 2019).

Bartolone, P. 2019. Their home survived the Camp Fire—but their insurance did not. National Public Radio. 17 February. https://www.npr.org/2019/02/17/695205917/their-home-survived-the-camp-fire-but-their-insurance-did-not. (31 May 2019).

BCCFPA (Butte County Cooperative Fire Protection Agencies). 2015. Butte County Community Wildfire Protection Plan, 2015–2020. Oroville, CA. 87 p. https://www.buttecounty.net/Portals/14/Evac%20Maps/2015_Countywide_CWPP_FINAL.pdf. (30 May 2019).

BCFSC (Butte County Fire Safe Council). 2018a. Lessons learned/success stories. Paradise, CA. http://www.buttefiresafe.net/browse-downloads/lessons-learned-success-stories. (31 May 2019).

BCFSC (Butte County Fire Safe Council). 2018b. Disaster preparedness. Paradise, CA. http://www.buttecounty.net/oem/DisasterPreparedness. (1 June 2019).

BCWC (Butte Creek Watershed Conservancy). 2005. Floodplain management plan, map 12: public and private ownership. http://shell22.tdl.com/~bcchkw/Watershed/FMP_Map-12.pdf. 1 p. (31 May 2019).

Bramwell, L. 2014. Wilderburbs: communities on the edge. Seattle, WA: University of Washington Press. 344 p.

Brown, H. 2004. "The air was fire": fire behavior at Peshtigo in 1871. Fire Management Today. 64(4): 20–30. https://www.fs.fed.us/sites/default/files/legacy_files/fire-management-today/64-4.pdf. (30 May 2019).

Cal Fire (California Department of Forestry and Fire Protection). 2012. California's wildland-urban interface code information. Sacramento, CA: State of California. http://www.fire.ca.gov/fire_prevention/fire_prevention_wildland_codes. (31 May 2019).

Cal Fire (California Department of Forestry and Fire Protection). 2018. Camp Fire incident update, 11/25/18, 7 a.m. Sacramento, CA: State of California. http://cdfdata.fire.ca.gov/pub/cdf/images/incidentfile2277_4326.pdf. (30 May 2019).

CCI (California Chaparral Institute). 2018. Letter to the California Board of Forestry and Fire Protection. 12 January. Escondido, CA. 36 p. http://www.californiachaparral.com/images/2017_Draft_VTP_CCI_comments_FINAL_II.pdf. (1 June 2019).

Christiansen, V. 2018. Opportunities to improve the wildland fire system. Fire Continuum Conference: preparing for the future of wildland fire. Missoula, MT: Association for Fire Ecology. https://www.fs.fed.us/speeches/opportunities-improve-wildland-fire-system. (30 May 2019).

EII (Earth Island Institute). N.d. Camp Fire photos: logged areas burned much more intensely, while mature forest burned mostly at lower intensities. Big Bear City, CA: The John Muir Project. 5 p. http://johnmuirproject.org/wp-content/uploads/2018/12/JMPCampFirePhotoMemo.pdf. (31 May 2019).

EII (Earth Island Institute). 2019. Logging didn't stop the Camp Fire. Blog. Big Bear City, CA: The John Muir Project. http://johnmuirproject.org/2019/01/logging-didnt-stop-the-camp-fire/. (31 May 2019).

Gabbert, B. 2018. On 60 Minutes, Chief Pimlott describes the rapid rate of spread of the Camp Fire. Wildfire Today. 5 December. https://wildfiretoday.com/2018/12/05/on-60-minutes-chief-pimlott-describes-the-rapid-rate-of-spread-of-the-camp-fire/. (31 May 2019).

Gafni, M. 2018. Rebuild Paradise? Since 1999, 13 large wildfires burned in the footprint of the Camp Fire. San Jose Mercury News. 2 December. https://www.mercurynews.com/2018/12/02/rebuild-paradise-since-1999-13-large-wildfires-burned-in-the-footprint-of-the-camp-fire/. (30 May 2019).

Ho, V.; Canon, G. 2018. How did California's wildfires start? Two electrical utilities face scrutiny. The Guardian. 17 November. https://www.theguardian.com/us-news/2018/nov/16/california-wildfires-causes-investigation-pge-edison-sce. (30 May 2019).

Hodgins, J. 2019. Most California fires occur in area of wildland-urban interface with less fuel and more people. St. Paul, MN: USDA Forest Service, Northern Research Station. https://www.nrs.fs.fed.us/news/release/wui-interface-intermix. (5 October 2019).

InciWeb (Incident Information System). 2018a. Camp Fire: Incident updates. November 9–25. https://inciweb.nwcg.gov/incident/article/6250/48772/. (31 May 2019).

InciWeb (Incident Information System). 2018b. Camp Fire: Fire progression map. November 25. https://inciweb.nwcg.gov/incident/map/6250/1/90909. (31 May 2019).

Kaplan, S.; Sellers, F.S. 2018. How they survived: owners of the few homes left standing around Paradise, Calif., took critical steps to ward off wildfires. The Washington Post. 30 November. https://www.washingtonpost.com/national/how-they-survived-owners-of-the-few-homes-left-standing-around-paradise-calif-took-critical-steps-to-ward-off-wildfires/2018/11/30/db323782-f34b-11e8-80d0-f7e1948d55f4_story.html?utm_term=.b0686fe84f04. (31 May 2019).

Kasler, D. 2018. In Trump administration's third visit to Paradise, the message remains clear: thin the forests. Sacramento Bee. 27 November. https://www.sacbee.com/news/politics-government/capitol-alert/article222097760.html. (31 May 2019).

Kasler, D.; Reese, P. 2019. "The weakest link:" why your house may burn while your neighbor's survives the next wildfire. Sacramento Bee. 11 April. https://www.sacbee.com/news/state/california/fires/article227665284.html. (31 May 2019).

Kramer, H.A.; Mockrin, M.H.; Alexandre, P.M.; Radeloff, V.C. 2019. High wildfire damage in interface communities in California. International Journal of Wildland Fire. DOI: https://doi.org/10.1071/WF18108. https://www.fs.fed.us/nrs/pubs/jrnl/2019/nrs_2019_kramer_001.pdf. (26 September 2019).

Martinuzzi, S.; Stewart, S.I.; Helmers, D.P. [and others]. 2015. The 2010 wildland–urban interface of the conterminous United States. Res. Map NRS–8. Newtown Square, PA: USDA Forest Service, Northern Research Station. 128 p. http://www.fs.fed.us/nrs/pubs/rmap/rmap_nrs8.pdf. (31 May 2019).

Meigs, J.B. 2018. Living on the edge. Slate. 20 November. https://slate.com/technology/2018/11/camp-fire-disaster-causes-urban-wildland-interface.html. (30 May 2019).

Moriarty, D.; Rigdon, R.; Wang, J. 2018. Trapped in Paradise. The Wall Street Journal. 30 November. https://www.wsj.com/graphics/trapped-in-paradise-fire/. (31 May 2019).

NASA (National Aeronautics and Space Administration). 2018. NASA Landsat 8 Operational Land Imager: Camp Fire. Washington, DC. https://commons.wikimedia.org/wiki/File:Camp_Fire_oli_2018312_Landsat.jpg. (31 May 2019).

NDMC (National Drought Mitigation Center). 2019. United States Drought Monitor. Lincoln, NE: University of Nebraska. https://droughtmonitor.unl.edu/Maps/MapArchive.aspx. (30 May 2019).

NFPA (National Fire Protection Association). N.d. Firewise USA sites: State listing of participants. Washington, DC. https://www.nfpa.org/Public-Education/By-topic/Wildfire/Firewise-USA/Firewise-USA-Resources/Firewise-USA-sites/State-listing-of-participants https://www.nfpa.org/Public-Education/By-topic/Wildfire/Firewise-USA/Firewise-USA-Resources/Firewise-USA-sites/State-listing-of-participants. (31 May 2019).

NICC (National Interagency Coordination Center). 2018. Wildland fire summary and statistics: annual report, 2018. 13 p. https://www.predictiveservices.nifc.gov/intelligence/2018_statssumm/intro_summary18.pdf. (30 May 2019).

NIDIS (National Integrated Drought Information System). 2019. Drought in California. Washington, DC: National Oceanic and Atmospheric Administration. https://www.drought.gov/drought/states/california. (30 May 2019).

Prestemon, J.P.; Hawbaker, T.J.; Bowden, M. [and others]. 2013. Wildfire ignitions: a review of the science and recommendations for empirical modeling. Gen. Tech. Rep. SRS–171. Asheville, NC: USDA Forest Service, Southern Research Station. 20 p. https://www.srs.fs.fed.us/pubs/gtr/gtr_srs171.pdf. (30 May 2019).

