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On the Cover:

Conifer mortality on the Sierra National Forest in 2016. Photo: USDA Forest Service, Pacific Southwest Region (April 5, 2016).

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

- *Innovation:* We will respect and value thinking minds, voices, and thoughts of those that challenge the status quo while focusing on the greater good.
- *Execution:* We will do what we say we will do. Achieving program objectives, improving diversity, and accomplishing targets are essential to our credibility.
- *Discipline:* What we do, we will do well. Fiscal, managerial, and operational discipline are at the core of our ability to fulfill our mission.

Firefighter and public safety is our first priority.

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ANCHOR POINT

By Shawna A. Legarza, Psy.D.
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FULFILLING OUR MISSION

The United States has the best and most highly trained wildland firefighters in the world. One statistic says it all: of the wildfires that the Forest Service decides to fight, we control 97–98 percent during initial attack. That phenomenal record of success goes back for decades, for as long as I can remember in the course of my career.

Our wildland firefighters not only fight fires for our agency and others but also complete restoration work on the national forests and grasslands. Together with communities and our partners, we manage smoke, conduct prescribed fires, reduce hazardous fuels, improve trails, and more. In multiple regards, we lead the way in wildland fire management.

> We will work to increase fire on the landscape where appropriate.

As we strive to reduce exposure to risk and maximize efficiencies, we will continue to respond to various challenges within the wildland fire environment. Given such challenges as the growing wildland–urban interface, the rising number of large and devastating wildfires, and the steady creep of increased fuel loadings, we must constantly respond to the need for greater efficiency and for change in the way we do business.

We will continue to analyze the wildland fire environment accordingly, using the best available data and science. We will also work to increase fire on the landscape where appropriate. Our overarching goal is to help our agency fulfill our mission of sustaining the health, diversity, and productivity of our Nation’s forests and grasslands to meet the needs of present and future generations. ■

CONIFER MORTALITY IN CALIFORNIA: FIRE RISK AND DEAD TREE MANAGEMENT

Russell D. Briggs and Susan C. Cook-Patton

The adverse effects of climate change on forest ecosystems are many and varied (IPCC 2014). In the Western United States, drought frequency and severity (both magnitude and period of water deficit) are rising. Hot and dry conditions increase the susceptibility of trees to fire and bark beetle attack, resulting in excessive mortality. Hicke and others (2016) estimated cumulative bark beetle mortality in the Western United States from 1979 to 2012 at 16 million acres (6.4 million ha), which amounted to 7.1 percent of the entire forested area (fig. 1).

More Than 100 Million Dead Trees

Increasing periods of drought also extend the duration and economic impact of fire season (Brown 2016a; Romme and others 2006). The number of wildfires exceeding $1 billion in damages (in 2011 dollars, adjusted for inflation) rose from 0 in 1980–1990 to 4 in 1991–2000 and to 9 in 2001–2015 (NOAA NCDC 2016). Similarly, the Forest Service's yearly wildfire suppression costs (in 2016 dollars) rose eightfold, from $200 million in 1984 to more than $1.7 billion in 2015 (Brown 2016a). The cost of fire protection is rising, in part because more and more people are building in the wildland–urban interface, making it more difficult to let fires burn and requiring more resources to protect structures and lives (Liu and others 2015; Theobald and Romme 2007).

Trees in the Western United States are dying in unprecedented numbers due to drought and beetle infestation.

Extended periods of drought affect more than fire seasons and the associated costs. They are also disrupting systems that have evolved over thousands of years. Historically, both bark beetles and wildland fire have been important elements in conifer systems that undergo periodic burning. For example, lodgepole pine (*Pinus contorta*), a common species in the West, will not regenerate in the absence of fire. Periodic attacks by mountain pine beetle (*Dendroctonus ponderosa*) generate fuel loads that promote fire (Lotan and Critchfield 1990). Low-severity fires also increase the production of resin, allowing trees to resist beetle attack (Hood and others 2015). However, trees in the Western United States are dying in unprecedented numbers due

Figure 1—*Pine mortality (red/gray trees) due to a mountain pine beetle epidemic in Colorado's Rocky Mountain National Park, March 2009. Photo: Brian Kurtz, USDA.*

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to drought and because drought-stressed trees are more susceptible to bark beetle infestation (Carroll and others 2006; Cullingham and others 2011; Dahr and others 2016; Manion 1981).

Recent estimates by the Forest Service suggest that California has more than 100 million dead trees.

Recent estimates by the Forest Service suggest that California has more than 100 million dead trees (fig. 2). Many land managers are concerned that the standing dead trees increase the likelihood and severity of wildfire, further increase fire protection costs, and threaten human lives and structures due to fire and/or falling trees. In response, Governor Jerry Brown of California released a Proclamation of a State of Emergency to expedite tree removal in high-hazard areas and created a Tree Mortality Task Force to formulate management options.

This paper addresses the question: What steps (if any) should be taken to manage more than 100 million dead trees in California?

Most of the research examining the relationship between beetle infestation and the potential for increased wildfire occurrence and severity has been conducted in Colorado. Literature specific to California is rare. Here, we examine the scientific literature linking beetle- and/or drought-killed trees to wildfire likelihood and severity, with wildfire severity defined as the amount of organic matter (that is, trees and forest floor) consumed by fire (Keeley 2009). We then discuss the implications for managing the 100 million-plus dead trees in California.

Relevant Literature

A good understanding of how bark beetles affect wildfire has only recently emerged. The most relevant refereed papers published from 2011 to 2016 are listed in table 1. The researchers applied a variety of analytical approaches. They collected data from on-the-ground field plots as well as from remote-sensing images of beetle-infested stands. Analyses ranged from comparison (and modeling) of prefire and postfire stand composition, morphology, and structure to assessments of fire intensity and rates of spread estimated from aerial images.

Figure 2—*Conifer mortality due to drought and bark beetle attack on the Sierra National Forest in California's Sierra Nevada, April 2016. An estimated 100 million trees have been lost to drought and bark beetle attack in California. Photo: USDA Forest Service.*

The level of analytical sophistication and the geographic extent of the studies, impressive from the beginning, increased with each successive paper. The earliest paper by Klutsch and others (2011) modeled potential surface and crown fire behavior for stand and tree morphology data collected from 170 infested and 51 uninfested plots distributed in lodgepole pine forest on the Arapaho National Forest, CO. A later paper by Meigs and others (2016) used georectified imagery to compile a sample of 81 fires exceeding 988 acres (400 hectares) in area in mixed-conifer forests of the Pacific Northwest east of the crest of the Cascades; these data span 14 years and include areas affected by bark beetles (*Dendroctonus* spp.) and western spruce budworm (*Choristoneura freemani*). Meigs and others (2016) measured fire severity using state-of-the-art techniques (that is, Landsat-derived index postfire relative differenced normalized burn ratio, or RdNBR) to identify the variables that have the greatest influence on fire severity. The most recent paper (Schoennagel and others 2016) synthesized the literature and considered the policy implications.

Table 1—*Summary of recent studies assessing the relationship between beetle kill and wildfire incidence and/or severity.*

Approach	Study area(s)	Forest types	Insect species	Conclusions	Authors
FFE–FVS model applied to field data collected from 170 infested and 51 un-infested plots	Arapaho National Forest (CO)	LP	MPB	Uninfested plots predicted to have greater potential for crown fire than infested plots.	Klutsch and others (2011)
Literature synthesis	Yellowstone Colorado Intermountain Central Rockies	LP LP/SP–F SP–F	MPB SPB	Conceptual model of fuel and fire behavior based on time since outbreak; fires do not necessarily occur after beetle outbreaks; ignition and weather play a greater role than fuels.	Hicke and others (2012)
Literature synthesis	Yellowstone Colorado Intermountain Central Rockies	LP LP/SP–F SP–F	MPB SPB	Beetle outbreaks do not increase fire risk in lodgepole pine and ES forests under most conditions.	Black and others (2013)
ROS via photos of wildfire and experimental burns in MPB-impacted stands modeled as function of initial spread index	Interior British Columbia	BF BS LP JP WS	MPB SPB	ROS in beetle-impacted stands averaged 2.7 times higher than expected for nonimpacted stands. Fire intensity is likely higher due to increased ROS.	Perrakis and others (2014)
Spatial overlay of remotely sensed data	Western United States	LP PP	MPB	Annual area burned has not increased in direct response to bark beetle activity.	Hart and others (2015)
Prefire (reconstructed) and postfire data from field plots stratified by fire severity classes (correlation and regression trees)	Northern Rockies	ES DF LP WBP SAF	MPB	Fire severity was unrelated to outbreak severity with two exceptions: increased % basal area with deep charring on boles and into crowns when fires burned in red-phase stands under extreme conditions.	Hood and others (2015)
Prefire (reconstructed) and postfire data from 143 field plots stratified by degree of beetle infestation and fire severity range	Southwest Colorado	ES	SBB	Prefire beetle severity had no effect on fire severity regardless of burning conditions.	Andrus and others (2016)
Regression of burning likelihood as function of SBB occurrence for remotely sensed data	Kenai Peninsula (Alaska)	BS WS	SBB	Likelihood of burning increased with SBB outbreak for sites with intermixed BS and WS.	Hansen and others (2016)
Sequential auto regression of prefire (reconstructed) and postfire data via georectified imagery	Pacific Northwest	DF F SP	MPB WSBW	Burn severity is lower in forests with greater cumulative insect damage.	Meigs and others (2016)
Policy discussion informed by literature synthesis	Western United States	Not specified	Bark beetles	Weather and climate drive increasing fire frequency; fuel reduction will not impact area burned; insect infestations do not necessarily make fires worse; land use planning and prescribed burning can reduce fire risk.	Schoennagel and others (2016)

Note: BS = black spruce (*Picea mariana*); DF = Douglas-fir (*Pseudotsuga menziesii*); ES = Engelmann spruce (*Picea engelmannii*); F = fir (*Abies* spp.); FFE = fire and fuels extension; FVS = forest vegetation simulator; JP = jack pine (*Pinus banksiana*); LP = lodgepole pine (*Pinus contorta*); MPB = mountain pine beetle (*Dendroctonus ponderosa*); PP = ponderosa pine (*Pinus ponderosa*); ROS = rate of spread; SAF = subalpine fir (*Abies lasiocarpa*); SBB = spruce bark beetle (*Dendroctonus rufipennis*); SP = spruce (*Picea* spp.); WS = white spruce (*Picea glauca*); WBP = whitebark pine (*Pinus albicaulis*); WSBW = western spruce budworm (*Choristoneura freemani*).

Beetle Infestation and Fire Severity Through Time

The relationship between beetle infestation and fire severity changes with time, passing through three sequential phases (Andrus and others 2016; Harvey and others 2014). The first phase is the "red phase," characterized by retention of dry, dead (typically red) needles. During this relatively short period, there is an elevated likelihood of crown fire; less heat is required to ignite the crown (Jolly and others 2012a). Several authors consider this phase to last 1–2 years, but Hicke and others (2012) suggest that it can extend up to 4 years (fig. 3).

The second, the "gray phase," occurs after the needles fall to the forest floor. This phase lasts for 5 to 10 years, during which the absence of highly combustible fine fuels (that is, needles), combined with reduced canopy density, substantially diminishes the risk of fire reaching the crowns.

Eventually, the stems fall and the "old phase" begins; the rate of decay of material close to the forest floor is constrained by soil moisture (Swift and others 1979). Moisture deficits contribute to a buildup of fuels, whereas excess moisture promotes accelerated decomposition. The potential for severe crown fire increases during the old phase because regeneration growing into the canopy provides continuity of fuels, from the decomposing stems jackstrewn about the forest floor into the canopy.

Summary of the Research

Insect outbreaks both increase and decrease fuel loads over time.

Observations of stands that burn after beetle outbreaks generally support the model predictions shown in figure 3. As Black and others (2013) noted, "These empirical findings are consistent with modeling studies that predict reductions in the probability of active crown fire for one to two decades after high-severity bark beetle outbreaks in pure stands of Engelmann spruce (*Picea engelmannii*)." However, inherent spatial and temporal variation affects this general trend (Hicke and others 2012). Infested stands can contain patches of dead and living trees, and the three phases are actually part of a continuum (Jolly and others 2012b). Some fine twigs still persist early in the gray phase, for example, and needles may take anywhere from 1 to 4 years to fall. At larger spatial scales and longer time scales, however, the theoretical model (fig. 3) is consistent with on-the-ground observations.

The relationship between beetle infestation and fire severity changes with time.

Insect outbreaks do not increase the likelihood of fire occurrence.

Many papers reported that fires are not more likely after insect outbreaks (Black and others 2013; Hart and others 2015; Klutsch and others 2011; Schoennagel and others 2016). Only Hansen and others (2016), the study conducted in Alaska, contradicted this finding: more flammable black spruce (*Picea mariana*) was intermixed with beetle-affected white spruce (*Picea glauca*), increasing the likelihood of fire occurrence. However, Alaska has a 400- to 600-year fire cycle that differs drastically from that in the western continental United States.

Fire severity is driven mostly by weather.

The literature generally shows that fire severity is driven by hot and dry weather conditions rather than beetle outbreak (Bradstock and others 2009; Reinhardt and others 2008). Spruce bark beetle (*Dendroctonus rufipennis*) outbreaks, for example, had minimal or no impact on fire severity in spruce–fir forests, where infrequent severe drought drove fire behavior.

Beetle-killed trees increase fire severity initially but not for long.