Prudhomme, C. 2018. Residents reducing wildfire risks through the Firewise USA™ program. Fire Management Today. 76(4): 32–34. https://www.fs.fed.us/sites/default/files/fire-management-today/fs_fire_management_v76-4_508_v2.pdf. (31 May 2019).

Pyne, S.J. 2001. Year of the fires: the story of the great fires of 1910. New York, NY: Viking. 322 p.

Pyne, S.J. 2015. Between two fires: a fire history of contemporary America. Tucson, AZ: The University of Arizona Press. 539 p.

Quarles, S.L. 2018. Reducing the vulnerability of homes to wildfire. Fire Management Today. 76(4): 16–19. https://www.fs.fed.us/managing-land/fire/fire-management-today/fire-management-today-volume-76-issue-4. (31 May 2019).

Reyes-Velarde, A. 2019. California's Camp fire was the costliest disaster last year, insurance report shows. Los Angeles Times. 11 January. https://www.latimes.com/local/lanow/la-me-ln-camp-fire-insured-losses-20190111-story.html. (30 May 2019).

Simon, M. 2018. The terrifying science behind California's massive Camp Fire. Wired Magazine. 9 November. https://www.wired.com/story/the-terrifying-science-behind-californias-massive-camp-fire/. (30 May 2019).

Spies, T.A.; White, E.M.; Kline, J.D. [and others]. 2014. Examining fire-prone forest landscapes as coupled human and natural systems. Ecology and Society. 19(3): article 9. https://www.ecologyandsociety.org/vol19/iss3/art9/. (30 May 2019).

St. John, P.; Phillips, A.M.; Serna, J. [and others]. 2018. California fire: what started as a tiny brush fire became the state's deadliest wildfire. Los Angeles Times. 18 November. https://www.latimes.com/local/california/la-me-camp-fire-tictoc-20181118-story.html. (30 May 2019).

Swain, D. 2018. In wake of California's worst wildfire catastrophe, significant rain finally on the horizon. Weather West: The California Weather Blog. 17 November. https://weatherwest.com/archives/6538. (30 May 2019).

Thompson, M.P.; MacGregor, D.G.; Dunn, C.J. [and others]. 2018. Rethinking the wildland fire management system. Journal of Forestry. 116(4): 382–390. https://www.fs.fed.us/rm/pubs_journals/2018/rmrs_2018_thompson_m001.pdf. (30 May 2019).

Tubbesinga, C.L.; Frya, D.L.; Rollerb, G.B. [and others]. 2019. Strategically placed landscape fuel treatments decrease fire severity and promote recovery in the northern Sierra Nevada. Forest Ecology and Management. 436: 45–55. https://www.sciencedirect.com/science/article/pii/S0378112718320462. (1 June 2019).

USDA Forest Service. 2016. Life First leadership engagements: appendix D—Complexity in wildland fire system; appendix E—Long-term intention and rationale white paper. Washington, DC. 8 p.

USDA Forest Service. 2018. Toward shared stewardship across landscapes: an outcome-based investment strategy. Washington, DC: USDA Forest Service. 24 p. https://www.fs.fed.us/sites/default/files/toward-shared-stewardship.pdf. (30 May 2019).

USDA Forest Service/BLM (Bureau of Land Management). 2011. Record of decision: Concow Hazardous Fuels Reduction Project. Oroville, CA: Plumas National Forest. 14 p. https://www.fs.usda.gov/nfs/11558/www/nepa/12254_FSPLT2_054921.pdf. (31 May 2019).

Valachovic, A. 2018. What can we learn from the 14,000 homes lost during the Camp Fire? Forest Research and Outreach. 21 December. University of California Cooperative Extension Forestry, Berkeley, CA. https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=29019. (31 May 2019).

Van Derbeken. 2018. No audit of PG&E high-voltage power line linked to Camp Fire: Investigation. NBC News. 21 November. https://www.nbcbayarea.com/investigations/No-Audit-of-PGE-High-Voltage-Power-Line-Linked-to-Camp-Fire-Investigation-501055952.html?amp=y. (30 May 2019).

Wells, R.W. 1968. Fire at Peshtigo. Englewood Cliffs, NJ: Prentice-Hall. 243 p.

WERT (Watershed Emergency Response Team). 2018. Camp Fire: final report. CA–BTU–016737. Sacramento, CA: State of California. 14 p. http://cdfdata.fire.ca.gov/pub/cdf/images/incidentfile2277_4330.pdf. (30 May 2019).

Optimizing Firefighter Nutrition: Average Glycemic Index of Fireline Meals

Ben McLane

Idaho City Hotshots eating dinner on the 2016 Pioneer Fire, Boise National Forest, ID. Photo: USDA Forest Service.

During a 16-hour shift, wildland firefighters can burn more than 6,000 calories.

As wildfire seasons have expanded in duration and intensity, the effort and dedication required of wildland firefighters have increased (Withen 2015). Firefighters now work from April, when fuels first become available for burning, until well into the winter months of December and January. As fire seasons have grown into "fire years," maintaining firefighter health and well-being has become a rising concern.

NUTRITIONAL REQUIREMENTS

During a 16-hour shift, wildland firefighters can burn more than 6,000 calories (Domitrovich and Sol 2017), so chronic fatigue is a constant concern (Zaske 2018). Both nutrition and fatigue can affect the physical and cognitive ability of wildland firefighters to do their jobs well and safely (Aisbett and others 2012). The National Interagency Fire Center and the Forest Service have established nutritional requirements for companies providing firefighter meals (NIFC/FS, n.d.). The requirements pertain to food type and quality, caloric content, and serving size.

This article summarizes results of a case study I did on nutritional requirements for wildland firefighters as part of completing my graduate degree at the University of Idaho. I reviewed the literature on optimal nutrition for endurance athletes, assessed the glycemic index (GI) of meals offered to the fire crew I am on, and conducted an informal survey of my fellow firefighters about their energy levels.

My subjects were the 20 members of the Elk Mountain Interagency Hotshot Crew throughout their 2018 fire season, when they worked more than 950 overtime hours in four Western States. The crew recorded almost 1,300 hours on active fire incidents. For hotshots, the daily duration and magnitude of physical exertion can equal that of elite endurance athletes such as marathon runners (Loftin and others 2007). For endurance athletes, proper nutrition is essential for best performance (Baar 2014).

GLYCEMIC INDEX

A nutritional requirement for endurance athletes is to manage blood-sugar levels during exercise, and different carbohydrate foods can cause differing blood-sugar responses (Dunford and others 1995). One way of managing blood glucose is through the GI of food and drink. GI is a measure, on a scale of 1 to 100, of how much a food or drink will affect the level of glucose in the bloodstream. You can tell the GI of a food by measuring the blood-glucose response after eating it compared to the blood-glucose response to a reference food, usually pure sugar or white bread (Atkinson and others 2008). I used a pure-sugar reference scale, so a GI of 100 would be a blood-glucose response equivalent to the response from pure sugar.

Foods with high GI can result in hyperglycemic levels of blood sugar,

Ben McLane is an apprentice with the Elk Mountain Interagency Hotshot Crew, Mendocino National Forest, Upper Lake, CA.

followed by very low blood-sugar levels after the glucose has cleared away (Fabricatore and others 2011). Such rapid carbohydrate energy fluctuations can be advantageous when intense physical exertion is expected over a short period of time (Vandenbogaerde and Hopkins 2011).

However, this style of carbohydrate consumption can be less ideal for long-term physical endurance over an extended period of time (Baranauskas and others 2017). The GI of a single meal preceding physical exertion might have little influence on performance (Burdon and others 2017), but the overall pattern of GI in an endurance athlete's diet can affect performance (Durkalec-Michalski and others 2018).

The results suggest that catered meals for wildland firefighters are in the moderate to high glycemic index category.

STUDY METHODS

From June to October 2018, I collected the GI information for hot breakfasts, sack lunches, and hot dinners served by caterers to my hotshot crew. I categorized a food based on its level of impact on blood sugar as low GI (< 55), moderate GI (55–70), or high GI (> 70) (Atkinson and others 2008). For each meal, I summed up the GIs of foods containing carbohydrates in order to find an average GI for the meal. I extrapolated the values for the entire season and performed statistical significance tests.

Over the course of the 2018 fire season, the hotshot crew spent 90 shifts assigned to an active fire incident where meals were provided. Whenever the crew members ate catered meals, I used a cell phone camera to take pictures of either the menu for the meal or the food items. Although each crew member was supposed to get three meals per day (NIFC/FS, n.d.), the nature of our assignments meant that meals were skipped or that firefighters got "meals ready to eat" in place of catered meals. In such cases, I did not collect data.

I used a survey of crew members to correlate meal data with energy levels. The survey allowed the firefighters to assess their own levels of mental and physical energy after consuming a catered meal. The survey was voluntary and could be completed at any time using any device with the SurveyMonkey application. The survey comprised six questions:

1. Rate your physical energy on a scale of 1–5.
2. Rate your mental energy on a scale of 1–5.
3. How long ago did you last eat?
4. Did you consume any stimulants (coffee, tobacco, energy supplements) between eating and filling out this survey? (Yes/no.) If so, what type?
5. What parts of your most recent meal did you choose to eat?
6. What parts of your most recent meal did you choose to avoid?

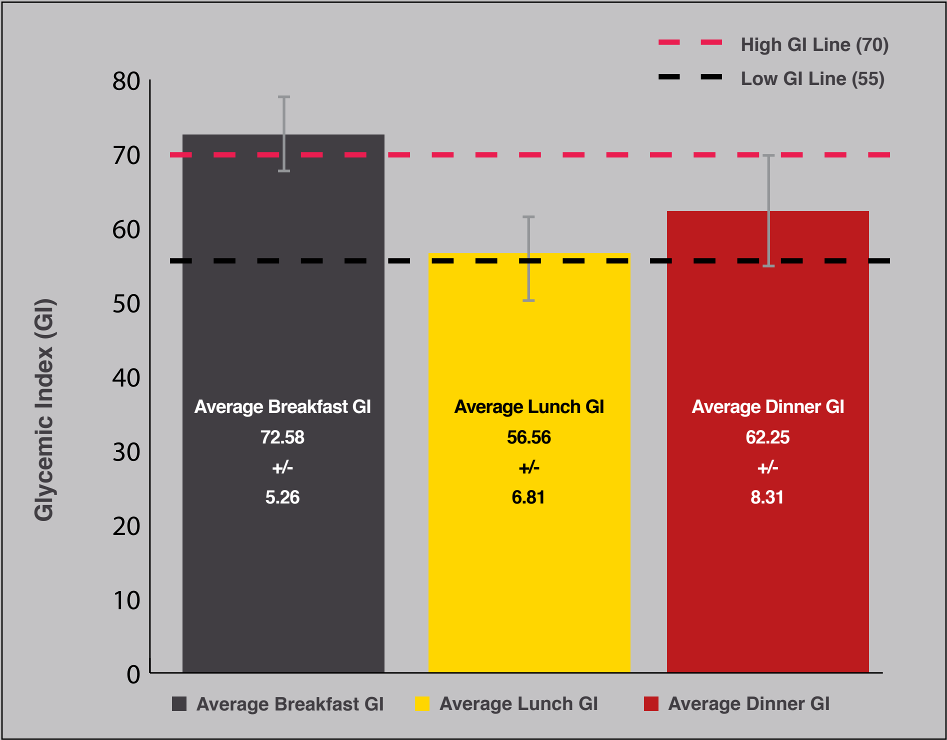


Figure 1—*Average glycemic index (GI) of catered breakfasts, lunches, and dinners eaten by members of the Elk Mountain Interagency Hotshot Crew during the 2018 fire season (including standard deviations). The GI was moderate to high on the GI scale published by Atkinson and others (2008).*

RESULTS

The nutritional information varied considerably among meals but was fairly consistent within each type of meal. For breakfasts, the average GI was 72.58 ± 5.26. For lunches, the average GI was 56.56 ± 6.81. For dinners, the average GI was 62.25 ± 8.31 (average GI ± standard deviation) (fig. 1).

Six firefighters took the voluntary survey, all from 1 to 3 hours after eating. Four of the six rated their postmeal physical energy as 4 out of 5, and five of the six rated their cognitive readiness as 4 out of 5. Only one respondent reported consuming no stimulant after eating; three consumed coffee/caffeine and two chewed tobacco. Consumed foods included

Figure 2—*A fireline dinner with a low average GI of 47.75 (left), compared to an example of a dinner with a high average GI of 69.25 (right). Photos: Ben McLane, USDA Forest Service.*

eggs, milk, and potatoes; avoided foods included breakfast cereals, breads (such as dinner rolls or sandwich breads), and desserts (such as candy, muffins, doughnuts, and cinnamon rolls).

DISCUSSION

The results suggest that catered meals for wildland firefighters are in the moderate-GI or high-GI category based on a glucose reference scale (Atkinson and others 2008), which makes firefighters subject to the highly variable blood-sugar levels of a high-glycemic diet (Kochan and others 2012). Of course, my study was limited by variability and bias. My own possible influence on the dietary preferences of my fellow hotshot crew members as well as the small number of survey responses were both limitations.

Nevertheless, my study does suggest that the GI of the diets of wildland firefighters is a possible nutritional metric that warrants further study.

Historically, research on wildland firefighter nutrition has focused on the caloric and macronutrient levels of fireline meals (Robertson and others 2017). Although such information is valuable, my study shows that GI can vary greatly between foods with very similar macronutrients (fig. 2, table 1).

Collecting GI data on fireline meals is both possible and useful for understanding nutrition in wildland firefighters. Although my study suggests that fireline meals make for a high-GI diet, the effects of high GI can be mitigated by eating low-GI foods as well (Tufts University 2017). In fact, the fireline meals I studied also contained low-GI foods like nuts and dairy products. Further study might be needed to relate the actual postmeal blood-sugar response of wildland firefighters to GI; previous research has suggested that predicted and actual blood-glucose responses to food can vary based on meal composition (Dodd and others 2011).

The survey results, though limited, suggest that wildland firefighters are inconsistent in the way they consume fireline meals: all six survey respondents chose not to eat certain parts of their latest meal. Even though fireline caterers meet nutritional guidelines (NIFC/FS, n.d.), the firefighters are not necessarily consuming the amount of food that fire management organizations recommend. Collins and others (2018) found negative changes in the body composition of smokejumpers over the course of the 2017 fire season, which can adversely affect job performance—and might be due, in part, to nonoptimal nutrition.

Further study into the performance of wildland firefighters who are not taking in the recommended amounts of calories and macronutrients might be of merit. Louie and others (2012) have suggested that low-GI diets might better meet nutrient requirements than the high-GI alternatives. The findings of this study might be useful in researching the potential benefits of a low-GI diet for wildland firefighters.

Table 1—*Glycemic index (GI) and other values for two fireline meals shown in figure 2, by food item.*

Meal 1 (low GI)	Value	Meal 2 (high GI)	Value
GI			
Pork	n.a.	Pork	n.a.
Steamed sweet potatoes	46	Au Gratine potatoes	86
Mac ‘n cheese	49	Fettuccine Alfredo	49
Steamed corn	52	Green beans	n.a.
Coleslaw	44	Dinner rolls	75
–	–	Apple pie	67
Average	**47.75**	**Average**	**69.25**
Other values			
Total calories	1,266	Total calories	1,209
Protein	63 grams	Protein	71 grams
Fat	55 grams	Fat	56 grams
Carbohydrate	133 grams	Carbohydrate	105 grams

Note: n.a. = not available.

In addition to prescribing diets for wildland firefighters, fire management organizations advise firefighters on how to eat. The Forest Service's Missoula Technology and Development Center recommends that firefighters consume 150 to 200 calories every 2 hours during their work shifts (Sharkey 2007). Though feasible for some endurance activities, taking frequent breaks to eat is not always possible on a fire assignment, especially for firefighters like hotshots and smokejumpers who typically get the most arduous assignments (Heil 2002). Such firefighters might rarely get a chance to eat. When they do, they are likely to eat a lot, subjecting themselves to the brunt of the effect of high-GI meals on blood sugar and energy levels.

Much work has gone into researching diets for personnel in the Armed Forces, who can also be subject to long and arduous work shifts, with scant allowance for frequent breaks to consume small amounts of food (Duffie 2015). Dietary study has also been done to optimize the performance of elite endurance athletes (Egan and D'Agostino 2016). Such research suggests that a diet with a lower intake of simple carbohydrates could provide wildland firefighters with the sustained energy they need to perform at a high level without concern about low blood-glucose levels. The prospect of a lower carbohydrate diet for wildland firefighters could merit further study, especially since firefighters might already be consuming well below the recommended levels of carbohydrates on fire assignments (Robertson and others 2017). A better understanding of how blood-sugar levels in wildland firefighters are affected by catered meals could help fire managers tailor food offerings for optimal physical and mental firefighter performance.