Meigs and others (2016) reported lower burn severity in forests with greater cumulative insect damage in the Pacific Northwest. Several other studies similarly reported reduced fire severity after beetle kill and attributed it to loss of canopy density. The studies that found more severe fires after insect outbreak examined the early years after outbreak (red and early gray phases). Hood and others (2015) documented deep charring (the only fire severity variable to show an impact) when fires occurred in the red phase under extreme fire weather conditions. Perrakis and others (2014) found that fire rate of spread in pine stands 1–5 years after peak beetle attack averaged 2.7 times greater than expected for unimpacted stands. Higher potential for crown fire in the red phase was also noted by Jolly and others (2012b). Black and others (2013) also pointed out that during the Yellowstone Fires of 1988, the incidences of crown fire were higher in stands where beetle-induced mortality exceeded 50 percent. For this study, however, it is difficult to disentangle the effect of stand age from the effect of beetle activity. Older stands had greater beetle mortality, and older stands also had higher fuel loads that placed them at higher risk of

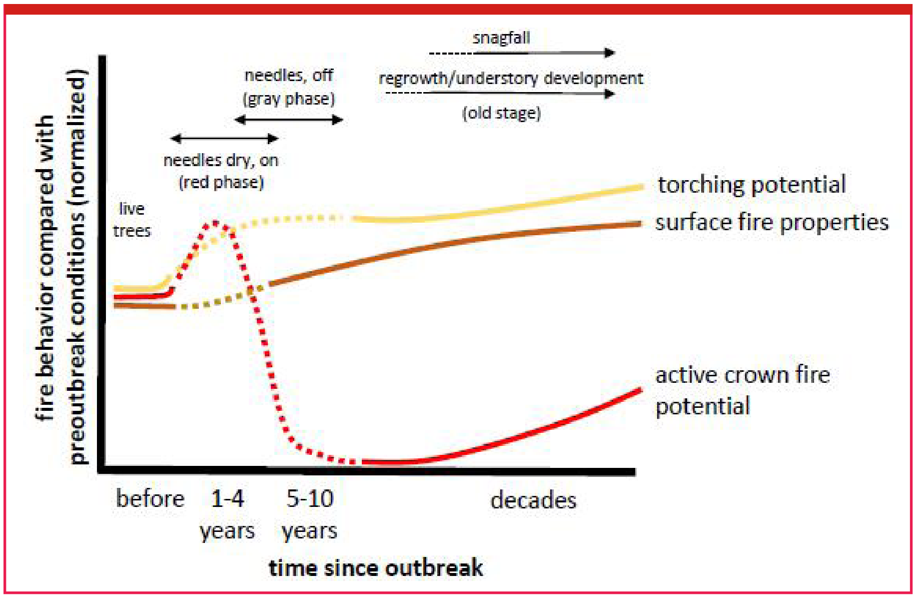

Figure 3—*Conceptual framework of fire behavior relative to preoutbreak conditions for red, gray, and old (snagfall and regrowth) phases (redrawn from Hicke and others (2012)).*

severe fires, even in the absence of beetle activity. Collectively, these studies lend support to the model shown by Hicke and others (2012; fig. 3). Empirical evidence for fire severity in the old phase remains to be gathered.

Length of time for substantial increase in fire severity is uncertain.

Nelson and others (2016) recently provided empirical evidence for the timing of increased fire severity associated with the end of the gray phase (fig. 3). Lodgepole pine stands, sampled 11 years after severe fires in Yellowstone, were resampled 24 years after the fires. Seventy-six percent of the plots sampled exhibited 1,000-hour fuel loads exceeding levels associated with high-severity surface fire potential. Similarly, 63 percent of the plots exceeded fuel loads associated with crown fire potential. Currently, fuels in many of the dense young lodgepole pine stands are sufficient to sustain fire.

Extrapolation to California

Although much of the research cited here derives from the Intermountain West and discusses beetle-killed stands specifically, it is reasonable to extrapolate these results to the 100 million-plus dead trees in California. Climate change is shortening the fire return interval in Colorado. With the exception of the one Alaska study (Hansen and others 2016), the cited papers describe ecosystems similar to those in California (table 2). Specifically, they are ecosystems with short fire return intervals (0–35 years and 35–100 years), where fire plays a key role in regulating species composition and stand structure. There is also no reason to expect the cause of mortality to change patterns. Trees killed entirely by drought will likely burn similarly to trees killed by a combination of drought and bark beetle outbreaks.

With respect to the dead trees in California, the most appropriate management action is not readily apparent; borrowing from the medical profession, it could be described as “watchful waiting.” Removal of trees during the red phase would reduce potential fire severity. However, the probability of ignition is low; operationally, the logistics of scheduling and completing a removal harvest within the narrow time window would be challenging.

Research suggests that dead trees per se do not increase the likelihood of fire occurrence.

The gray phase, a period characterized by low potential fire severity preceding the old phase, opens a window for developing an action plan based on knowledge of prevailing weather patterns. Informed consideration is important; removal of dead trees would be costly, requiring substantial subsidies (Crandall and others 2017). Both sufficient moisture and high temperature are essential for decomposition (A’Bear and others 2014). Although decomposition is a continuous process that begins while trees are still standing, decomposition rates are minimal until wood contacts the ground and attains 25-percent moisture content (Swift and others 1979).

Extended periods of drought concurrent with the old phase would restrict decomposition of woody material and promote fuel buildup; preemptive removal prior to stand breakup might be prudent. Alternatively, extended periods of moisture would favor a decision to leave dead trees in place; sufficient moisture would facilitate decomposition of fallen woody debris, reducing fuel accumulation. However, rotten woody fuels ignite more readily than sound fuels and can smolder for a longer time (Peterson and others 2015). The decision could be more fully informed by research specifically addressing the level of soil moisture required to promote decomposition of conifer stems.

> For the dead trees in California, the most appropriate management action is "watchful waiting."

Management Prescription: "Watchful Waiting"

Climate change is bringing increasingly frequent and severe droughts to the Western United States, weakening trees and predisposing them to attack by bark beetles. The combination of increased stress and favorable conditions for beetle reproduction and development leads to trees dying in large numbers. California currently has more than 100 million dead trees, and as long as climate change is not mitigated, the rising trend in tree mortality is expected to continue unabated. However, research in the Forest Service's Intermountain and Pacific Northwest Regions suggests that dead trees per se do not increase the likelihood of fire occurrence; weather and climate are primary factors influencing fire occurrence and behavior.

Beetle infestation does alter the distribution of fuels and can affect fire severity, but the impact is nuanced. Observations reported in the literature generally support the current model of changes in fire severity over time after infestation (fig. 3; Hicke and others 2012). The red phase, characterized by dead needles remaining on the tree, is a 1- to 4-year period of greater potential for crown fire. During the subsequent 5- to 10-year gray phase, the potential for crown fire is greatly reduced by absence of needles and lower crown density. The potential for increased fire severity rises during the old phase as regeneration creates a ladder from decaying stems on the forest floor into the canopy. The most recent postfire analysis of the 1988 Yellowstone Fire documents fuel loads sufficient to support ground and crown fire in much of the forest across the area burned (Nelson and others 2016).

Table 2—*Conifer species of California forests and their primary bark beetle pests.*

Tree species	Insect pests
Ponderosa pine	Mountain pine beetle, western pine beetle
Jeffrey pine (*Pinus jeffreyi*)	Jeffrey pine beetle (*Dendroctonus jeffreyi*)
Sugar pine (*Pinus lambertiana*)	Mountain pine beetle
Pinyon pine (*Pinus edulis*)	Pinyon ips
Coulter pine (*Pinus coulteri*)	Western pine beetle
Lodgepole pine	Mountain pine beetle
Douglas-fir	Douglas-fir beetle, mountain pine beetle
White fir (*Abies concolor*)	Fir engraver beetle (*Scolytus ventralis*)
Red fir (*Abies magnifica*)	Fir engraver beetle
Incense cedar (*Libocedrus decurrens*)	Western cedar bark beetle (*Phloeosinus punctatus*)

Note: Although mountain pine beetles develop mostly in pines, as populations increase they may attack most large trees in an outbreak area (Leatherman and others 2011). Amman and others (1990) note that Coulter, foxtail, whitebark, pinyon, and bristlecone pines are also attacked by mountain pine beetle.

These observations, combined with the postdisturbance fire severity model proposed by Hicke and others (2012), suggest a 10- to 20-year window of reduced potential fire severity available to execute management plans.

The best course of action to deal with the dead trees in California is not clear at this point in time. Preemptive harvesting, typically referred to as fuel treatments, might be the best choice among the active management alternatives. However, it might not be effective. Brown (2016b) noted that treated areas are sometimes bypassed when fire burns into untreated areas or when blowing embers skip past treated areas.

Fuel treatments incur significant costs that must be weighed against the benefits. Tree removal adds additional stress to an ecosystem; Donato and others (2006) showed that soil disturbance by postfire logging reduced regeneration by 71 percent. Removing standing dead trees improves safety; falling snags have caused firefighter fatalities (Mangan 2007). Additional activity for contractors increases economic activity. The benefits of fuel treatments are greater in the wildland–urban interface due to the high value of structures relative to unimproved forest land. Considerations associated with costs and benefits of tree removal may be more important than the fire effects.

Fuel buildup is influenced by moisture. Weather patterns in California in the winter of 2017 became increasingly moisture laden following years of severe drought and well below-normal rainfall. Dry conditions constrain both regrowth (slowing live fuel buildup) and decomposition (contributing to fuel loads). Periods of excess moisture favor regrowth (enhancing the fuel ladder) and decomposition (reducing fuel buildup). As fuel hazards go down, the benefits of fuel removal are reduced. Understanding the moisture impact on fuel buildup will lead to a more informed decision of whether to remove or leave dead trees. ■

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WILDFIRE AND BARK BEETLE DISTURBANCE IN WESTERN U.S. FORESTS: IS INTERVENTION NEEDED FOR VEGETATION RECOVERY?

Russell D. Briggs

The incidence and degree of stand disturbance (that is, from fire, insects, and disease) are driving excess tree mortality in the Western United States. Hot and dry conditions associated with drought have stressed forests over a wide geographic area, contributing directly to tree death (van Mantgem and others 2009).

Following the 1988 Yellowstone Fire, variation in fire severity and site conditions contributed to the recovery of the mixed-conifer systems.

Drought conditions interacting with expanding human activity have increased wildfire incidence and severity (Balch and others 2016; Harvey 2016). The average area burned each year on the National Forest System rose steadily from 240,000 acres (97,000 ha) in the 1970s to more than 1.6 million acres (650,000 ha) in the 2000s (Brown 2016). The terms “mega-fire” (Adams 2013) and “megadisturbance” (Millar and Stephenson 2015) convey a sense of the magnitude and geographic extent of the impacts. Megadisturbances curtail an array of ecosystem services (for example, wood production, nutrient cycling, carbon sequestration, and aesthetics). When severe erosion follows catastrophic fire, vegetative trajectory may be permanently altered. McDowell and Allen (2015) hypothesized that drought-induced megadisturbances may drive species composition towards shrubby, low-statured plants, substantially altering forest structure and function.

Conifer mortality due to drought and bark beetle attack at Bass Lake on California’s Sierra National Forest. Photo: USDA Forest Service, Pacific Southwest Region.

Drought is an external stress that increases the susceptibility of trees to be attacked by bark beetles. Warmer temperatures also expand beetle elevational and latitudinal ranges (Anderegg and others 2015; Bentz and others 2010), and the impacts are reflected in increasing tree death. Cumulative mortality attributed to bark beetle infestation in the Western United States from 1979 to 2012 was estimated at 16 million acres (6.5 million ha), or about 7.1 percent of the total forested area (Hicke and others 2016).The infestations have also affected Canada. Alfaro and others (2015) noted beetle-induced mortality on 49 million acres (20 million ha) of pine forest in the United States and Canada.

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Vegetation plays a key role in delivering many ecosystem services (for example, carbon sequestration, biodiversity, nutrient cycling, and watershed functions) (Abella and Fornwalt 2015). The increasing numbers and wide geographic extent of megadisturbances, coupled with the passage of time, provide an opportunity to assess vegetation recovery. This paper examines the literature assessing vegetation response of lodgepole pine (*Pinus contorta*) and mixed-conifer systems to wildfire and mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB) infestation in the Western United States and Canada. I selected the most recent papers available in the literature that examined relatively large areas (thousands of acres) with the longest available time since disturbance (table 1).

Table 1—*Select studies regarding postdisturbance vegetation development in the Western United States and Canada for two disturbance types.*

Year initiated	Location and area affected	Dominant tree species	Reference(s)
		Wildfire	
1988	Yellowstone 617,800 acres (247,120 ha)	*Pinus contorta* *Pinus ponderosa* *Abies lasiocarpa* *Picea engelmannii*	Turner and others (2003, 2016) Romme and others (2016)
2000, 2007	21 fires in central Idaho/ western Montana >400 acres (>160 ha) each	*Pinus contorta* *Pinus ponderosa* *Pseudotsuga menziesii* *Abies grandis*	Kemp and others (2016)
1999–2007	14 fires/10 national forests in central/northern California >10,000 acres (>4,000 ha) each	*Pseudotsuga menziesii* *Pinus ponderosa* *Pinus jeffreyi* *Abies concolor* *Abies magnifica*	Welch and others (2016)
2002	Cone Fire, Blacks Mt. Experimental Forest, northeastern California 2,000 acres (800 ha)	*Pinus ponderosa* *Pinus jeffreyi* *Abies concolor Calocedrus decurrens*	Knapp and Ritchie (2016) Ritchie and Knapp (2014)
		Beetle infestations	
2009	Grande Prairie, Alberta, Canada 154,441 acres (61,776 ha)	*Pinus contorta* *Picea glauca* *Abies balsamea* *Picea mariana* *Betula papyrifera* *Populus tremuloides*	Pec and others (2015)
Late 1970s	White Mountain National Forest, Colorado 190,270 acres (76,108 ha)	*Pinus contorta* *Picea engelmannii* *Pseudotsuga menziesii* *Abies lasiocarpa* *Populus tremuloides*	Pelz and Smith (2012)
1976	Flathead Valley, interior British Columbia	*Pinus contorta* *Larix occidentalis* *Pseudotsuga menziesii* *Picea glauca x engelmannii* *Abies lasiocarpa*	Amoroso and others (2013)
1975	Chilcotin Plateau, interior British Columbia	*Pinus contorta* *Picea glauca* *Populus tremuloides* *Betula papyrifera*	Alfaro and others (2015)

Climate change has expanded the mountain pine beetle's latitudinal and elevational ranges, extending its geographic impact.

Vegetation Recovery After Wildfire

Regrowth of vegetation, which restores infiltration capacity, is the most cost-effective means to reduce overland flow of water and erosion (Elliott and Vose 2006). As vegetation develops, mean erosion rates immediately after a wildfire substantially decline. In general, aerial seeding has not improved vegetation establishment compared to adjacent unseeded areas (Robichaud and others 2006).

Turner and others (2016), extending the time period and the level of detail in their earlier paper on lessons learned from the Yellowstone Fire of 1988 (Turner and others 2003), resampled 72 of 96 plots originally established to capture the range of variability in fire severity and abiotic factors across the burned landscape. Mean 24-year postfire stem density of 8,797 stems per acre (range 0–137,593) (3,560 stems/ha (range 0–55,682 stems/ha)) was lower than the 11-year mean (13,377 stems per acre (5,413 stems/ha)). More interesting was the variation in stand structural development: 58 percent of the plots were still gaining stems, which was unexpected for such high densities. The breakpoint at which stem density began to decline, 29,137 stems per acre (11,791 stems/ha), was identified using segmented regression (fig. 1). As density for individual patches approaches that breakpoint, the authors hypothesized that self-thinning could bring stand structure towards convergence across the landscape as recruitment of new stems slows and self-thinning of dense patches proceeds. Stand function, represented by biomass accumulation and annual net primary productivity (ANPP), increased with increasing stand density (fig. 2). Unlike stand structure, the coefficient of variation for biomass and ANPP declined, leading the authors to hypothesize that functional convergence would occur long before structural convergence.

Romme and others (2016), working with the Yellowstone data and focusing on the understory, found no indication of convergence of species richness and composition across the burned landscape. Richness increased rapidly during the first 5 years, then slowed or leveled off; only 6 percent of 227 species were nonnative. Wildfire did not appreciably alter species composition; postfire species richness patterns resembled prefire patterns, a relationship referred to as "ecological memory." Variation in fire severity and site conditions

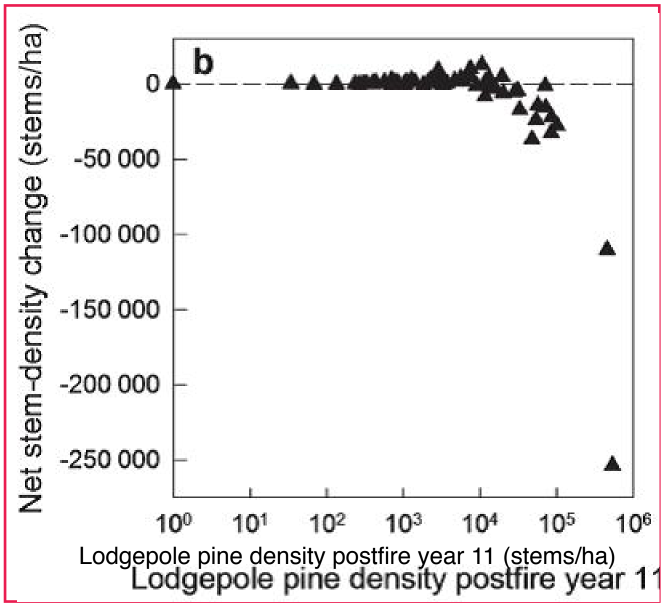


Figure 1—*Net change in lodgepole pine stem density between postfire years 11 and 24, plotted by stem density in postfire year 11 for the 1988 Yellowstone Fire. Source: Turner and others (2016). © 2016 by the Ecological Society of America, reprinted with permission.*

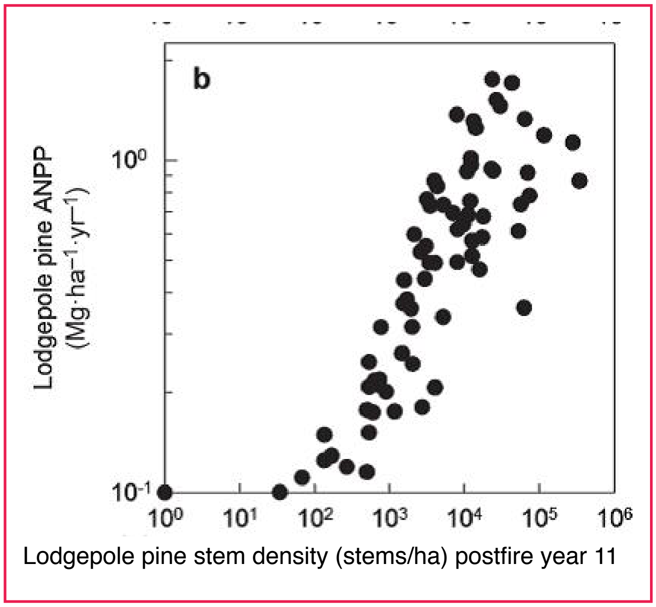


Figure 2—*Lodgepole pine aboveground net primary production (ANPP) increased with stem density at postfire year 24 in stands regenerating from the 1988 Yellowstone Fire. Source: Turner and others (2016). © 2016 by the Ecological Society of America, reprinted with permission.*

Figure 3—*Burn pattern from the 1988 Yellowstone Fire in Upper Geyser Basin near Old Faithful. Fire created a complex mosaic of burned and unburned patches. In areas of crown fire (black) and severe surface fire (brown), the fires were stand replacing. Photo: Jim Peaco, National Park Service (July 24, 1989).*

contributed to the recovery of the mixed-conifer systems (fig. 3). The authors pointed out the uniqueness (in terms of geographic and temporal extent) of this 25-year postfire dataset.

Recovery of western conifer systems from wildfire is not unique to Yellowstone. Large fires in dry mixed-conifer forests in Idaho and Montana in 2000 and 2007 provided additional opportunities to study postfire vegetation development. Kemp and others (2016) distributed 182 plots across 21 fires (>400 acres (>160 ha)) 5–13 years following a fire across a 4-degree south-to-north latitudinal gradient. With the exception of lodgepole pine (which has serotinous cones that promote regeneration after a fire), the primary control on seedling density was adjacency to live trees; dispersal distance is a primary regeneration filter. Beyond a distance of about 310 feet (94 m), the probability of seedling establishment was very low (fig. 4). The distribution of high-severity burn patches (all trees killed) among light- and moderate-severity patches facilitated seedling establishment across the landscape; only a small proportion of the area of high-severity patches was distant from live trees that served as seed sources (Kemp and others 2016).

There has been some postfire analysis of vegetation recovery in California. Welch and others (2016) assessed conifer regeneration across 14 fires (>1,000 acres (>400 ha)) on 10 national forests within the North America Mediterranean Climate Zone (NAMCZ), where frequent low- and moderate-severity fires are common. Their work spanned five forest vegetation types: mixed evergreen, moist mixed conifer, dry mixed conifer, yellow pine, and fir. In contrast to the prolific lodgepole pine regeneration in the Greater Yellowstone Area, conifer regeneration 5 to 7 years following a fire was spotty and highly variable; seedling densities were below Forest Service Pacific Southwest Region stocking guidelines for 10 of 14 fires. Low seedling densities were associated with high fire severity and absence of live seed trees combined with competition from fire-following shrubs. In addition, plots with failed regeneration also had lower mean annual precipitation. The authors noted that the stocking guidelines might be excessive, given a shift in management emphasis towards a broader suite of ecosystem services than timber production alone (for example, nutrient cycling, carbon sequestration, and aesthetics). In addition, they pointed out that species composition of the understory was dominated by shade-tolerant firs (*Abies* spp.), Douglas-fir (*Pseudotsuga menziesii*), and incense cedar (*Calocedrus decurrens*), all of which are intolerant of fire.

Ritchie and Knapp (2014), studying the 2,000-acre (800-ha) Cone Fire in northeastern California, also reported poor regeneration; maximum conifer seedling density was below the 70-stems-per-acre guideline for adequate stocking. Ponderosa pine (*Pinus ponderosa*) systems have a much shorter fire return interval; large stand-replacing fires are more disruptive for conifer regeneration compared to lodgepole pine forests (which have both serotinous and nonserotinous cones). Although the focus of their work was on salvage logging, removal of dead stems had no impact on seedling density; results can be applied to revegetation in general following a fire. Fire generated a suitable (bare mineral soil) seedbed, but too few surviving trees remained as a seed source, consistent with the results reported by Welch and others (2016).

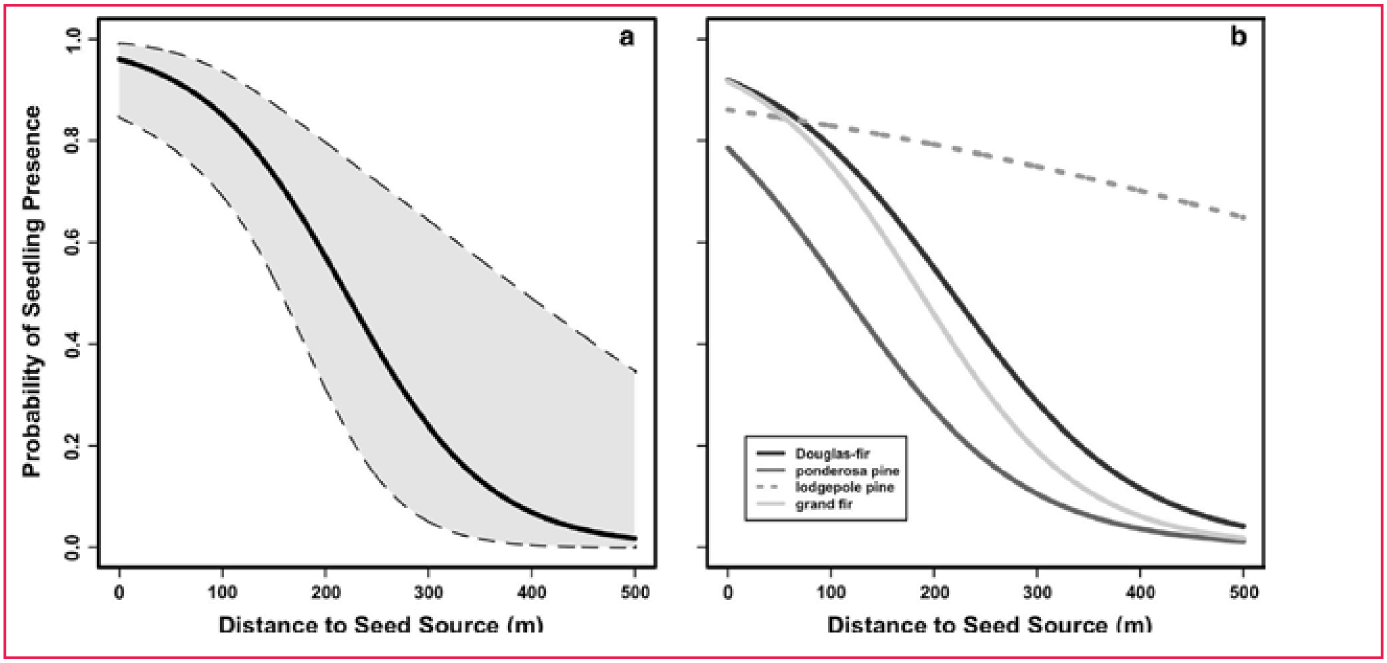


Figure 4—*Logistic regression model results from the Northern Rocky Mountains. Relationship between probability of seedling presence and distance to a live seed source for (a) all species (shaded region between dashed lines represents the 95-percent confidence interval for the all-species model); and (b) the four most abundant species, when all other variables in the model are held at their median values (dashed line = statistically insignificant for that species). In (b), the dashed line indicates that the relationship between distance and seedling presence was not significant for that species (p > 0.05). Confidence intervals are not shown in panel (b) because they overlap for all species. Source: Kemp and others (2016). © 2016 by Elsevier, reprinted with permission.*

Knapp and Ritchie (2016), focusing on the understory noncommercial vegetation, reported annual, perennial, forb, graminoid, and shrub vegetation increasing from 2006 to 2010, with annuals and forbs lower in 2012. The percentage of bare ground declined from 77 percent in 2006 to 28 percent in 2012, coincident with litter and duff increasing from 8 to 64 percent over the duration of the study. Postfire understory plant recovery in ponderosa pine forests was also reported by Fornwalt (2010) after the 2002 Hayman Fire in Colorado. Although not all ecosystem services (wood and fiber production, for example) recover immediately, rapid postfire revegetation rejuvenates the capacity of the soil to support the biota. The developing root systems and foliar canopy promote water infiltration, movement, and storage, minimizing soil erosion and supporting nutrient cycling.

All of the fire-related studies cited in table 1 documented recovery following wildfire. The variability in fire severity combined with variability in abiotic (site) features resulted in rapid revegetation, with a greater number of plant species present following a fire, the majority of which were native. Although the loss of overstory trees may be considered catastrophic from a timber utilization point of view, rapid revegetation in the absence of management intervention apparently is keeping these systems intact following disturbance, maintaining ecosystem function. The conclusion drawn by Abella and Fornwalt (2015) from their analysis of revegetation following the Hayman Fire articulately captures this common thread: “Landscape-scale severe burning was catastrophic from a tree overstory perspective, but from an understory perspective, burning prompted rich and productive native understories ….”

Vegetation Recovery After Beetle Kill

The MPB continues to play an important role in the ecology of western forests and “probably has been active in the ecosystem as long as there have been lodgepole pine trees” (Roe and Amman 1970). Infestations, which recur every 20 to 40 years, last for 6 years on average (Cole and Amman 1980; Jarvis and Kulakowski 2015). Climate change has expanded the insect’s latitudinal and elevational ranges, extending its geographic impact. In addition, the increasing frequency and severity of drought reduce tree vigor and predispose trees to attack. The physical manifestations of MPB infestation differ from those of wildfire, which consumes part or all of the forest floor; beetle infestation adds to it (Pelz and Smith 2012). Several researchers have taken advantage of the wide extent of bark-beetle-fueled disturbance to advance understanding of vegetation response. Table 1 shows papers that focused on response of the understory in the wider context of the density and distribution of the surviving trees, referred to as secondary structure (Alfaro and others 2015; Amoroso and others 2013).

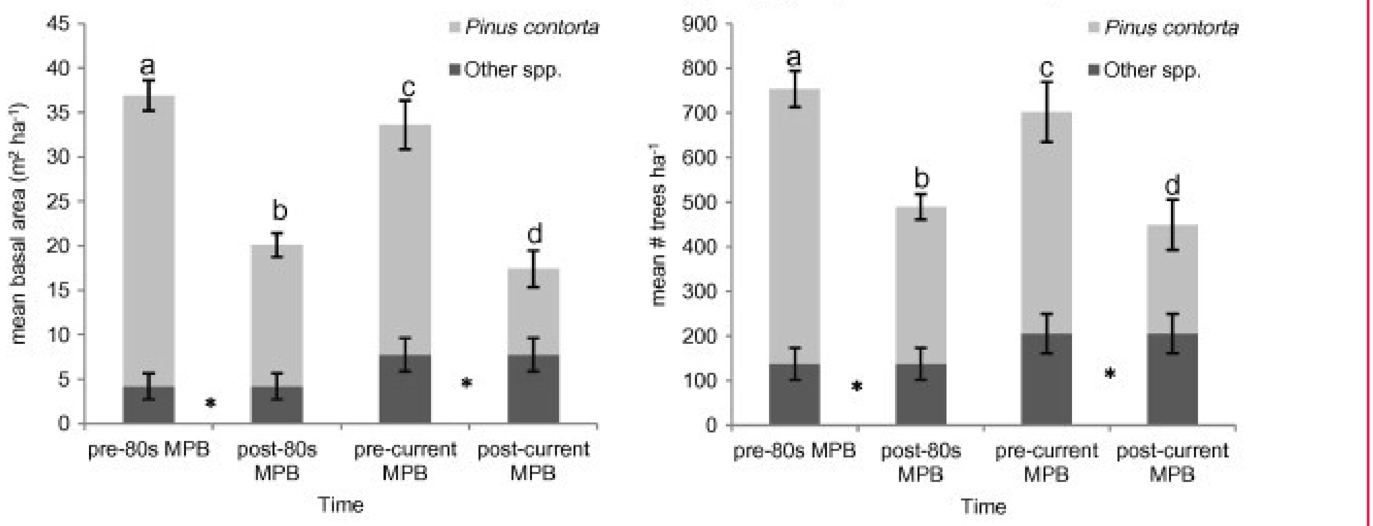
The mortality of canopy trees following a bark beetle infestation releases resources, accelerating development of the understory.