I intended my study only as an initial indication of whether further research into this topic is needed. My study's limited scope and duration do not allow for significant conclusions about the effect of the average GI in fireline meals on firefighter energy levels. However, my study does provide valuable information about the potential of GI as a measure of firefighter nutrition. Important recommendations can be made for further research in this area.

RECOMMENDATIONS

Additional research on the effect of fireline meals on energy levels for firefighters depends on controlling for certain variables, if possible.

One variable is the effect of overall meal composition on firefighters' blood-sugar response to the GI of foods within the meal. This study showed that collecting GI data for fireline meals is feasible, given the readily available GI indexes. However, if the actual impact of a meal's GI on blood glucose is not adequately represented by the GI value in the index because of the overall meal composition, then the GI information is not as useful.

One possible way to control for this variable would be to incorporate "glycemic load" into further study. Glycemic load takes the amount of carbohydrates within a food's serving size into account in order to measure the impact of that food on blood sugar. O'Reilly and others (2010) suggest that glycemic load more accurately reflects the potential peak-and-valley effect of carbohydrates within a food on blood-glucose levels than GI alone.

The ultimate solution to the problem of controlling for this variable would be to take actual blood-glucose measurements from wildland firefighters after they have consumed fireline meals. Then the average GI of a meal could be directly correlated with the magnitude and duration of elevated blood-glucose levels.

Another variable to closely monitor in future research is the selectiveness of wildland firefighters in what they eat. Although my survey data was limited, none of the respondents entirely consumed their most recent meal. Any nutritional study on fireline meals is meaningful only if firefighters are actually eating the food that the study is about. A study that focuses not only on the food available to wildland firefighters but also on what they actually eat could help to optimize firefighter nutrition as well as control food waste.

Every survey respondent used some sort of stimulant after eating, a common practice among firefighters.

Every survey respondent used some sort of stimulant after eating, a common practice among firefighters (Poston and others 2013). The habitual use of stimulants might be a symptom of low energy, which is consistent with recent findings of chronic fatigue and sleep deprivation among wildland firefighters (Vincent and others 2018). Deficient nutrition could also contribute to low energy levels and stimulant use, with long-term adverse effects on health (Oliveira and others 2017).

Combining the best science-based nutrition, rest, and physical preparation is the way to create a wildland firefighting force that can mitigate the continuing effects of climate change, excessive fuel loading, and expansion of the wildland–urban interface (Liu and others 2015; Pyne 2010).

LITERATURE CITED

Aisbett, B.; Wolkow, A.; Sprajcer, M.; Ferguson, S.A. 2012. "Awake, smoky, and hot:" providing an evidence-base for managing the risks associated with occupational stressors encountered by wildland firefighters. Applied Ergonomics. 43(5): 916–925.

Atkinson, F.S.; Foster-Powell, K.; Brand-Miller, J.C. 2008. International tables of glycemic index and glycemic load values: 2008. Diabetes Care. 31(12): 2281–2283.

Baar, K. 2014. Nutrition and the adaptation to endurance training. Sports Medicine. 44(Suppl. 1): 5–12.

Baranauskas, M.N.; Miller, B.; Olson, J.T. [and others]. 2017. Differential in maximal aerobic capacity by sex in collegiate endurance athletes consuming a marginally low carbohydrate diet. Journal of the American College of Nutrition. 36(5): 370–377.

Burdon, C.A.; Spronk, I.; Cheng, H.L.; O'Connor, H.T. 2017. Effect of glycemic index of a pre-exercise meal on endurance exercise performance: a systematic review and meta-analysis. Sports Medicine. 47(6): 1087–1101.

Collins, C.N.; Brooks, R.H.; Sturz, B.D. [and others]. 2018. Body composition changes of United States smokejumpers during the 2017 fire season. Fire. 1(3): 48.

Dodd, H.; Williams, S.; Brown, R.; Venn, B. 2011. Calculating meal glycemic index by using measured and published food values compared with directly measured meal glycemic index. American Journal of Clinical Nutrition. 94(4): 992–996.

Domitrovich, J.; Sol, J. 2017. Wildland firefighting: research offers valuable data on the health of wildland firefighters. Firehouse Supplement: Fire Service Health and Safety Report. A28–A29. https://ulfirefightersafety.org/docs/NFFF_Supplement1017.pdf. (27 August 2019).

Duffie, W. 2015. Deep dive: ONR-supported research combats oxygen toxicity in Navy divers. Office of Naval Research. https://www.onr.navy.mil/en/Media-Center/Press-Releases/2015/Oxygen-Toxicity-Navy-Divers. (27 August 2019).

Dunford, M.G.; Doyle, J.A.; Ortiz, M.; Giusti, J. 1995. Glucose and insulin response to carbohydrate foods in male endurance athletes. Journal of the American Dietetic Association. 95(9): A18.

Durkalec-Michalski, K.; Zawieja, E.E.; Zawieja, B.E. [and others]. 2018. Effects of low versus moderate glycemic index diets on aerobic capacity in endurance runners: three-week randomized controlled crossover trial. Nutrients. 10(3): 3–7.

Egan, B.; D'Agostino, D.P. 2016. Fueling performance: ketones enter the mix. Cell Metabolism. 24(3): 373–375.

Fabricatore, A.N.; Ebbeling, C.B.; Wadden, T.A.; Ludwig, D.S. 2011. Continuous glucose monitoring to assess the ecological validity of glycemic index in obese adults with type 2 diabetes. American Journal of Clinical Nutrition. 94(6): 1519–1524.

Heil, D.P. 2002. Estimating energy expenditure in wildland fire fighters using a physical activity monitor. Applied Ergonomics. 33(5): 405–413.

Kochan, A.M.; Wolever, T.M.; Chetty, V.T. [and others]. 2012. Glycemic index predicts individual glucose responses after self-selected breakfasts in free-living, abdominally obese adults. Journal of Nutrition. 142(1): 27–32.

Loftin, M.; Sothern, M.; Koss, C. [and others]. 2007. Energy expenditure and influence of physiologic factors during marathon running. Journal of Strength and Conditioning Research. 21(4): 1188–1191.

Louie, J.C.; Buyken, A.E.; Brand-Miller, J.C.; Flood, V.M. 2012. The link between dietary glycemic index and nutrient adequacy. American Journal of Clinical Nutrition. 95(3): 694.

Liu, Z.; Wimberly, M.C.; Lamsal, A. [and others]. 2015. Climate change and wildfire risk in an expanding wildland–urban interface: a case study from the Colorado Front Range corridor. Landscape Ecology. 30(10): 1943–1957.

NIFC/FS (National Interagency Fire Center/USDA Forest Service). [N.d.]. National mobile food services. AG–024B–S–07–9001. Boise, ID. 102 p. https://gacc.nifc.gov/oncc/docs/14_Mobile_Food_Service_Contract.pdf. (27 August 2019).

O'Reilly, J.; Wong, S.H.; Chen, Y. 2010. Glycaemic index, glycaemic load and exercise performance. Sports Medicine. 40(1): 27–39.

Oliveira, M.; Slezakova, K.; Magalhaes, C.P. [and others]. 2017. Individual and cumulative impacts of fire emissions and tobacco consumption on wildland firefighters' total exposure to polycyclic aromatic hydrocarbons. Journal of Hazardous Materials. 334: 10–20.

Poston, W.S.; Haddock, C.K.; Jahnke, S.A. [and others]. 2013. An examination of the benefits of health promotion programs for the national fire service. BMC Public Health. 13: 1–14

Pyne, S.J. 2010. America's fires: a historical context for policy and practice. Rev. ed. forest History Society Issues Series. Durham, NC: Forest History Society. 94 p.

Robertson, A.H.; Lariviere, C.; Leduc, C.R. [and others]. 2017. Novel tools in determining the physiological demands and nutritional practices of Ontario fire rangers during fire deployments. PLoS ONE. 12(1): E0169390. DOI: 10.1371/journal.pone.0169390.

Sharkey, B. 2007. Wildland firefighter nutrition education program. Tech Tip 0751–2302P–MTDC. Missoula, MT: USDA Forest Service, Missoula Technology and Development Center. 4 p.

Tufts University. 2017. New insights: glycemic index. Health and Nutrition Letter. 35: 3. https://www.nutritionletter.tufts.edu/issues/13_9/current-articles/New-Insights-Glycemic-Index_2213-1.html. (27 August 2019).

Vandenbogaerde, T.J.; Hopkins, W.G. 2011. Effects of acute carbohydrate supplementation on endurance performance: a meta-analysis. Sports Medicine. 41(9): 773–792.