The mortality of canopy trees following an MPB infestation immediately releases resources (light, moisture, and nutrients), profoundly accelerating development of the understory as overstory trees succumb. Pec and others (2015), sampling 110 1-square-meter plots along a mortality gradient across 11 mature lodgepole pine forests in western Canada, found increasing biomass as well as herbaceous species richness and diversity with increasing overstory mortality; perennial herb biomass nearly doubled across the mortality gradient. Changes in herbaceous perennials were driven by the increasing availability of moisture and nutrients. In contrast, the diversity of woody species was not affected. While the understory response reduces leaching and retains nutrients, the burst in understory perennials could delay seedling recruitment and forest recovery. Further study that incorporates tree seedling pulses into the mix is needed.

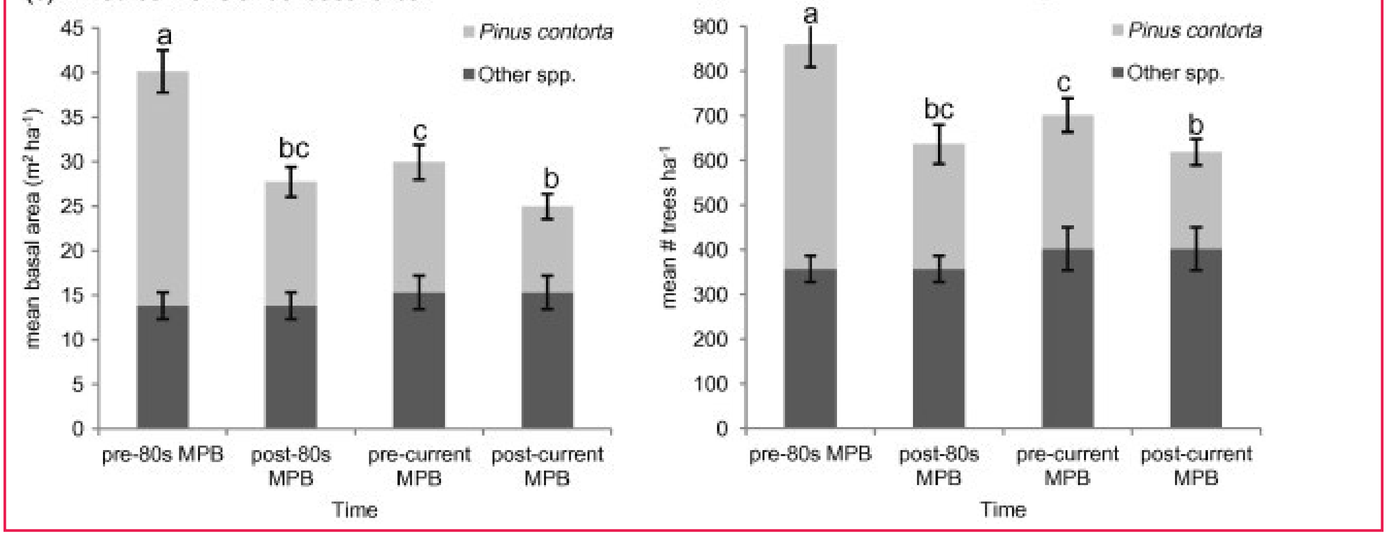
Pelz and Smith (2012) studied forest recovery 25–30 years after MPB infestation across 190,000 acres (76,000 ha) in Colorado in the early 1970s and 1980s. The area was subsequently reinfested in the 2010s. The vegetative response depended on preoutbreak species composition, categorized as lodgepole pine (with *Pinus contorta* comprising 86–100 percent of the basal area) and mixed-conifer stands (with *P. contorta* comprising 39–79 percent of the basal area). Fourteen plots were established in each of the two stand types. Beetles killed about half of the pine trees in both stand types (fig. 5). Greater reduction in total and *P. contorta* basal area in lodgepole pine stands promoted understory pine growth into the overstory, which recovered to 91 percent of the preinfestation basal area before the second infestation. Pelz and Smith (2012) suggested that *P. contorta* will remain dominant in the lodgepole pine stands in the absence of management for the next 20 to 30 years. In contrast, the pine basal area did not recover (attributed to lower light levels) in the mixed-conifer stands, where overstory mortality was lower and there were fewer overstory *P. contorta* stems to begin with.

The future ultimately lies in the understory. Evapotranspiration is largely responsible for loss of moisture from soil; evaporation is greatly reduced once the surface dries. Death of large canopy trees reduces evapotranspiration and nutrient uptake, reallocating resources, including light, to the understory. Seedling and sapling density increased fivefold from 1980 to 2010 in lodgepole and mixed-conifer stands (fig. 6). Quaking aspen (*Populus tremuloides*) expanded into the subcanopy in lodgepole pine stands, taking advantage of increased light availability. Aspen growing into the overstory acts as a natural fuel break. Although *P. contorta* in the lodgepole pine stands is expected to maintain dominance for the next 25 to 30 years, in the absence of fire, stand composition will shift toward subalpine fir (*Abies lasiocarpa*) as overstory trees decline and advance regeneration is released. This is consistent with Collins and others' (2011) projection and Kayes and Tinker's (2012) observation that *A. lasiocarpa* would become the most abundant species in MPB-infested lodgepole pine stands. The mixed-conifer stands, which had fewer *P. contorta* stems, already are moving towards dominance by *A. lasiocarpa* and Engelmann spruce (*Picea engelmannii*).

Amoroso and others (2013) sampled 22 stands to assess forest recovery 30 years after MPB infestation in the southeast corner of interior British Columbia. The stand basal area recovered by 69 percent, similar to results reported by Pelz and Smith (2012) for lodgepole pine stands in Colorado. In addition, the pine response was generally highest for sites that had high mortality and lowest for sites with low mortality. Higher mortality focused existing site resources on the remaining stems. Diameter growth response to release from competing overstory trees killed by beetles was concentrated in trees with a diameter at breast height of less than 20 centimeters and was most impressive for lodgepole pine (fig. 7). Dhar and others (2016a) framed this response as a "reset" of pine development to an earlier, more productive stage. The absence of dead, dying, or suppressed trees at the time of measurement, combined with a low incidence of mistletoe and pine stem rusts or galls, was interpreted as evidence of vigorous, healthy stands 30 years following an infestation.


(a) Lodgepole pine stands' basal area

(b) Lodgepole pine stands' density


(c) Mixed conifer stands' basal area

(d) Mixed conifer stands' density

Figure 5—*Changes in overstory (≥ 12.7 cm diameter at breast height) basal area and density through time, showing mean overstory basal area (a, b) and trees ha-*^{1} *(c, d) of* Pinus contorta *and all other species in lodgepole pine (a, c) and mixed-conifer (b, d) stands through time. Differences in letters above bars indicate significant differences in total and* P. contorta *basal area or trees ha-*^{1} *in stands through time. Asterisks (*) indicate significant differences between 1980s and 2010s nonpine species basal area and density. There was a significant increase of nonpine species in lodgepole pine stands (a, b) but not in mixed-conifer stands. Source: Pelz and Smith (2012). © 2012 by Elsevier, reprinted with permission.*

The positive growth response of subalpine fir and white spruce (*Picea glauca* x *engelmannii*) advance regeneration increased structural and species diversity, expanding successional pathways beyond the pathway for single-cohort lodgepole pine. Greater diversity is generally associated with stronger ecosystem resistance to disturbance and higher productivity (Reich and others 2012).

MPB impacts on Canadian forests have been viewed largely through the lens of provisioning ecosystem services. Long-term impact on timber supply has been the leading issue (Dhar and others 2016a); results of research have been incorporated into stand stocking guidelines by the British Columbia Ministry of Forestry (n.d.). Dhar and others' (2016b) review showed that infested stands would contribute to the timber supply 30 to 50 years following an infestation.

Alfaro and others (2015) sampled permanent plots in 11 stands that had not been salvage-logged following infestations by MPB in the 1980s and again in the 2000s on the Chilcotin Plateau in British Columbia. The patterns of organisms and organic matter (such as snags, stumps, and surviving trees) that persisted after disturbance, referred to as biological legacies, influenced vegetation recovery. Alfaro and others (2015) applied cluster analysis to postinfestation understory and overstory stand data and identified five legacy types (fig. 8).

Discriminant analysis was not able to statistically differentiate among the five groups, which were collapsed into two broader groups: high understory stocking and high regeneration (with an average of 1,043 seedlings and saplings per acre (422 per ha)) and low understory stocking and low regeneration (with an average of 134 seedlings and saplings per acre (54 per ha)).

> The high degree of compositional and structural diversity across the landscape contributes to recovery of these systems.

No Compelling Need to Intervene

The interaction of wildfire and MPB infestations has shaped development of the mixed-conifer and lodgepole pine forests of the Western United States and Canada. Climate change has increased the frequency and geographic extent of extreme events (Stott 2015), enhancing and intensifying the disturbances. In their aftermath, knowledge of postdisturbance vegetation recovery is critical for informing management decisions. The physical manifestation of wildfire, which—depending on its intensity—consumes litter and some or all of the forest floor (fig. 1), differs from that of MPB infestation. The latter not only leaves (pun intended) the litter and forest floor intact but also adds additional fine and coarse woody debris to the surface (fig. 8).

Physical manifestations notwithstanding, the two disturbances share common features. Both generate an immediate pulse of above-ground and below-ground resources (respectively, light and nutrients), promoting seed germination

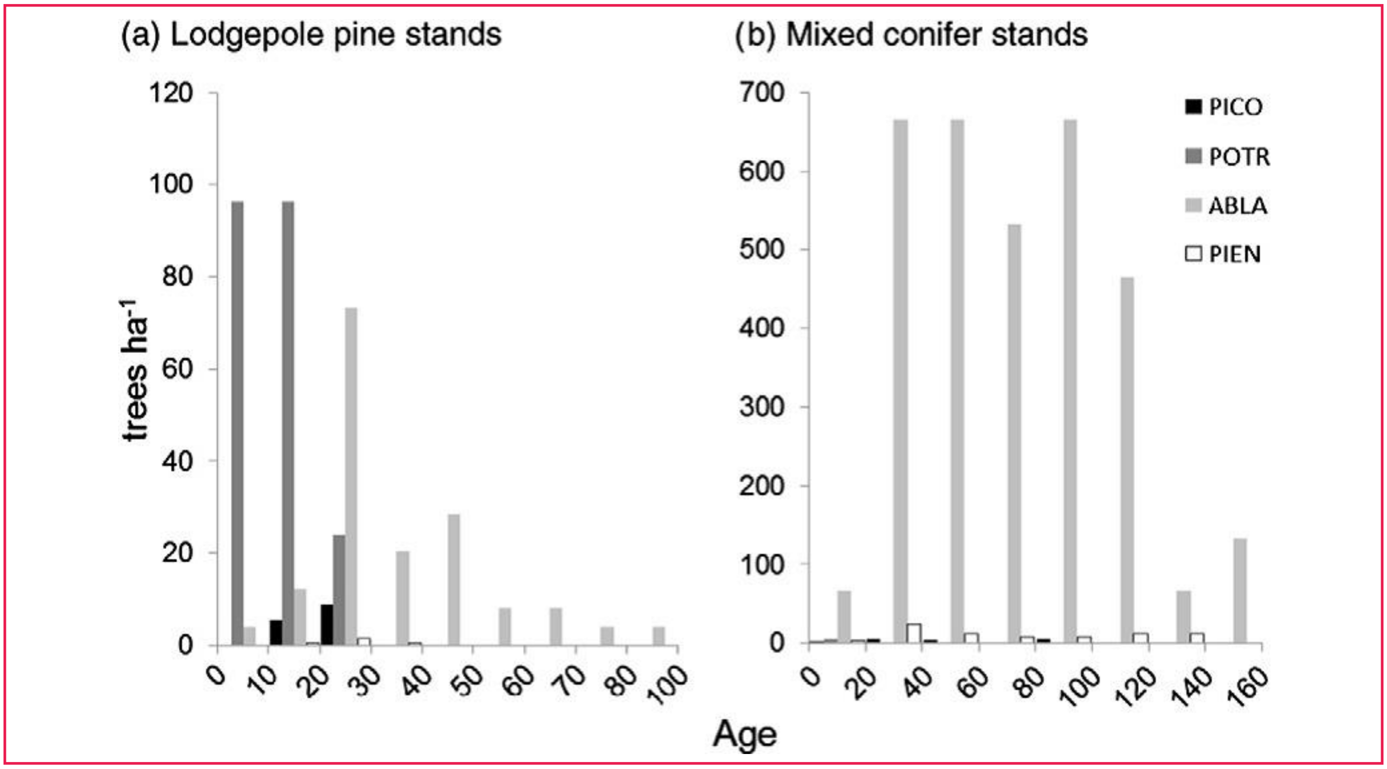


Figure 6—*Ages and numbers of seedlings/saplings (> 0.6 m tall and > 3.8 cm diameter at breast height) ha*$^{-1}$ *in lodgepole pine (a) and mixed-conifer (b) stands in the 2010s. Median ages of seedlings/saplings were significantly younger (P < 0.0001) in lodgepole pine (21 years) than in mixed-conifer stands (58 years). In lodgepole pine stands, 76 trees were age dated: 13* Pinus contorta *(PICO), 18* Populus tremuloides *(POTR), 40* Abies lasiocarpa *(ABLA), and 5* Picea engelmannii *(PIEN). In mixed-conifer stands, 84 trees were age dated: 14* Pinus contorta*, 4* Populus tremuloides*, 48* Abies lasiocarpa*, and 18* Picea engelmannii*. The graphs represent the ages of the 160 trees scaled up by species to the 2010s average trees ha*$^{-1}$ *of each forest type. Note differences in x- and y-axes between graphs. Source Pelz and Smith (2012). © 2012 by Elsevier, reprinted with permission.*

and fueling development of the understory vegetation, seedlings and saplings, and any surviving trees. Conifer regeneration following wildfire, dominated by lodgepole pine in the Intermountain States, has been prolific. Conifer regeneration in the drier NAMCZ of California has been less robust, relying on adjacent unburned and lightly burned areas as seed sources. However, understory species quickly revegetate sites. Although conifer seedling stocking generally fell below Forest Service silvicultural guidelines in the NAMCZ (which constitute only one metric for considering regeneration following a disturbance), the shifting emphasis towards a broad array of ecosystem services may make those guidelines less important as the focus shifts from commercial species to revegetation of the entire understory.