Vincent, G.E.; Aisbett, B.; Wolkow, A. [and others]. 2018. Sleep in wildland firefighters: What do we know and why does it matter? International Journal of Wildland Fire. 27: 73–84.

Withen, P. 2015. Climate change and wildland firefighter health and safety. New Solutions. 24(4): 577–584.

Zaske, S. 2018. Survey says fatigue primary cause of wildland fire site accidents. University of Idaho, College of Natural Resources. https://www.uidaho.edu/cnr/research/stories/wildlandfirefighter. (27 August 2019).

Pardon Our Smoke

Pete Lahm

Smoke from a prescribed fire on Florida's Merritt Island National Wildlife Refuge south of the Kennedy Space Center Visitor Complex on June 14, 2013, to reduce the threat of wildfire to local residents and improve wildlife habitat. Photo: Michael Good, U.S. Fish and Wildlife Service.

Where there's fire, there's smoke. In fact, smoke from wildfires has become the greatest source of air pollution in the United States. As wildfires increase in duration, communities often face multiple weeks of exposure. In 2018, fine-particulate levels exceeded the 24-hour standard in the Western United States more than 3,700 times.

To help minimize these impacts, the USDA Forest Service helped create and now leads the *Interagency Wildland Fire Air Quality Response Program* with the U.S. Department of the Interior. Working with Federal, State, local, and Tribal partners, the Forest Service's Pacific Northwest Research Station AirFire team uses state-of-the-art smoke modeling and air quality prediction tools to help mitigate health and safety risks to the public and to wildland firefighters.

The program also maintains a national cache of 38 air quality monitors available for emergency dispatch and deploys 95 trained technical specialists. Called air resource advisors, the specialists are trained in air quality monitoring, smoke modeling, meteorology, air pollution health thresholds, fire behavior and fuel consumption, fire emissions, and communicating about smoke risks and mitigation.

Although prescribed fires generate smoke, the corresponding problems are much smaller than the problems that large wildfires would cause without fuels treatments.

When smoke becomes a concern for public health and safety, air resource advisors are dispatched to a wildfire incident, where they analyze potential smoke impacts and communicate with those affected, including incident management teams, public health partners, agency administrators, and the public. They prepare daily forecasts of projected smoke impacts, including on

Pete Lahm is the fire air quality specialist for the Forest Service, Fire and Aviation Management, Washington Office, Washington, DC.

transportation corridors. The forecasts convey information to people with special sensitivities to smoke, such as those with asthma or other respiratory or cardiac conditions, so that they can reduce their risk of exposure. Residents can visit the *AirNow website* to check the air quality in their areas.

Interagency fire managers conduct prescribed fires on about 1.2 million acres (500,000 ha) each year to reduce fuel loads. Reducing smoke emissions from prescribed fires is a priority for land managers, part of actively managing the national forests and grasslands. Managers conduct prescribed fires for short periods when the winds are favorable, and they closely monitor each prescribed fire. Protecting communities, keeping transportation corridors clear, and limiting smoke impacts take precedence in active management. Although prescribed fires generate smoke, the corresponding problems are much smaller than the problems that large wildfires would cause without fuels treatments. ■

SUCCESS STORIES WANTED

We'd like to know how your work has been going!

Let us share your success stories from your State fire program or your individual fire department. Let us know how your State Fire Assistance, Volunteer Fire Assistance, Federal Excess Personal Property, or Firefighter Property program has benefited your community. Make your piece as short as 100 words or longer than 2,000 words, whatever it takes to tell your story!

Submit your stories and photographs by email or traditional mail to:

USDA Forest Service
Fire Management Today
201 14th Street, SW
Washington, DC 20250

If you have questions about your submission, you can contact our FMT staff at the email address below.

SM.FS.FireMgtToday@usda.gov

Fire Tanker: Potential New Tool for Wildland Firefighting

Phil D. Sadler

Climate change is altering the intensity, frequency, and scale of wildland fires around the world. In countries from Australia to Canada, the European Union, Russia, and the United States, entire towns have been threatened or incinerated by wildfires, such as happened to the town of Paradise, CA, in November 2018. Hundreds of citizens have been killed or injured, with property losses in the tens of billions of dollars, along with greatly increased fire suppression costs. We are entering a new era of wildland firefighting, with fires threatening densely populated areas with lots of wildland–urban interface (WUI) fuels.

FIREFIGHTING ENVIRONMENT

Nevertheless, growing numbers of people are still moving into the WUI, where homes and lives are increasingly susceptible to loss by wildfire. Developers cater to the widespread wish for a home in the WUI while governments try to make such areas safer through greater fire protection.

Hand crews building fireline in the WUI often benefit from mechanized support. During extended attack, heavy equipment is often ubiquitous; on project fires, dozers are usually employed. The mechanized firefighting environment varies from heavy timber in the Pacific Northwest to the grasslands of the Great Plains. Not all firefighting hardware will always have the same efficacy in these diverse environments.

Airtankers are a key tool in fire suppression, but they have limitations: they don't fly at night or in smoke or high winds, and they are expensive to operate. Engines are another key tool but have limited ability to operate offroad. The brush truck can get closer to an offroad fire but is limited by capacity, brush, and trees. Skidgines are dedicated tracked vehicles that can get even closer to offroad firelines, but they also have limited capacity.

POTENTIAL NEW TOOL

Equipment used in the mining and construction industry might offer better capabilities for fighting fire in the WUI. One potential tool is a dozer-drawn fire tanker, a tracked tanker trailer of substantial size that is pulled by a bulldozer or similar vehicle (fig. 1). The tanker would obviate the need for a dedicated prime mover (such as a tractor), greatly reducing the cost while enabling greater versatility.

The best time to establish control lines is at night, when temperatures drop and

Figure 1—*Scale model of the Dozer-Drawn Fire Tanker. Photo: Phil Sadler.*

Phil Sadler, a former Forest Service hotshot and heavy-equipment operator, owns and operates the Sadler Machine Company, a small prototype development shop in Tempe, AZ. Pete Lahm is the fire air quality specialist for the Forest Service, Fire and Aviation Management, Washington Office, Washington, DC.

Figure 2—*A rubber-tracked tractor used as part of the U.S. Arctic Program could tow a fire tanker. It could be used on a wildfire in the wildland–urban interface both offroad and on paved roads without tearing up the asphalt. Photo: National Science Foundation, U.S. Arctic Program.*

the winds die down. For safety reasons, aircraft don't fly in the dark and hand crews are often reduced. The tanker could take up some of the slack.

Heavy-equipment manufacturers provide vehicles or chassis to their authorized subcontracted original-equipment manufacturers (OEMs), who convert these vehicles to water haulers and then return them for sale under the heavy-equipment manufacturer's brand. Many OEMs produce "kits" for adding water-distribution tanks and applicators to a wide variety of heavy equipment chassis. Capacities can be up to 60,000 gallons (230,000 L) of water, but a more reasonable target might be 5,000 gallons (19,000 L).

Additionally, OEM track manufacturers supply track assemblies for tractor manufactures, allowing wheeled equipment to have individual tracks. An OEM could design a tracked tanker trailer that would allow any heavy vehicle to pull it. With the only link to the operator being a wireless control unit in the cab, the fire tanker would be self-contained. As needed, the operator could turn over control of the trailer to someone in fire camp or elsewhere.

Tractor manufacturers for agricultural applications have recently developed rubber-tracked tractors that can travel on paved roads without tearing up the asphalt (fig. 2). Such tractors could tow a tanker on all road surfaces as well as offroad. On a fire in the WUI, the dozer blade would be important for clearing a road of fallen trees, burned-out or abandoned cars, and other debris. The blade would also enable the tractor to travel offroad through fences and backyards in a WUI neighborhood on fire, such as in Santa Rosa, CA, during the 2017 Tubbs Fire.

The fire tanker could be equipped with monitors so that it can be placed at a structure and operated remotely.

With the only link to the operator being a wireless control unit in the cab, the fire tanker would be self-contained.

The fire tanker's load of 5,000 gallons (19,000 L) of water would not last long. The tanker could be refilled by nurse tanker, by hoses connected to a water source, or by helicopter. The tanker could have helicopter doors on the tank, and a helicopter pilot using global positioning system could safely refill it in a clearing.

The fire tanker could be a platform for advanced firefighting technologies such as microdroplets, affording better use of its water. Other advanced technologies that an engine doesn't have could be incorporated. For example, the tanker could be equipped with monitors so that it can be placed at a structure and operated remotely, allowing the tractor operator to retreat to a safety zone. Through advances in driverless car technologies, the tractor and fire tanker could be operated remotely in the future.