Both wildfire and MPB infestations superimpose a high degree of variability across the landscape following disturbances, but the mechanisms responsible for that variability differ. In the case of wildfire, wind conditions interact with local topography, fuel conditions, stand structure, and composition to determine fire intensity. The result is a complex landscape mosaic of patches

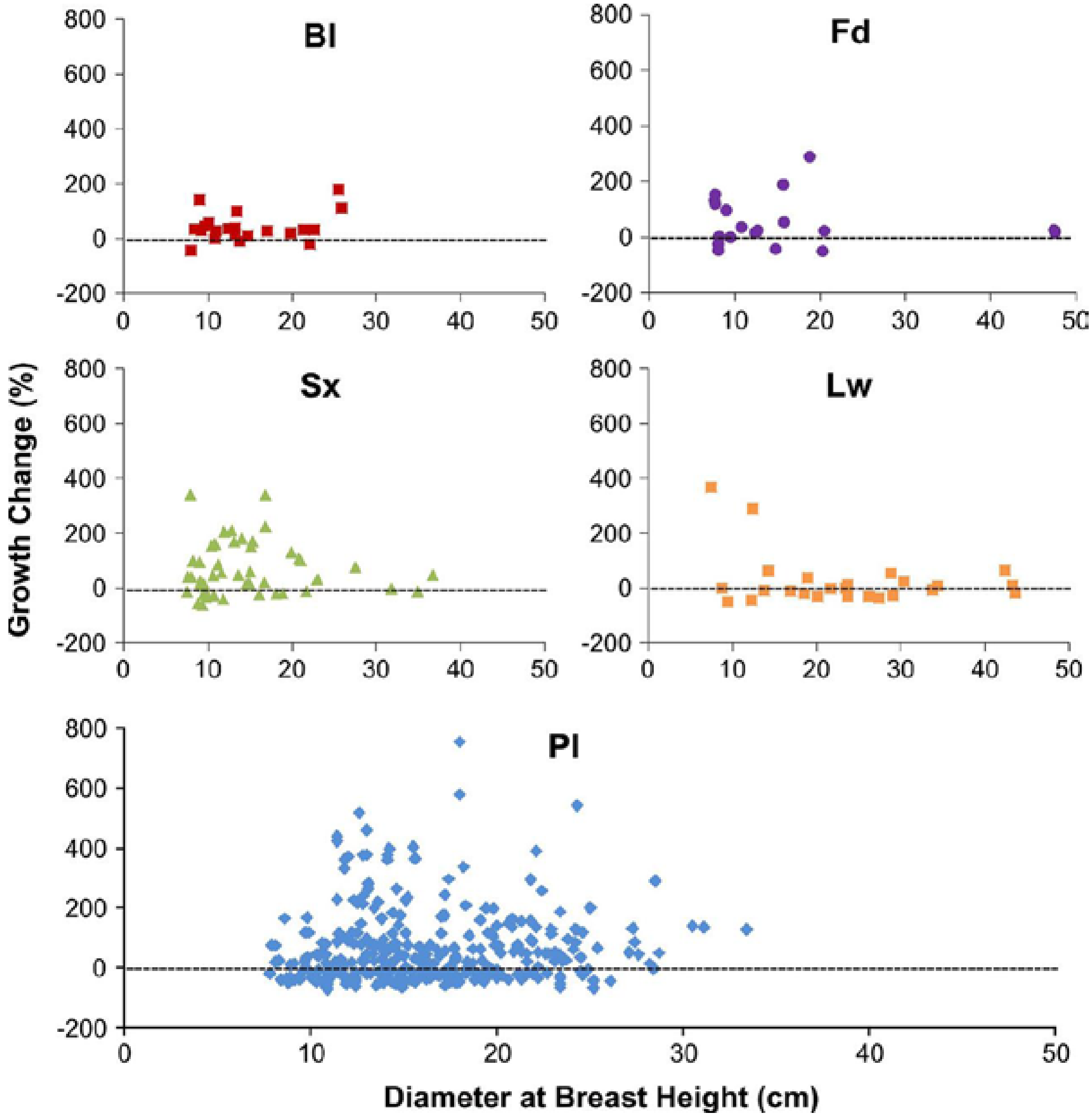


Figure 7—*Growth change percent for secondary structure (trees surviving beetle attack, currently > 7.5 cm diameter at breast height) by species and diameter at breast height at the time of the outbreak. Species codes are lodgepole pine (Pl), subalpine fir (Bl), interior spruce (Sx), Douglas-fir (Fd), and western larch (Lw). Growth change is 10-year postoutbreak minus 10-year preoutbreak radial growth expressed as a percentage of preoutbreak radial growth. Source: Amoroso and others (2013). © 2012 Elsevier B.V. All rights reserved.*

Figure 8—*Remaining live legacy types in lodgepole pine forests impacted by two mountain pine beetle outbreaks on the Chilcotin Plateau of British Columbia. The 1980s outbreak occurred between 1975 and 1985 and the 2000s outbreak occurred between 2002 and 2010. Legacy types are described as follows: Small Pl regen = abundant small lodgepole pine regeneration (< 50 cm tall) and sparse pine overstory; Aspen = abundant overstory aspen and sparse pine overstory; Advance regen = abundant lodgepole pine understory and large regeneration; Sparse = low-density overstory and understory and regeneration; Remnant Pl = remnant lodgepole pine overstory. Source: Alfaro and others (2015). © 2015 Canadian Science Publishing or its licensors, reproduced with permission.*

varying in size and ranging from unburned to severely burned (fig. 3). Lodgepole pine seed dispersal following fire contributes to its prolific regeneration. For other conifers, the adjacency of lightly and severely burned patches maintains seed sources and contributes to vegetation recovery.

In the case of beetle infestation, the larger lodgepole pine trees are usually killed, reallocating site resources to the smaller stems that survive the attack. Postinfestation stand structure (referred to as secondary structure) varies across the landscape, reflecting the number of large-diameter lodgepole pine trees killed during the infestation. Effectively, intermixed patches of varying tree density interrupt a formerly vast expanse of even-aged trees, imposing habitat discontinuity for MPB. Amoroso and others' (2013) conclusion from their 30-year-postinfestation analysis articulately captures one of the common threads among the disturbance papers reviewed: "[T]he MPB epidemic resulted in more structurally and compositionally diverse stands leading to multiple successional pathways different from those of even-age pine dominated stands." That conclusion could have been inserted into any of the papers summarized in table 1 by substituting "wildfire" for "MPB epidemic" or vice versa.

The high degree of compositional and structural diversity across the landscape is an important factor contributing to recovery of these systems. In the absence of objectives to direct regeneration in a particular path in terms of species composition, there is no compelling reason to intervene at this point in time. Ecosystem services (such as carbon sequestration, biodiversity, nutrient cycling, and watershed functions) are being restored in the absence of management. Alfaro and others' (2016) statement regarding the work in British Columbia rings true for all these papers: "[F]or the next decades, forests impacted by MPB and fire, in the Chilcotin Plateau, will continue to deliver most if not all of the ecosystem services they have for the last 100 years." The caveat expressed by Kemp and others (2016) is worth noting: "… provided that seedlings survive, fire[s] do not become more frequent, high-severity patches do not get significantly larger, and post-fire climate conditions remain suitable for seedling establishment and survival."

That caveat is most apparent for the ponderosa pine forests that evolved under a regime characterized by a frequent fire return interval compared to the large stand-replacing fires in lodgepole pine forests every 200 to 300 years. Fornwalt and others (2016) showed that only 5 percent of polygons examined after the Hayman Fire retained any living trees. The degree of fire severity and consequent mortality exceeded the historical range.

Lodgepole pine forests have evolved with the interaction of bark beetles and fire, with a long disturbance return interval. As fire return intervals are reduced and beetle ranges are expanded by climate change, the systems will continue to evolve. The analysis by Brown and others (2017) of the paleoecological record for lodgepole pine on the Chilcotin Plateau in British Columbia suggested the possibility that lodgepole pine will be replaced by arboreal and open forest communities as the climate continues to change. Long-term monitoring will be critical to improve our understanding of these changes and their implications for ecosystem services. ■

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HOTSHOTS: THE ORIGINS OF THE INTERAGENCY HOTSHOT CREW

Lincoln Bramwell

Interagency hotshot crews (IHCs) form the backbone of the Federal Government's response to wildland fire. Their high level of physical fitness, training, self-reliance, and expertise make the IHCs the world's elite wildland firefighters; these men and women are dispatched to the worst fires in the toughest terrain under the most life-threatening circumstances.

The Forest Service developed hotshot crews specifically to fight fires in the rugged West. At major points, the history of the creation and maturation of the IHC program paralleled the Federal Government's aggressive policy of combating western wildland fire.

Members of the Smith River Interagency Hotshot Crew on the 2016 Cedar Fire, Sequoia National Forest, California. Photo: Lance Cheung, USDA (August 23, 2016).

Policy of Rapid Response

In 1910, following devastating fires in the Northern Rockies that claimed the lives of 78 firefighters, public and congressional insistence that the Forest Service fight all fires intensified (Cook 1998; Pyne 2002). In the following year, Congress doubled the Forest Service's budget and passed the Weeks Act, which legislated permanent emergency firefighting funds to make aggressive wildland fire suppression a priority.

In the decade following the Northern Rockies fires, the Forest Service experimented with various firefighting strategies to accomplish its new priority. Newly designated Forest Service Chief Henry S. Graves (1910–20) commented on the importance of using trained, organized crews to protect forests from destructive blazes. In a Forest Service bulletin from 1910, he wrote: "The following are of 1st importance: (1) Quick arrival at the fire; (2) an adequate force; (3) proper equipment; (4) a thorough organization of the fighting crew; and (5) skill in attacking and fighting fires" (Graves 1910).

Hotshot crews, now totaling 114, continue to shoulder the responsibility for suppressing large fires.

After 25 years of fledgling firefighting efforts by the agency, Chief Ferdinand "Gus" Silcox (1933–39) issued a national wildland fire directive in 1935. Known as the 10 A.M. Policy, the mandate attempted to standardize the response to wildfire. The policy ordered firefighters to control every fire by 10 a.m. on the morning after its first report, making aggressive fire suppression the standard response. Suppressing fires by 10 a.m. was also viewed as cost effective because managing a number of small fires, as opposed to one large conflagration, proved far less expensive (Pyne 1982).

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The 40-Man Crew

For many years, Forest Service fire wardens and management officers desired better organized fire crews (CNF 1937; Guthrie 1939; Pyne 1982). After several disaster fires, including the 1933 Griffith Park Fire, Congress restricted the use of Civilian Conservation Corps enrollees to fight fires. This restriction led to experiments in economically efficient firefighting.

L.L. Colvill, assistant forest supervisor on the Siskiyou National Forest in Oregon, spent much of 1938 battling the largest fires in the Pacific Northwest. He found that poorly conditioned, trained, and supervised fire crews simply took too long to reach a fire, were too worn out from the hike to fight the fire effectively, and needed considerable support to live away from their base for several days. Colvill recognized the need for "trained crews of physically [sic] supermen capable of sustaining themselves on the fire line for periods of several days with a minimum of [support]" (Colvill 1939). Intrigued by his suggestion, the Forest Service ordered the Siskiyou National Forest supervisor to organize a 40-man crew of "supermen" to test the idea.

Nearly all future hotshot protocol and routine came from the Siskiyou experiment. First, supervisors chose a junior forester with 10 years of fire experience to lead the new crew, basing the selection from applicants on their "physical prowess, woodsmanship, and self motivation." Operating on the "every private a captain" principle, the supervisors wanted experienced personnel able to make decisions in critical situations (Colvill 1939).

Two recent hotshot superintendents, Paul Linse and Larry Edwards, wrote of the experiment's guiding principles: "Professionalism, thorough organization, training, and experience incorporated not only safety, but a commitment to excellence, technical expertise, strong esprit d'corps, and a no excuses 'can-do attitude'" (Linse and Edwards 1997). A forester colorfully described the crews as "compact gangs of smoke-eating hellions in which every last man is a triple threat to any fire" (Holbrook 1940).

In addition to having firefighting experience, potential candidates for 40-man crews had to be males between the ages of 21 and 40. The Forest Service held to a de facto policy that excluded women from working as firefighters except as fire lookouts. Typically, the job drew unmarried foresters, a pattern that is still evident today, because their responsibilities required extended time away from their duty stations. In addition to appealing to single foresters, the Siskiyou experiment attracted rural men comfortable with physical labor in the outdoors (Holbrook 1940).

To tackle fires in the backcountry where logistical support was difficult to arrange, each man carried enough provisions to support himself for 3 days. The supervisors from the Siskiyou National Forest estimated the caloric intake for each man at 3 calories per pound per hour.

The Forest Service developed hotshot crews to fight fires in the rugged West.

Early fire crew of Civilian Conservation Corps enrollees fighting a wildfire on the North Rim of the Grand Canyon in Arizona. Note the lack of power tools and of personal protective equipment. Source: National Park Service Historic Photo Collection.

Thus, a 180-pound man working 16-hour days for 3 days required an extraordinary 25,920 calories. For a crew that expected to work at unprecedented speeds to stop the first run of a fire, supervisors deemed the high calorie intake as essential to high performance. One forester described the crew's job: "It is man-killing work too, for the pace set is terrific and no woodsman likes to show or to admit fatigue" (Holbrook 1940). The 40-man crew experiment on the Siskiyou National Forest was a resounding success (Cliff and Anderson 1940).

Figure 1—*Early hotshot crew. Members of the Willamette Flying 20 on the McKenzie Fire on the Willamette National Forest in Oregon in 1938. Photo: USDA Forest Service.*

Emergence of the 20-Man Crew

America's entry into World War II in December 1941 reduced the Forest Service's manpower, necessitating a reliance on 40-man crews. During the war, women worked on the firelines for the first time, replacing large numbers of men drafted into military service. Like most wartime occupations, women were laid off after the war to make way for returning servicemen. Women did not return to the fireline for nearly 20 years (Renzetti and Curran 1989). Following World War II, the agency routinely pressed nonfire employees into fire crews known as "regulars" for local fires, but it relied on mobile, flexible, and well-organized crews to control fires by 10 a.m. on the morning after first reported.

Following World War II, 20-man crews in southern California first used the title "hotshot."

After the war ended and the Forest Service permanently lost the manpower and large budgets from New Deal programs like the Civilian Conservation Corps, experiments began to reduce the 40-man crew's size and cost. Near the Siskiyou in Oregon, the Willamette National Forest developed a 20-man crew. When calls came, the firefighters gathered at prearranged points before traveling to the fire. Dubbed the "Willamette Flying 20," the crew had an overhead management of one foreman and two squad bosses, a pattern familiar to generations of hotshot crews (fig. 1).

By 1947, following the examples of the Oregon Red Hats and the Willamette Flying 20, 20-man crews appeared on the chaparral-covered national forests of southern California. Based on the San Bernardino, Cleveland, Angeles, and Los Padres National Forests, the southern California crews first used the title "hotshot" (Anderson and others 1997; Stevenson 1997). The new title reflected the mobile crews' speed and their fearlessness as they shot into the hottest parts of the fire. The label also revealed the self-confident image the crews wanted to project as they established themselves as the most effective option for fighting large western fires. Streamlining as much as possible to decrease their response time to fires, the southern California crews shrank in size but maintained effectiveness.

The development of mechanized fire equipment had the greatest impact on IHC structure. The original 40-man crews needed 11 to 18 men to fell trees and clear smaller vegetation. By the 1950s, lightweight power chainsaws required only six men to accomplish an equal or greater amount of work. Also, the helicopter increased hotshot crew mobility by rapidly delivering crews to critical fire areas. In 1950, the use of helicopters so impressed a fire conference in Ogden, UT, that it recommended stationing "aerial shock troops" at critical locations throughout the

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[1] *In my personal experience on hotshot crews ("type 1" crews in fire community parlance), the Sawtooth IHC traveled with 8 chainsaws whereas the Logan IHC used 10. Traditionally, regular 20-person "type 2" hand crews carried three chainsaws into any fire assignment, requiring three sawyers and three swampers to clear the downed vegetation.*

Nation. Despite recent advances in weather prediction and observation, firefighting technology has not changed since the introduction of these two indispensable pieces of mechanized equipment—chainsaws and helicopters (Johnston 1978; Stevenson 1997; USDA Forest Service 1950).

Interregional Crews

In 1961, the Forest Service established five interregional fire suppression crews based on the idea proposed by the Ogden conference a decade earlier (Alexander 1974). The delay in placing "aerial shock troops" at strategic locations was due in large part to the size of the agency's bureaucracy and the time needed to adjust policy. Modeled on the half-dozen hotshot crews operating in California in the 1950s, interregional crews consisted of close to 20 members. The size, structure, and mobility of the crews placed them in the same lineage as today's hotshot crews.

Beginning each June, an interregional crew would remain on call 24 hours a day, 7 days a week. When crewmembers were off duty, signout sheets informed supervisors of their whereabouts in case of a fire call. The interregional crews were advantageous because they could reach any location in the West within 6 to 8 hours and arrive as a complete package: with supervisors, crewmembers, tools, radios, bedding, and enough food for 48 hours (Alexander 1974). The Forest Service coordinated all requests for interregional crews from the National Fire Control Center in Washington, DC.

By 1963, the number of interregional crews had doubled to 10 (Division of Fire Control 1963), and the number rapidly grew. But within a decade, hotshot crews had absorbed the interregional crew program and adopted its aerial mobile capabilities.

Figure 2—*Members of the Geronimo Interagency Hotshot Crew on the Big Windy Complex Fire in Oregon in August 2012. Each hotshot crew has distinctive clothing and equipment (such as the unique Geronimo hardhats), reflecting unit pride and building unit cohesion. Photo: Lance Cheung, USDA.*

Keys to Success

A key ingredient of IHC success was unit cohesion expressed through a sense of pride as the hotshots adopted unified crew clothing and trappings that served to distinguish IHCs from other fire crews (fig. 2). Some hotshots proudly displayed a distinctive shoulder patch, and the El Cariso (California) Hotshots wore berets during the 1960s, emulating U.S. Army Special Forces serving in Vietnam. By this time, hotshot crews wore orange flame-retardant shirts, hardhats, bluejeans, and White's logging boots as their own standard fireline attire (Alexander 1974; Campbell 1997; Pyne 1982, 1994).

The IHC program enjoyed success in the field and acceptance from Federal fire officials by the 1970s. Faced with the dual challenges of a shrinking budget during an economic recession and sharply rising fuel costs for mechanized equipment and aircraft, the Forest Service searched for ways to save money (Pyne 1982). Fire management officers pointed out the cost-effectiveness of hotshot crews: on any given fire, IHCs dug 50 percent more fireline than regular Forest Service crews (Biddison 1978). Jerry Ewart, fire officer for the Tonto National Forest in Arizona, explained that three hotshot crews on his forest had saved millions of dollars in projected suppression costs and resource losses (Ewart 1976).

Policy Modification

By the end of the 1970s, forest ecology research confirmed fire's

Figure 3—*Kim Seitzinger, a member of the Sacramento Interagency Hotshot Crew, on the Myrtle Fire in South Dakota in July 2012. Photo: Dave Cosling, USDA.*

> The postwar development of mechanized fire equipment had the greatest impact on hotshot crew structure.

beneficial role in maintaining forest ecosystem health. Concurrently, prescribed burning gained wider acceptance among policymakers and field personnel as an effective tool to increase forest health and prevent large conflagrations (Schiff 1962).

All these factors led to the reassessment of the 10 A.M. Policy at the interagency National Fire Planning Meeting in July 1977. The new National Forest Manual rejected the old policy's implicit assumption that all fires were bad, although it still mandated an aggressive initial attack on wildfires. If initial attack failed, the incident commander had other alternatives, such as allowing naturally caused fires to run their course or initiating a cost-benefit analysis before extending suppression efforts.

Hotshots had little to do with the 10 A.M. Policy's modification, and despite the change in policy, the hotshots' job on the ground remained largely the same. With an institutionalized mission and a continued national reliance on suppression, they went on aggressively fighting fires and putting themselves at risk to protect property and their reputations (Biddison 1979; Egging and Barney 1979; Pyne 1982).

Women on the Fireline

Because the agency still suppressed the vast majority of fires, the job of hotshot crews on the fireline changed little. One organizational aspect that did change was women becoming hotshots in the 1970s. No one knows for sure when the first woman joined a hotshot crew, but it was after the passage of Executive Order 11246, better known as Affirmative Action.

Performance on the ground became the main criterion for acceptance into the hotshot world. The same physical standards applied to women as to men, and as more and more women performed to hotshot standards, their numbers on the crews increased. Recent generations of female hotshots have encountered growing acceptance. Women today claim their positions on the crews without any deference to traditional gender roles (fig. 3).

Homes in Fire-Prone Wildlands

As national fire policy changed and women joined hotshot crews, another external factor profoundly shaped the IHCs. Across the country, developers built more homes along the edges of towns, in forests and grasslands, and larger numbers of people sought enjoyment through outdoor recreation. This increasingly put lives and property at risk from wildland fires (Fuller 1991). As an "exurban" population claimed the rural landscape and millions moved into the path of wildfires, the need for hotshot crews that could handle the technical challenge of wildland–urban interface fire escalated (Bramwell 2014).

The hotshots accepted the increased suppression burden. By 1982, there were 54 hotshot crews nationwide (Findley 1982). The U.S. Department of the Interior started its own hotshot crews, distributed among its agencies with responsibilities for wildland fire management. After the National Park Service organized the Arrowhead, Alpine, and Buffalo IHCs, the Bureau of Land Management and Bureau of Indian Affairs likewise fielded hotshot crews in the 1980s.

A review of the major disasters that involved hotshots illuminates the relationship between the hotshot program and national policy.

Firefighter Fatalities

As residential development pushed farther into undeveloped landscapes that regularly burned, hotshot crews became more efficient and more numerous. Stretched to the limit to protect homes and natural resources, they suffered a number of fatalities. A review of the major disasters that involved hotshots illuminates the relationship between the IHC program and national policy.

In 1956, disaster struck an organized hand crew on the Inaja Fire in California. Eleven firefighters died while trying to escape a sudden blowup on a hillside. Forest Service Chief Richard McArdle (1952–62) appointed a task force to study the ways in which the agency could strengthen its efforts to prevent firefighter fatalities. The task force examined everything from fire behavior to protective clothing. It recommended additional training for fire crew supervisors and considered national training courses and a fire research/training center (Pyne 1982).

In 1958, the agency instituted the 10 Standard Firefighting Orders and 18 Watchout Situations. Standard order number 10 read, “Fight fire aggressively but provide for safety first.” When Chief McArdle announced the 10 standard orders, he stated that “training is not complete until the trainee is convinced that the safest, most effective way to fight forest fires is to understand the enemy and to attack it aggressively” (Moore 1959).

Ten years later, the Loop Fire trapped another crew on a hillside on California’s Angeles National Forest and inflicted major casualties. After one hotshot crew refused to work on the hillside, the El Cariso Hotshots, possibly impelled by “the ‘can-do’ attitude, [and] a sense of ability and invincibility” (Cooke 1998), accepted the assignment and placed themselves in a dangerous situation. An undetected spot fire below the crew unexpectedly raced up the hillside in less than a minute, killing 12 crewmembers.

Again, the Forest Service formed a task force to study the Loop Fire and reassess basic firefighting training. The investigation placed a new emphasis on the evaluation of fuels and their effect on fire behavior. In addition, the task force developed rules against downhill fireline construction, and the use of hand-held radios for crew communication became standard. The Fire Policy and Procedure Review Committee meeting in February 1967 in Washington, DC, sustained the 10 A.M. Policy and responded to the Loop Fire by advocating for national training standards and a central training center. In 1967, the Forest Service stablished the National Fire Training Center at Marana, AZ (Cook 1998; Gleason 1994; Pyne 1982).

In 1976, three hotshots died on the Battlement Creek Fire in Colorado when firefighters intentionally started a backfire to protect themselves by reducing fuels between their fireline and the main blaze. The backfire escaped the fireline, trapping four men, only one of whom survived. As a result of these casualites, the Forest Service mandated that all employees carry fire shelters while engaged in fireline activities (Cook 1998; Pyne and others 1996).

Compromised Safety and Policy Response

The following year, the Forest Service rescinded the 10 A.M. Policy, but the hotshot mission continued to govern actions on the fireline. Confidence in the physical abilities of each hotshot, combined with a mission to aggressively fight fires, created a character flaw in the hoshot crews’ work culture. Egos and unit pride impelled the hotshots to push themselves beyond what they could safely accomplish. This confidence, considered a beneficial trait as early as the 1930s, proved detrimental after two fire disasters in the 1990s.

One of them was the Dude Fire in Arizona in 1990. Six firefighters were killed. The accident investigation report for the Dude Fire cautioned (Cook 1998):

> Do not let your ego or other people’s high expectations of your capabilities influence you to acccept assignments with high levels of risk. Specialized fire resources such as helitack crews, hotshot crews, and smokejumpers are especially susceptible to this pressure.

On July 6, 1994, 14 wildland firefighters lost their lives in a single incident on Storm King Mountain near Glenwood Springs, CO. One hotshot crew, 16 smokejumpers, and a collection of regular employees from the Forest Service, Bureau of Land Management, and National Park Service fought to contain a blaze as it crept downhill toward a resort community. The firefighters worked furiously and, in the process, ignored many of their safety guidelines. Meanwhile, their command structure crumbled, and warnings about a storm system moving into the area never reached the firefighters.

At about 4 p.m., with half the firefighters digging a fireline down a steep hillside covered by Gambel oak, the fire jumped the control line and exploded to engulf the entire west drainage and all those working in it in a wall of flame. The 14 who died on the South Canyon Fire included 9 members (4 of them female) of the Prineville Hotshots, 3 smokejumpers, and 2 helitack personnel (Adler 1994; DeClaire and Donohue 1995; Grey 1994; Maclean 2009; Weller 1994).

The Director of the Bureau of Land Management and the Forest Service Chief ordered their respective agencies to produce an interagency report within 45 days of the tragedy. The South Canyon Fire Investigation Team noted the complete breakdown in the chain of command but concluded that the can-do attitude of the firefighters involved in the incident led to the violation of 8 of the 10 Standard Firefighting Orders and 13 of the 18 Watchout Situations (IMRT 1995). By the 1990s, hotshots were typically bending and breaking some of the safety guidelines to achieve their agencies' suppression goals. High expectations prompted safety violations and increased risk to firefighers, raising the potential for disaster to strike (Pyne and others 1996).

For the first time in 60 years, a disaster that involved hotshots precipitated a change in fire suppression policy. The Secretaries of the Interior and Agriculture chartered the Federal Wildland Fire Management Policy and Program Review in 1994. As a result of the review, the safety of firefighters assigned to an incident became the number one priority. In addition, the changes mandated annual refresher training courses, an external review of firefighting culture, and the study of decision-making dynamics in high-risk environments. Finally, the report challenged the current fire suppression policy by declaring that agencies and the public needed to recognize that not all wildland fires could or should be suppressed (NWCG 1995).

An Enduring Mission

Hotshot crews, now totaling 114 (USDA Forest Service 2017), continue to shoulder the responsibility for suppressing large fires. With the public's escalating pressure to protect homes in the wildland–urban interface, the specialized skills of the hotshots remain in high demand.
In light of tragedies after the South Canyon Fire, however, fire management has adopted the tenet, "Firefighter safety comes first on every fire, every time" (Apicello 1996). Still, tragedies involving hotshots continue to occur, reflecting the dangerous nature of the job. Nineteen members of the Granite Mountain IHC perished on June 30, 2013, in an Arizona burnover incident that was the deadliest in IHC history (Karels and Dudley 2013).

Although the public's perception of the Forest Service's ability, obligation, and eagerness to suppress all wildland fires may not change, the agency and the hotshots recognize that there are definite limitations to their fire suppression mission. Their tempered aggressiveness is reflected in today's National Interagency Hotshot Crew Steering Committee's official motto: "Safety, Teamwork, Professionalism" (NIHCSC 2004; NWCG 1995).

Wildland fire is an ever-increasing threat in the West. The intensity and frequency of fires rise each year. As more and more people move into formerly rural areas, the demand for fire suppression and protection increases each year. The history of the Nation's elite firefighters illuminates the changing nature of Federal fire policy and its relationship to the men and women who carry it out. ■

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WHAT IS FIRETEC (AND WHY SHOULD I CARE)?

James H. Furman and Rodman Linn

Current fire spread models are inadequate for predicting the complex influences of atmosphere, forest structure, and self-generating fire processes on wildland fire behavior. FIRETEC is a physics-based, three-dimensional computer code developed at Los Alamos National Laboratory (LANL) to capture the constantly changing, interactive relationship between wildland fire and its environment (fig. 1; Linn 1997; Linn and others 2003). To accurately represent interactive fire processes, FIRETEC combines physics models that represent combustion, heat transfer, aerodynamic drag, and turbulence with a computational fluid-dynamics model, HIGRAD, which represents airflow and its adjustments to terrain, vegetation, and the fire itself.

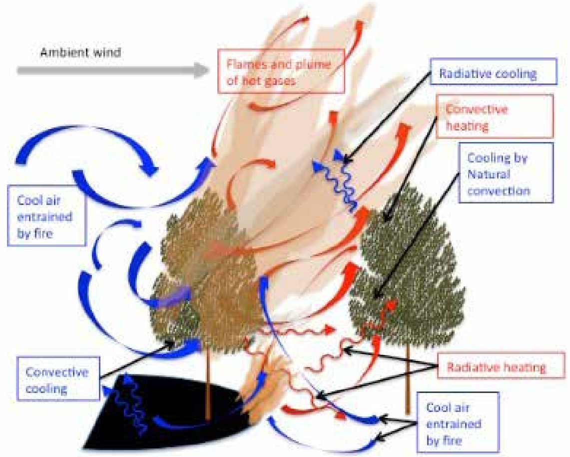

Figure 1—*Multiple interactive physical processes are integrated in FIRETEC simulations.*

> FIRETEC can be used to investigate facets of wildland behavior associated with a wide range of environmental influences.