As more people move into the WUI, more prescribed burning will be needed to keep forests healthy after thinning them. Having overwhelming suppression capabilities onsite during prescribed burns would reassure homeowners, giving wildland fire managers more social license for prescribed burning. The presence of a fire tanker would offer such reassurance.

One additional feature of a fire tanker is related to another kind of emergency response. A tanker that has tracks and a capacity of 5,000 gallons (19,000 L) or more could have an auxiliary vacuum component for vacuuming up oilspills. During the Deepwater Horizon oilspill in 2010,

A potential new tool is a dozer-drawn fire tanker, a tracked tanker trailer of substantial size that is pulled by a bulldozer or similar vehicle.

sleds with vacuum trucks tied onto them were used to vacuum up oil on the Gulf Coast. Fire tankers could do the same job better.

COST-EFFECTIVENESS

An OEM contractor who specializes in manufacturing similar products for a major construction/mining tractor manufacturer estimated the price of a prototype fire tanker at about $150,000. That is about half the replacement cost of one of the hundreds of homes that burned in Ventura, CA, during the 2017 Thomas Fire.

The 2018 Camp Fire in Butte County, CA, was even costlier, with almost 14,000 homes destroyed at a cost of about $16.5 billion. Worse, 85 people lost their lives. With the challenges facing firefighters in the WUI today, any hardware that can help should be investigated.

CHANGING FIRE ENVIRONMENT

Changing climates and weather patterns, along with a burgeoning WUI, have changed the game for wildland fire management by creating a new kind of wildland fire environment. Wildfires encroaching on the WUI are now incinerating whole subdivisions and towns. Our approach to wildland firefighting in the WUI must change to meet the challenge.

Municipal fire services focus on single-structure fires, whereas wildland firefighters focus on large areas of wildland vegetation with scattered homes but where relatively few people live. Today, wildfires are increasingly entering densely populated areas and burning through WUI rather than wildland fuels. The mining industry, with its dust-control solutions, might offer technologies for adaptation to this new fire environment.

The Fourth-Tier Dispatcher: A Personal Perspective

Randall C. Thomas

For most of the last 20 years of my Forest Service career, I worked in a third-tier dispatch center formed by combining fourth-tier dispatch centers. Recent decades have seen a push to consolidate smaller wildland fire dispatch centers into larger ones.

In the era of climate change, however, wildland fires are becoming larger and more frequent. In some locations, a fourth-tier dispatch center could make dispatching, coordinating, and tracking resources more easily manageable than a third-tier center covering much larger areas.

DISPATCH SETUP

The National Interagency Coordination Center is the first-tier dispatch center responsible for mobilizing resources at the national level. The 10 geographic area coordination centers (GACCs) comprise the second tier, responsible for mobilizing resources within a specific geographic area. The Red Book ("Interagency Standards for Fire and Aviation Operations," NFES 2724) makes no distinction between third- and fourth-tier dispatch centers, referring to both as local dispatch centers. Local centers have a designated dispatch boundary within a particular geographic area.

Having the dispatcher and fire manager working together in the same fourth-tier dispatch center would allow for more efficient initial-attack dispatching. The fourth-tier dispatcher would have the benefit of working with no more than one or two supervisors rather than multiple supervisors stationed at various locations in the dispatch zone. The current third-tier setup can make it difficult to learn the various work styles and expectations of multiple fire managers.

Fourth-tier dispatchers would have better local knowledge of personnel assigned to their zones. More awareness of fire personnel's skills and experience levels would lead to better coordination of district or unit resources and a more personal connection with local landscapes, operations, and people. With good local knowledge, a fourth-tier dispatcher could help locate the resources that can respond fastest to a fire report. In addition, a fourth-tier dispatcher would be in a better position to gather accurate and complete information for better fire documentation, with the fire manager able to help dispatchers document important events pertinent to the fire.

An initial-attack dispatcher working in the same location as a fire manager would lead to better and quicker communication between the two, with each understanding and seeing firsthand the tasks and workload of the other. Improved communication would allow a fire manager or duty officer to move resources more quickly in response to a fire report. Such flexibility would improve response planning.

IMPROVED COMMUNICATIONS

The radio system for a fourth-tier dispatch center would be simpler and less expensive than for a third-tier dispatch center, even with more dispatch offices within the area. A fourth-tier office area would need room only for a small radio, reducing noise from multiple speakers. Moreover, fourth-tier systems need only a few data lines for the dispatch radio system, whereas a third-tier system requires a more expensive and expansive radio system, with more data lines for more frequencies.

Having the dispatcher and fire manager working together in the same fourth-tier dispatch center would allow for more efficient initial-attack dispatching.

In a lightning storm, with multiple fire starts and smoke reports, a fourth-tier system could efficiently manage the initial-attack workload. The dispatcher would have fewer radio frequencies to monitor for sorting out incoming communications. Fewer distractions and interruptions in the

Randall Thomas is a retired forestry technician for the Forest Service, Idaho Panhandle National Forests, Coeur d'Alene, ID.

The author (in white shirt) at a third-tier dispatch center in the early 2000s. Photo: Randall Thomas.

communications process would keep the dispatcher more focused.

In addition to their normal day-to-day dispatch operations, fourth-tier dispatchers would be trained in collateral duties. The fire organization would benefit from a fourth-tier dispatcher trained as a communications technician. Knowing how to recognize and solve complex problems with radio and phone systems, the dispatcher could help forest technicians install and maintain their systems.

The third-tier dispatch system has the advantage of direct communications with the second-tier dispatcher at the GACC. However, a fourth-tier dispatcher has the advantage of a direct connection to local wildland fire managers, with better knowledge of the local resources, values at risk, and critical needs such as for hand crews. The dispatcher could accurately convey that information to the third-tier dispatch center for communication to the GACC for better prioritization when resources are scarce.

ENSURING COVERAGE

Part of the continuity of operations plan (COOP) for a dispatch center should be developing good working relationships with local amateur radio operators. Such relationships could make a backup system available when a dispatch radio system is incapacitated by the effects of hurricanes or other natural disasters. The COOP should be tied to local county and municipal disaster plans.

In the event that the link to the microwave or repeater site is disabled or a router goes down, a dispatch center should have a base station mobile radio as a backup, potentially with various types of power sources. Depending on terrain, radio coverage for a fourth-tier dispatch center would be about 30 miles (48 km), with about 50 watts of power output. If coverage does not extend across the zone, human repeaters could be staged at strategic locations (such as lookouts, people in vehicles with mobile radios, or personnel with hand-held radios). A fourth-tier dispatcher should have a good understanding of radio blind spots as well as lookout areas and mountaintops for posting human repeaters.

TIPS FOR A FOURTH-TIER DISPATCHER

Wildland fire managers and a fourth-tier dispatch operation should coordinate closely with local fire departments and other emergency management services. They should get to know fire chiefs as well as structural firefighters and their equipment, and they should have a good understanding of their protocols and how to make suppression operations more cohesive.

Having a strong working relationship with local fire prevention personnel is also important, including planning together to deal with human-caused fires. In spring and fall, the dispatcher could help coordinate interagency fire prevention programs, which would help the dispatcher get to know personnel from multiple fire organizations in the zone.

The dispatcher should also develop a good working relationship with the unit archeologist. Notifying the archeologist of new fire starts can help personnel follow rules for preserving heritage sites.

The dispatcher can benefit from working with timber staff to learn about timber sales in the dispatch area. Some fires start on timber sales because of the logging equipment used, so the dispatcher can benefit from knowing the locations of harvesting operations, the types and sizes of slash piles, and the equipment onsite. If a fire is close to an ongoing logging operation, the dispatcher can help get the equipment onsite redirected to initial attack if the incident commander orders the resource.