Applications

FIRETEC can be used to investigate facets of wildland fire behavior associated with a wide range of environmental influences, from the local effects of specific tree configurations (Linn and others 2005; Parsons 2007; Pimont and others 2011), to the interaction between separately ignited fires (Depuy and others 2011), to the larger scale effects of evolving weather conditions. FIRETEC has been applied to study basic fire behavior phenomena (Cunningham and Linn 2007; Linn and others 2007, 2010, 2012a; Pimont and others 2006, 2009), and it has begun to be used to understand implications of simplified fire behavior model formulations (Pimont and others 2012).

The applications of FIRETEC span ecosystems from sparse grass to heavily forested woodlands on both flat terrain and in rugged topography (Linn and others 2007, 2010; Pimont and others 2011). FIRETEC was designed for size scales ranging from hundreds of square feet to tens of square miles and with resolutions on the order of feet. The coupled physics-based formulation of FIRETEC and its range of size scales allows investigation of the interactions between ignition strategies, local meteorology, and ecosystem structure. FIRETEC can therefore be used to investigate fire management practices that result in successful or unsuccessful prescribed fire operations in terms of fire behavior or emissions transport and fate (Cassagne and others 2011).

James Furman is the Forest Service liaison for the Northeastern Area State and Private Forestry with the Air Force Wildland Fire Center, Niceville, FL; and Rodman Linn is a senior scientist in the Computational Earth Sciences Division, Los Alamos National Laboratory, Los Alamos, NM.

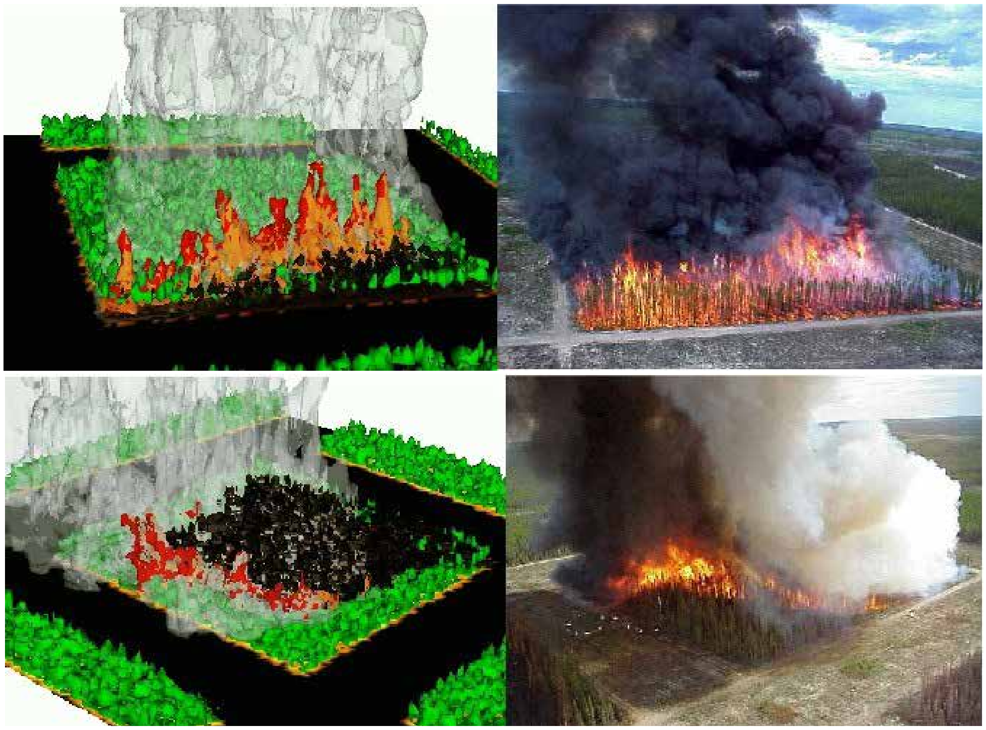

Figure 2—*FIRETEC simulations (top—left and right) paired with photographs (bottom—left and right) of plot 1 of the International Crown Fire Modeling Experiment (ICFME), which took place in Canada's Northwest Territories between 1995 and 2001. FIRETEC simulations of several of the ICFME burns produced spread rates and burn patterns that replicated the actual fires well. Photos courtesy of Natural Resources Canada, Canadian Forest Service.*

Under development and refinement since 1995, FIRETEC has been used for simulations of and comparisons with both historical fires (Bossert and others 2000; Bradley 2002) and field experiments such as the 2005 International Crown Fire Modeling Experiment illustrated in figure 2 (Linn and Cunningham 2005; Linn and others 2005; Pimont and others 2009; Linn and others 2012b). These simulations have demonstrated this model's ability to capture realistic fire behavior in a variety of situations. Continued efforts to broaden the scope of these comparisons include a current project, in collaboration with Natural Resources Canada, to simulate key aspects of the 2016 Fort McMurray wildfires in Alberta, Canada.

FIRETEC has also been utilized to simulate key aspects of historical fires, including the 2012 Las Conchas Fire near Los Alamos, NM, and the tragic 1949 Mann Gulch Fire in Montana. These simulations are valuable not only for validating the modeled phenomenology but also for deciphering unexplained or controversial aspects of these fires. FIRETEC has been used to study the interaction between multiple lines of fire (Depuy and others 2011) and the impacts of massive insect attacks on fire behavior in lodgepole pine (Hoffman and others 2015) and pinyon–juniper (Linn and others 2013) ecosystems. In recent years, the State of New Mexico used FIRETEC to examine the effects of fuels management treatments near mountain communities. FIRETEC is not available on desktop computers because it requires large amounts of input data and a supercomputer, but the simulations produced by FIRETEC have far-reaching implications and applications for fire managers.

Funding

Funding for the research and development leading to FIRETEC came largely from three sources:

1. LANL's Directed Research and Development program,
2. The Forest Service through the National Fire Plan and Joint Fire Science Program, and
3. The U.S. Department of Defense's Environmental Security Technology Certification Program (ESTCP).

LANL's Institutional Computing Program has provided computational resources that have been crucial for the development and use of FIRETEC. The Joint Fire Science Program and LANL's Collaborative University of California/Los Alamos Research program funded the development and implementation of the spotting model within FIRETEC, which allows the model to estimate probabilistic trajectories and points of ignition from burning firebrands. The ESTCP funding is being used to simulate prescribed fire scenarios in southern pine forests in order to further explore FIRETEC's capabilities and to develop training tools for fire managers. In addition, a wide range of U.S. and international collaborators, such as France's Institut National pour la Recherche

Figure 3—*Top: Aerial/spot ignition firing pattern in a southeastern pine forest. Bottom: Graphic illustration of the same effects based on a preliminary FIRETEC simulation of distributed aerial ignitions. The image illustrates the influence of the fires' draw on one another, resulting in some fires spreading nearly perpendicular to the ambient left-to-right wind. Photo: William Bollfrass, USDA Forest Service.*

Agronomique, have contributed inkind support for the advancement and application of this tool.

Modeling the Essence

Although FIRETEC's modeling capabilities are impressive, fire behavior results from many ever-changing, interactive, and very complex physical processes. Fire behavior is sensitive to both averages and fluctuations of numerous environmental conditions.

However, FIRETEC is based on the assumption that you can model the essence of wildland fire behavior and predict the important characteristics of fire behavior without knowing all of the fine-scale details of winds (timing, duration, and spatial arrangement of gusts) and fuels (location, shape, and orientation of individual needles or branches.) Accordingly, the details of FIRETEC fire behavior simulations will not match the fine-scale details of an experimental burn, but they accurately represent macroscale fire behavior and atmospheric response.

In layman's terms: no model is perfect, but FIRETEC is proving to be robust. It captures the general phenomenology, intensity, and spread rates from highly instrumented experimental burns (fig. 3).

Seed Project

In 2011, Eglin Air Force Base funded an exploratory FIRETEC effort addressing aspects of prescribed fire ignition techniques in southern pine forests (figs. 3, 4). This early "seed project" provided the proof of concept and confidence that led to the ESTCP project exploring the implications and phenomenology associated with a range of prescribed fire conditions and ignition strategies in southern pine.

LANL worked with fire managers from Eglin Air Force Base to address specific "burning questions," fill knowledge gaps, and provide teaching tools for current and future fire managers.

The project leverages data from the RxCADRE experimental burns on Eglin Air Force Base, which represent some of the most heavily instrumented fires in history.

Currently in progress, the project will be described in more detail in terms of its design, results, and

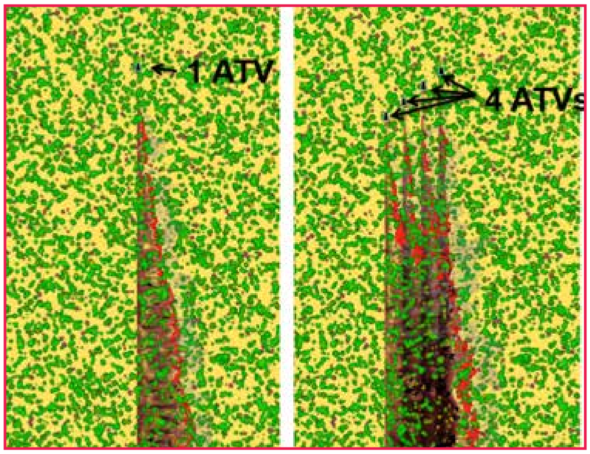

Figure 4—*Proof-of-concept prescribed fire simulations from the seed project sponsored by Eglin Air Force Base in southern pine forests. In these FIRETEC simulations, the image on the left represents a single ignition line by an all-terrain vehicle (ATV). The image on the right represents four simultaneous ATV ignition lines with the same elapsed time as the image on the left. Wind is blowing from left to right. The additional upwind strip ignitions in the image on the right decreased the downwind spread rate from 80 m to 44 m compared to a single strip, but the interactions between the lines produced intense burning in some areas, as indicated by the charred canopy (black coloration). These phenomena are commonly observed on the fireline.*

implications in future issues of *Fire Management Today*. To view a webinar on the project hosted by Southern Fire Exchange, go to https://www.youtube.com/watch?v=TOrkny2ILik&feature=youtube.

Platform for Learning

Since its inception in 1995, FIRETEC has demonstrated impressive capabilities for capturing fire behavior and phenomenology for a wide range of wildland fire scenarios. Although FIRETEC's computational and data requirements preclude its use by fire managers for developing individual prescribed fire plans or incident action plans, FIRETEC provides a powerful platform for learning as well as a glimpse into the potential capabilities of next-generation operational fire models.

This article is the first in a three-part series. The next two articles will delve more deeply into the design, objectives, and results from the ongoing ESTCP project, with particular emphasis on its implications and its utility for wildland fire managers. ■

Acknowledgments

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EXCESS FEDERAL EQUIPMENT BUILDS FIREFIGHTING CAPACITY IN OREGON

Michael McKeen

Through Federal programs dating to 1956, the Oregon Department of Forestry acquires excess Federal equipment and transfers it to State fire protection districts, rangeland associations, forest protective associations, and local fire districts. The property passes through the Forest Service's Federal Excess Personal Property (FEPP) program and through the Fire Fighter Program (FFP) administered by the Oregon Department of Forestry. Local fire organizations across Oregon receive the equipment in exchange for the cost of shipping and a small State administrative fee.

> The Oregon Department of Forestry has placed almost 40 truck tractors converted into water tenders with local fire organizations across Oregon.

A good example is a water tender built from an excess military 6-by-6 truck tractor (fig. 1), originally from the U.S. Department of Defense. This particular $166,000 Freightliner Truck Tractor went to the North Douglas Rural Fire Department for about $1,200; the fire department then paid for modifying the military tractor into fire equipment. Through the FFP, the Oregon Department of Forestry has placed almost 40 such trucks with local fire organizations across Oregon. All will eventually be owned by the units that operate them, as long as the units comply with program agreements.

The tender in figure 1 is refilling a type 4 wildland fire engine on loan through the FEPP program. After serving the Forest Service for years, such engines are made available to local fire departments through FEPP for the serviceable life of the equipment. When the equipment is no longer serviceable, it is sold at auction, with the proceeds returned to the Federal Treasury.

Figure 2 shows an example of a converted M916A3 military truck tractor, this one operated by the Medical Spring Rural Fire Department. No doubt the best part of these trucks' service is for the taxpayer. Medical Springs is a small rural fire department that got an additional grant to modify this truck into a tender. Very likely, the tender will remain in service to the community for the next 20 years.

Figure 1—*A water tender refilling a wildland fire engine on an incident. Both pieces of equipment were acquired through Federal surplus equipment programs. Photo: Oregon Department of Forestry.*

Michael McKeen is the Oregon Federal Property coordinator for the Oregon Department of Forestry, Salem, OR.

Figure 2—*A water tender converted from a military truck tractor through a Federal surplus equipment program. Photo: Oregon Department of Forestry.*

Figure 3—*With a smaller water tank, a modified surplus military truck can pull a dozer. Photo: Oregon Department of Forestry.*

Figure 4—*An original military Freightliner Truck Tractor next to a truck modified as a water tender. Photo: Oregon Department of Forestry.*

The Sweethome Unit of the Oregon Department of Forestry modified one of the same excess military trucks by adding a smaller water tank (fig. 3). The smaller tank allows the truck to pull the unit's dozer for suppression support, freeing up a wildland fire engine to remain on the fireline.

Figure 4 shows a Freightline Truck Tractor before and after modification. In this case, the tender belongs to the Illinois Valley Rural Fire Department operating from Cave Junction in southern Oregon. The department has six stations, and it has built a truck called "The Beast," with another truck called "The Beauty" in construction.

These truck tractors are only one example of how Federal, State, and local partners are working together through FEPP and FFP to strengthen the "militia," the frontline initial response organizations throughout Oregon. A new concept in rural fire protection involves the rangeland associations throughout eastern Oregon. The associations depend on excess military equipment modified for rangeland protection.

Figure 5 shows the fleet of the Silver Creek Rangeland Fire Association, with Humvees converted into type 6 engines and a cargo truck converted into a water tender. The association also has statically placed tanks of water as well as large D7G bulldozers. The rangeland fire associations have successfully used such equipment in working for rural fire protection with the Oregon Department of Forestry, the Bureau of Land Management, and the Forest Service.