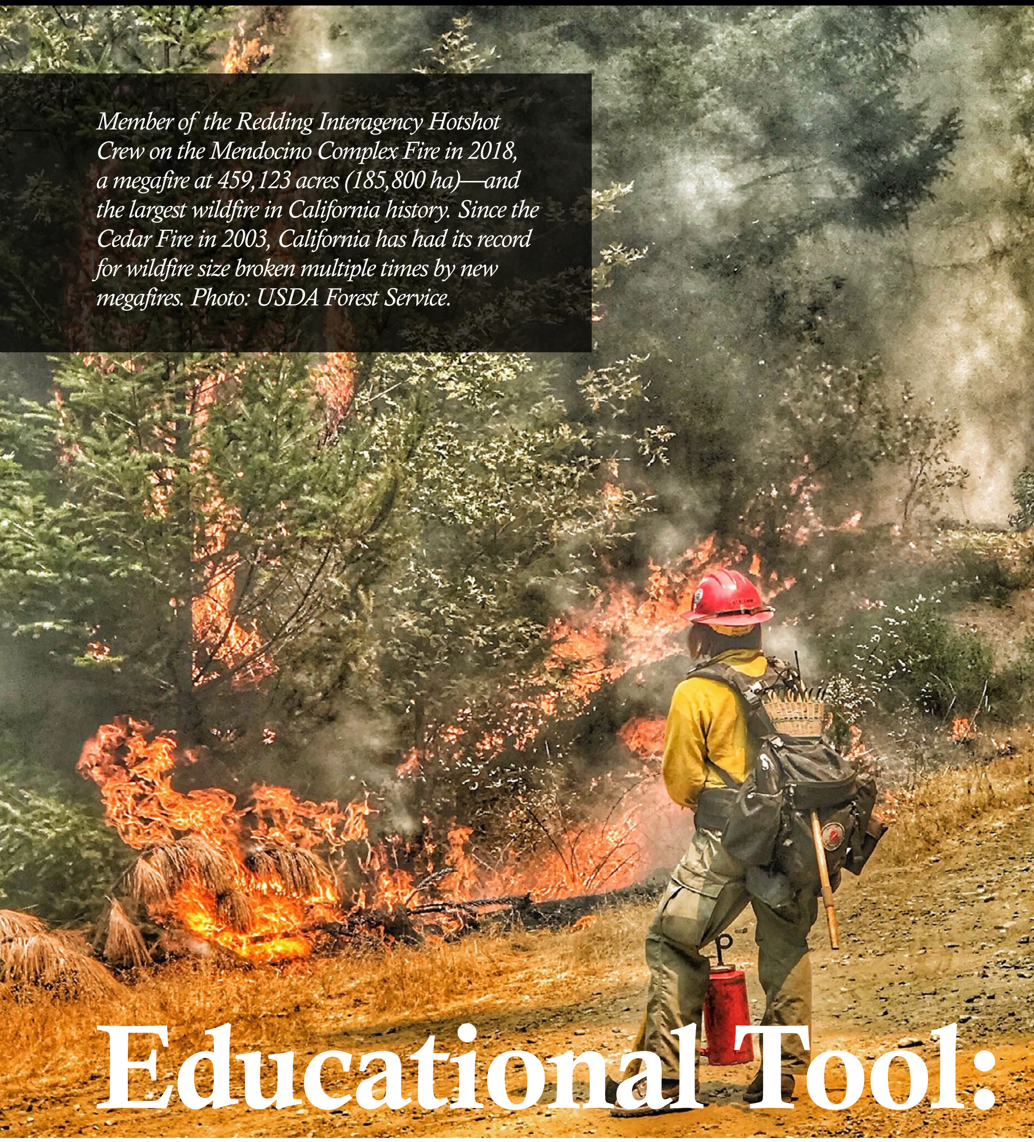
Taking part in collecting fuel samples and checking fuel moisture content gives a dispatcher an awareness of potential wildland fuel conditions for better situational awareness. Getting involved in fleet operations can help a dispatcher arrange transportation for fire personnel, assist in vehicle repairs, and verify information on vehicle logs.

I would also suggest that the dispatcher wear a uniform. A uniform makes personnel feel and act more professional, giving them a sense of pride.

BETTER WORK ENVIRONMENT

In short, a fourth-tier dispatch system has numerous advantages. Wildland fire dispatching is inherently stressful, and the added complexity of the third-tier system makes for more stress. A third-tier dispatcher works in an office, miles away from the duty stations of the fire managers and firefighters they serve.

By contrast, the fourth-tier dispatcher's additional personal interaction with fire managers and better knowledge of field resources would create a less stressful and more positive and productive environment for dispatchers. The fourth-tier dispatch system could better recruit and retain initial-attack dispatchers, helping them become more efficient and effective in their work. ■



Member of the Redding Interagency Hotshot Crew on the Mendocino Complex Fire in 2018, a megafire at 459,123 acres (185,800 ha)—and the largest wildfire in California history. Since the Cedar Fire in 2003, California has had its record for wildfire size broken multiple times by new megafires. Photo: USDA Forest Service.

Educational Tool: "Era of Megafires" Presentation

Matthew Burks

In June 2016, Forest Service scientist Paul Hessburg of the Pacific Northwest Research Station, working with North 40 Productions, launched a presentation called "Era of Megafires" (Burks 2019). The presentation explains the historical and ecological context of wildland fire activity across the Nation, notably the rise of megafires.

Megafires are wildfires that burn more than 100,000 acres and can damage or destroy human communities, wildlife habitat, and natural resources. Since the 1990s, the number and size of megafires has soared (NIFC 2019). The policy of fire exclusion practiced in the United States from the turn of the 20th century into the 1970s (Pyne 1982, 2015), coupled with the removal of large old widely spaced and fire-resistant trees, has created forests overloaded with brush and small trees that are poised to fuel megafires.

The presentation gives people a common framework and language for discussing wildfires in the United States.

Since the 1970s, Federal policy for wildland fire management has changed to allow wildland fire "as nearly as possible … to function in its natural ecological role" (FEC 2009; NWCG 2001; WFLC 2003). Accordingly, there is less emphasis on full suppression and more on improving forest conditions through thinning and the use of planned and unplanned ignitions. The presentation explains the reasons for the changes.

The presentation thereby gives not only the wildland fire community but also policymakers and the general public a common framework and language for discussing wildfires in the United States. More than 53,000 people in more than 100 communities across the Nation have seen the presentation, and the 15-minute TED-Talk version has been viewed more than 1.2 million times online (Hessburg, n.d.).

Together with the Pacific Northwest Region's Fire and Aviation Management staff, the Pacific Northwest Research Station reached out to North 40 Productions to create a training video.

Matt Burks is a public affairs specialist for the Forest Service, Pacific Northwest Research Station, Portland, OR.

The region has inserted the 20-minute version into its S–130/190 "Introduction to Wildland Fire Behavior" classes for Federal and State firefighters. The training video explains why megafires have become increasingly common and why it is important to manage some wildland fires for resource benefits.

To learn more about using the "Era of Megafires" presentation, contact Pacific Northwest Research Station Public Affairs Specialist *Matthew Burks.*

LITERATURE CITED

Burks, M. 2019. "Era of Megafires" presentation helps Region 6 train firefighters. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. https://www.fs.fed.us/inside-fs/delivering-mission/sustain/era-megafires-presentation-helps-region-6-train-firefighters. (4 October 2019).

FEC (Fire Executive Council). 2009. Guidance for implementation of the Federal Wildland Fire Policy. Washington, DC: Fire Executive Council. 20 p.

Hessburg, P. [N.d.]. Why wildfires have gotten worse—and what we can do about it. TED: Ideas Worth Spreading. https://www.ted.com/talks/paul_hessburg_why_wildfires_have_gotten_worse_and_what_we_can_do_about_it. (4 October 2019).

NIFC (National Interagency Fire Center). 2019. Wildfires larger than 100,000 acres. Boise, ID. https://www.nifc.gov/fireInfo/fireInfo_stats_lgFires.html. (4 October 2019).

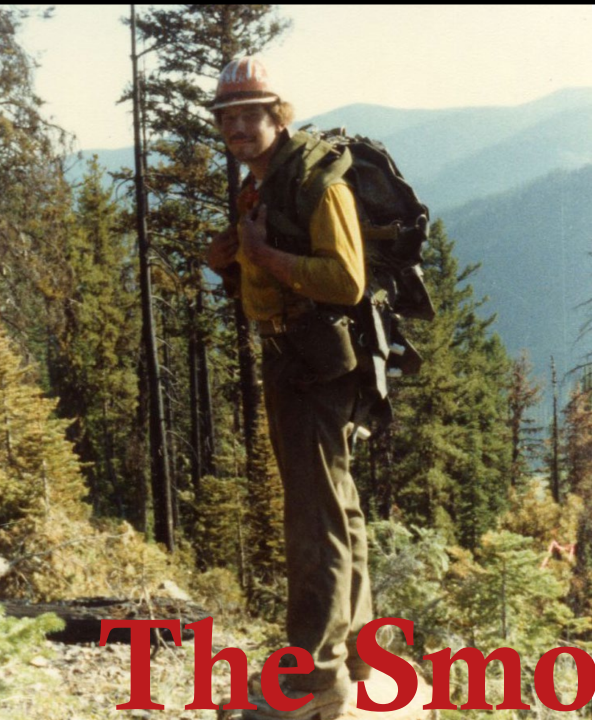
NWCG (National Wildfire Coordinating Group). 2001. Review and update of the 1995 federal wildland fire management policy. Boise, ID: National Interagency Fire Center. 76 p.

Pyne, S.J. 1982. Fire in America: a cultural history of wildland and rural fire. Seattle, WA: University of Washington Press. 654 p.

Pyne, S.J. 2015. Between two fires: a fire history of contemporary America. Tucson, AZ: The University of Arizona Press. 512 p.

WFLC (Wildland Fire Leadership Council). 2003. Interagency strategy for implementation of the Federal Wildland Fire Management Policy. Washington, DC: Wildland Fire Leadership Council. 57 p.

Safety means knowing and accepting your limitations as a firefighter, including your tolerance of smoke.



The author on a wildfire near Whitefish, MT, in 1981. Photo: Randall Thomas, USDA Forest Service.

The Smoke That You Shouldn't Have

Randall C. Thomas

In 2018, *Fire Management Today* carried an article on smoke exposure (6 Minutes for Safety 2018). The article describes actions you can take to mitigate smoke exposure and techniques for reducing the exposure of firefighters to heavy smoke. The article is very informative, with a lot of good points to consider.

I would suggest another consideration. I believe that some people, including me, are more susceptible to the effects of smoke than others—and that if you are highly sensitive to the effects of smoke, then you should seriously consider not fighting fires.

Randall Thomas is a retired forestry technician for the Forest Service, Idaho Panhandle National Forests, Coeur d'Alene, ID.

I made my decision after eight seasons as a wildland firefighter. I came to realize that smoke exposure made me irritable, affecting my ability to make good decisions on the fireline. I have to admit that I had other shortcomings as well, such as a lack of leadership skills and a low tolerance for stress and anxiety. These factors contributed to my decision to leave the fireline.

It was a difficult decision because I enjoyed the rigors of the fireline. When I was a teenager, I would help my father after school and on weekends with farming and logging, and I would work with him in my grandfather's sawmill. I was exposed to a life of hard work in the mountains of northwestern Montana, and it helped to instill in me a strong work ethic.

I came to realize that smoke exposure made me irritable, affecting my ability to make good decisions on the fireline.

I was 30 years old when I decided to stop fighting fire, a decision I had been gradually working toward for about 4 years. But one event in particular finally made me quit.

I was a dispatcher at the time, but I wanted to help with a prescribed burn. Although I was working in an office, I was riding my mountain bike and was in good shape.

Everything started out fine, but in the afternoon, the prescribed burn escaped its lines and became a wildfire. We ended up fighting that fire all night long and into the next morning.

I was pretty sick from my exposure to the smoke. That was when I told myself that enough was enough: I simply lacked the physical tolerance of smoke that a firefighter needs.

I guess I could have gone to a doctor and gotten some good medical advice, but if the smoke was making me sick anyway, it wouldn't have mattered. When I first started fighting fire, folks would sometimes wear a face mask or bandana to help filter out the smoke, but for me this was very uncomfortable and did not fully protect me from the smoke. My body had been telling me for years that I was not suited for a smoke-filled environment, even though I enjoyed digging line and mopping up. Also, I remembered my parents and brother complaining about sinus problems for years, so perhaps the physical ailment ran in my family.

I recently read about Ed Pulaski, who was famous for saving the lives of his crew members during the 1910 fires by making them stay in a mine tunnel to escape the fire outside. Afterwards, Pulaski was plagued by health issues due to smoke exposure, including lung damage and light sensitivity. In view of what happened to Pulaski, perhaps for me it was years of exposure to smoke combined with my low physical tolerance of smoke.

I am thankful that we have firefighters with higher smoke tolerance who are continuing to fight wildfires, but continuing to expose myself to smoke meant risking my health. My strong work ethic made me try to overcome the smoke problem for years until I realized that I was only human, with certain limitations. Safety means knowing and accepting your limitations as a firefighter, including your tolerance of smoke.

LITERATURE CITED

6 Minutes for Safety. 2018. Smoke exposure. Fire Management Today. 76(3): 47. https://www.fs.fed.us/sites/default/files/fire-management-today/fs_firemanagement763_508_v3.pdf (12 December 2019).

SPECIAL NEWSLETTER ON FOREST SERVICE FIRE-RELATED RESEARCH

Last year, Forest Service Research and Development released an *R&D Newsletter* that is a special issue on wildfire. It contains articles on topics related to research by Forest Service scientists, including the following:

- Economic benefits of wildfire prevention education;
- Benefits from American Indian approaches to wildland fire;
- The Interagency Wildland Fire Air Quality Response Program;
- "Era of Megafires" presentation for public education and firefighter training;
- A trail-blazing plan for using prescribed fire on a landscape scale in the Sierra Nevada;
- A three-dimensional tool to help predict fire behavior;
- The expanding wildland–urban interface;
- How the National Aeronautics and Space Administration tracks wildfires from above to aid firefighters below;
- Seeding experiments for postfire restoration;
- Fire/climate interactions;
- Post-hurricane wildfires in Puerto Rico;
- Insights and tools for firefighters from the Missoula Fire Sciences Lab;
- An overview of work by the Missoula Fire Sciences Lab;
- A summary of wildland fire and fuels research;
- An issue of *The Natural Inquirer* about wildfire prevention; and
- The origins of wildland fire research.

To read about any or all of these topics, you can access the special issue at www.fs.fed.us/research/docs/newsletter/201909%20September-Newsletter--Wildfires-Special-Issue.pdf.

Forest Service
Research and Development
Highlights from the World Leader in Forestry Research

Fire Management today

GUIDELINES for Contributors

Fire Management Today (FMT) is an international magazine for the wildland fire community. The purpose of FMT is to share information and raise issues related to wildland fire management for the benefit of the wildland fire community. FMT welcomes unsolicited manuscripts from readers on any subject related to wildland fire management.

However, FMT is not a forum for airing personal grievances or for marketing commercial products. The Forest Service's Fire and Aviation Management staff reserves the right to reject submissions that do not meet the purpose of FMT.

SUBMISSIONS

Send electronic files by email or traditional mail to:

> **USDA Forest Service**
> ***Fire Management Today***
> 201 14th Street, SW
> Washington, D.C. 20250

Email: **SM.FS.FireMgtToday@usda.gov**

Submit electronic files in PC format. Submit manuscripts in Word (.doc or .docx). Submit illustrations and photographs as separate files; do not include visual materials (such as photographs, maps, charts, or graphs) as embedded illustrations in the electronic manuscript file. You may submit digital photographs in JPEG, TIFF, or EPS format; they must be at high resolution: at least 300 dpi at a minimum size of 4 by 7 inches. Include information for photo captions and photographer's name and affiliation at the end of the manuscript. Submit charts and graphs along with the electronic source files or data needed to reconstruct them and any special instructions for layout. Include a description of each illustration at the end of the manuscript for use in the caption.

For all submissions, include the complete name(s), title(s), affiliation(s), and address(es) of the author(s), illustrator(s), and photographer(s), as well as their telephone number(s) and email address(es). If the same or a similar manuscript is being submitted for publication elsewhere, include that information also. Authors should submit a photograph of themselves or a logo for their agency, institution, or organization.

STYLE

Authors are responsible for using wildland fire terminology that conforms to the latest standards set by the National Wildfire Coordinating Group under the National Interagency Incident Management System. FMT uses the spelling, capitalization, hyphenation, and other styles recommended in the U.S. Government Printing Office Style Manual, as required by the U.S. Department of Agriculture. Authors should use the U.S. system of weight and measure, with equivalent values in the metric system. Keep titles concise and descriptive; subheadings and bulleted material are useful and help readability. As a general rule of clear writing, use the active voice (for example, write, "Fire managers know…" and not, "It is known…"). Give spellouts for all abbreviations.

TABLES

Tables should be logical and understandable without reading the text. Include tables at the end of the manuscript with appropriate titles.

PHOTOGRAPHS AND ILLUSTRATIONS

Figures, illustrations, and clear photographs are often essential to the understanding of articles. Clearly label all photographs and illustrations (figure 1, 2, 3; photograph A, B, C). At the end of the manuscript, include clear, thorough figure and photo captions labeled in the same way as the corresponding material (figure 1, 2, 3; photograph A, B, C). Captions should make photographs and illustrations understandable without reading the text. For photographs, indicate the name and affiliation of the photographer and the year the photo was taken.

RELEASE AUTHORIZATION

Non-Federal Government authors must sign a release to allow their work to be placed in the public domain and on the World Wide Web. In addition, all photographs and illustrations created by a non-Federal employee require a written release by the photographer or illustrator. The author, photograph, and illustration release forms are available upon request at ***SM.FS.FireMgtToday@usda.gov***.