Since 2014, the Oregon Department of Forestry, through FEPP and FFP, has distributed type 1, type 4, and type 6 engines, along with dozers, pumps, generators, tankers, trailers, Humvees, and every other imaginable type of military vehicle. The equipment has had a total value of $7 million to $9 million per year. Through FEPP and FFP, Federal excess equipment goes to help local communities mitigate wildland fire danger across the State. ■

Figure 5—*Fleet of the Silver Creek Rangeland Fire Association, with Humvees converted into type 6 engines and a cargo truck converted into a water tender. Photo: Oregon Department of Forestry.*

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FIRE: THE GREAT FOREST REGULATOR

Stephen W. Barrett

Editor's note: *The 2017 fires hit the West hard. Nationwide, more than 71,499 fires burned more than 10 million acres (4 million ha), mostly in the West (NIFC 2018). The area burned was larger than in any year since 1960 with only two exceptions, both within the last 12 years: 2006 and 2015.*

The Northern Rockies were hit especially hard. In 2017, about 3,900 fires burned almost 1.5 million acres (0.6 million ha) (NICC 2018a). More acres burned in the Northern Rockies than in any year since 1999, almost three times the 10-year average reported in 2016 (NICC 2018b).

What is going on? Here's a scientific perspective on the 2017 fires.

Some have wondered whether the 2017 Montana fire season was a rare apocalypse or whether it was simply Nature being Nature. The short answer is, some of both. Today's forests clearly are experiencing a highly active fire period, one of many during the past several thousand years. And while many of the fires were natural, some occurred outside the historical range of variation.

Like it or not, fire is the Great Forest Regulator in the West. Nothing controls and rejuvenates forests like large wildfires—not insects, not diseases, not windstorms. That's why researchers have coined such terms as "fire-dependent forests" and "disturbance-adapted ecosystems."

Steve Barrett is a consulting fire ecologist who has studied fire history in many parts of the Northern Rockies, including in Waterton–Glacier and Yellowstone National Parks.

The Sperry Chalet in Glacier National Park being destroyed by the Sprague Fire in 2017. Source: Inciweb (2017); photo: National Park Service.

Since about 1980, the Northern Rockies and the West in general have been experiencing another highly active fire period.

And no, fires generally don't devastate wildlife because native fauna can readily walk, run, burrow, fly, or otherwise escape from most wildfires.

Numerous studies during the past 4 decades provide important perspective about Northern Rockies fire history. In addition to lightning fires, fires often were ignited by American Indians to improve wildlife habitat and for many other reasons. In northwestern Montana's Flathead Basin, for example, tree ring and fire scar samples show that fires were widespread in the early to mid-1700s. Presumably, the valleys were often choked with smoke, but lush forests regenerated in the aftermath. In fact, many of today's remnant old-growth stands regenerated during that time and persisted until succumbing to fires or to logging some 2 centuries later. Today, less than 10 percent of the region's old-growth forest remains.

Speaking of old growth, most stands burned in 2017 by Glacier National Park's Sprague Fire (which also destroyed the venerable Sperry

Chalet) were between about 300 to 500 years old. So, statistically speaking, it was simply their time to be recycled by the Great Forest Regulator.

Continuing along our fire history timeline, the active fire period in the 1700s was followed by generally low fire activity during the cool, moist peak of the Little Ice Age in the early to mid-1800s. Then a warming trend between the late 1800s and early 1900s spawned large fires once again, with major fire years in 1889, 1910, 1919, 1929, and 1936. As before, the lush ecosystems that regenerated in the aftermath formed some of the best wildlife habitat in the West.

Subsequently, few fires occurred between about 1940 and 1980. Interestingly, that generally cool-moist period coincided with increasingly effective firefighting technology and know-how within the Forest Service and other land management agencies.

Now comes the modern era. Since about 1980, the Northern Rockies and the West in general have been experiencing another highly active fire period. And there's really no end in sight, especially considering current climatic trends.

So what to do about the so-called fire problem?

Forest fires will continue to be intractable and unnecessarily destructive if we refuse to become a fire-adapted society. Given the vast amount of fire-prone and relatively inaccessible terrain in the West—including in national parks and wilderness areas—removing trees simply isn't going to work in parks and wilderness. A mix of creative management strategies that include logging, prescribed fire, and fuel manipulation in and near wildland–urban interface areas would help promote society's transition to fire adaptation. ■

Forest fires will continue to manage us if we refuse to become a fire-adapted society.

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BATTLE OF SAN PASQUAL STAFF RIDE*

Rex Hambly

The "Californio" marksman, a citizen of the Republic of Mexico, waited patiently in the cold, damp morning air. His hands were stiff, but his focus was lightning hot. He heard someone yell *"Charge!"* in the distance.

Long before any of the 12 advancing American dragoons (cavalry) ever saw him, he raised his rifle and pulled the trigger. The bullet hit Captain Johnston squarely between the eyes, killing him instantly. Chaos immediately descended upon the American dragoons as they were outmaneuvered by their adversary.

This initial bout of confusion set the operational tempo for the entire Battle of San Pasqual.

Charles Waterhouse, Battle of San Pasquale. This painting, by a colonel in the U.S. Marine Corps Reserves, shows a scene from the battle, which took place in 1846 near Escondido, CA. Source: Marine Corps Recruit Depot Command Museum.

The battle took place in 1846, just outside of present-day Escondido, CA. Historians often refer to this fight as the bloodiest battle to ever take place on Californian soil. This battle's unintended outcome has valuable lessons to offer the wildland fire service as a learning culture.

Warning Order

It is once again a cool morning, this time in early April 2017—171 years later. We are on the same ground where the Battle of San Pasqual was fought between U.S. forces and the Californios of the Republic of Mexico. Fifty men and women—representing local fire staff, U.S. Marines, and the Rio Hondo Wildland Fire Academy—have come together to explore the lessons from this historic battle.

The day begins when historian and retired U.S. Marine Colonel Stan Smith delivers his historically accurate and very intense "Warning Order" (fig. 1). Wearing full battle dress from 1846, he quickly grabs the participants' attention:

> Mounted troops of Pico's rebellion have encamped and taken up positions in the eastern portion of this valley with the intent of attacking and destroying coalition forces of the American Republic, now in armed conflict with the Californios/Republic of Mexico.
>
> You are to reconnoiter as to exact location of enemy forces and perform action using advantages of terrain and nighttime operations to beat up the enemy camp, so as to achieve capitulation—while minimizing casualties to the extent possible.

This battle's unintended outcome has valuable lessons to offer the wildland fire service as a learning culture.

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* The piece is adapted from a blog on the website maintained by the Wildland Fire Lessons Learned Center.

Figure 1—*Staff ride participants listen to U.S. Marine Colonel Stan Smith. Photo: Rex Hambly, U.S. Fish and Wildlife Service.*

> They have the capability of eliminating U.S. forces available for action, given their ability to exercise superior local firepower and maneuverability. They can reinforce with organic and out-of-theater assets.

First Stand: Decision Rock

The first stand on the Battle of San Pasqual Staff Ride is Decision Rock. This granite promontory is located in a narrow canyon, just above the battlefield where General Steven W. Kearny, the U.S. Military Governor of New Mexico, likely delivered his "leader's intent" to the highly skilled yet ill-fated American dragoons.

General Kearny's intent had tremendous tactical significance. He wished Johnston's 12 dragoons to initiate a controlled tempo of engagement, giving time for reinforcements to get into place. It also marked the "decision point" to engage the enemy.

Staff ride participants hike to Decision Rock. Photo: Rex Hambly, U.S. Fish and Wildlife Service.

One staff ride participant later compared it to the decision by the Granite Mountain Hotshots on the 2013 Yarnell Hill Fire to leave the relative safety of the burned ridgetop and descend toward the ranch house. Today, of course, with the benefit of hindsight, we have the luxury of knowing the outcomes for both the Granite Mountain Hotshots and Johnston's dragoons.

Similarities Between Firefighting and Warfighting

At this point during the staff ride, Sergeant Dan Bothwell, a U.S. Marine Scout Sniper Instructor, starts to inform the staff ride participants about modes of decisionmaking, rules of engagement, and combat effectiveness (fig. 2). He relates this historic battle to modern-day wildland firefighting. We learn that

Figure 2—*Sergeant and Sniper Instructor Bothwell talks about modes of decisionmaking. Photo: Rex Hambly, U.S. Fish and Wildlife Service*

in both firefighting and warfighting, the enemy can often outperform our expectations.

After several hours of spirited discussion at Decision Rock, we move across the valley to the site of the actual engagement. Colonel Smith now leads a discussion on how to value and prioritize military objectives—which we relate to creating firefighting objectives.

Sergeant Bothwell talks about egress planning and how a single casualty can completely alter the outcome of a mission.

Tactical Exercise

The staff ride concludes with a brief tactical exercise held in a dry riverbed. We are all given explicit instructions to perform a very specific task. When a target of opportunity suddenly arises, we must make a split-second decision: follow previous instructions or seize a novel opportunity—just like Captain Johnston did 171 years ago, when he saw two enemy sentries in the early morning fog and gave the order to charge.

Of course, there are no lances, swords, or guns among us, but it is a great chance to test the ideas and concepts that we had studied throughout that day. As the staff ride formally concludes, fire cadets and staff leave the battlefield with a newfound understanding of these historical events—and their relevancy today.

Lingering Questions

Any profound experience will always include followup questions. There is no shortage of such questions as participants say their goodbyes in the parking lot that day.

“What would you have done?”

“Would you charge given the same set of circumstances?”

“Was Captain Johnston using analytical or recognition-based decisionmaking?”

“What would you do if the command structure broke down in your unit?”

Sometimes, a question can be the best answer. On this day and in the future, we can apply the new questions and lessons learned from the Battle of San Pasqual to our upcoming operations—both on wildland fires and on all-risk incidents. ■

THE "FOREST CIRCUS" RECONSIDERED

Kerry Greene and Hylah Jacques

Ever hear the Forest Service called the "Forest Circus"?

Calling something a circus usually paints a picture of disorganization and chaos. The impression is misleading because both the circus and the Forest Service can teach a lot about discipline, physical fitness/literacy, logistics, and teamwork.

And that is also true for the Forest Service's wildland fire organization.

The circus originated in Europe. In European cities, the term "circus" referred to a physical building; in most cities, it was a permanent structure where the public could go to view circus acts, much like a theater for drama or a concert hall for music.

Etching of John Bill Ricketts as "The Equestrian Hero," circa 1796. In 1792, Scottish trick rider John Bill Ricketts settled in Philadelphia and opened an equestrian academy. The next year, he staged the new Nation's first complete circus performance in his new amphitheater at 12th and Market Streets in Philadelphia. The year after this etching was made, Ricketts set sail for Europe after a fire destroyed his circus, and he was lost at sea. Source: Courtesy of the Historical Society of Pennsylvania.

When it came to America, the circus morphed into a traveling show, the first of its kind. American circuses were itinerant productions. They traveled to widely scattered population centers, as opposed to the public traveling to central locations to see them.

Before railroads, circuses were moved by horses, and they were primarily centered around horses and displays of horsemanship. The circus is steeped in a strong equestrian history. The size of a traditional circus ring is based on the circumference that a horse can turn comfortably at speed (42 feet (13 meters)). Many of the great ringmasters in the early American circus were great horsemen and had strong ties with the great equestrians of the day, beginning with our Nation's most distinguished and popular horseman. George Washington is known to have had a strong friendship with and admiration for John Bill Ricketts (1769–1800), the Father of the American Circus.

With the arrival of railroads, American circuses became expert at moving and supporting performers and crew as they traveled across the country, setting up highly functional and efficient tent cities wherever they went. The American military followed the circus, studying its logistics. During World War I, the Germans got their ideas for rolling field kitchens and loading equipment lengthwise on railroad flatcars from Buffalo Bill's Wild West, which toured Germany in 1891, and from Barnum and Bailey's Circus, which toured Germany and Austria-Hungary in 1900–01.

Much like the tent cities that spring up around project fires, it takes an entire team of support personnel to make the circus happen. There are tent masters, cooks, riggers, coaches,

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> Consider the ways in which circus performers and wildland firefighters are alike.

The Flying Wallendas perform their high wire act on the National Mall in July 2017. From left to right: son Alex, eldest daughter Alida, son-in-law Robin Cortes, grandson Lukas, patriarch Tino, and daughters Aurelia and Andrea. Photo: Kerry Greene, USDA Forest Service.

and costume makers, not unlike the support personnel who travel with an incident management team. Today, the Forest Service is routinely consulted as the lead agency in the development of the Incident Management System for emergency response, with logistics as a key function.

And that's not all that the circus has in common with the wildland fire organization. Consider the ways in which circus performers and wildland firefighters are alike. For example, it takes great physical fitness and discipline in both professions. Circus performers train for hours each day, rehearsing routines with their teams and training their bodies and minds so they are in top shape to execute daring feats.

Sound familiar?

It's also worth mentioning that the element of danger is very real in both worlds. As a firefighter, you depend on your team as if your life depends on it, because it does. The type of risk and danger you face and the mettle you need are unique to a handful of professions, among them firefighting, the military, the police, and the circus.

Your crew is your family away from home and in many regards knows you in more intimate and challenging ways than your kin. I think the same can be said for a team of aerialists or high-wire walkers. Their very lives hang in the balance of physical training, good communication, and a preternatural understanding of the task at hand, risks involved, and strengths and weaknesses of their team members.

It's true that many circus acts, such as the Flying Wallendas high-wire act, are a family legacy. Many performers are literally born into the circus and carry on the family traditions and way of life. That's not far off the mark for many Forest Service or firefighter legacies we find in our own families.

So next time you hear someone say "Forest Circus," consider it a compliment. Both traditions are steeped in excellence, life-on-the-road logistics, physical fitness, and teamwork—and that's something to be proud of. ■

One of the authors in clown attire as EDITH the Fire Clown. Her interest in clowning and circus arts has strengthened over the years through her work with Fire PALS in California's Siskiyou County. Fire PALS comprises interagency fire and emergency response professionals who bring life and fire safety messages through characterization, clowning, and puppetry to children throughout Siskiyou County. Photo: Kerry Greene, USDA Forest Service.

SMOKE EXPOSURE

6 Minutes for Safety

Exposure to smoke during fire operations can be a safety concern. Research has shown that smoke exposure on prescribed fires, especially in the holding and ignition positions, often exceeds that on wildfires. There are many precautions that can be taken to reduce personnel from exposure to smoke.

***Editor's note:** The piece is adapted from 6 Minutes for Safety, a program and website managed by the 6 Minutes for Safety Subcommittee under the guidance of the NWCG Risk Management Committee.*

Planning

Smoke exposure needs to be considered when planning suppression tactics and prescribed fires. Simple actions can mitigate smoke exposures, such as:

- Altering line locations, which can reduce smoke exposure.
- Placing firelines in areas of lighter fuels or moving lines to roads or other barriers that will require less holding, patrol, and mopup, thereby reducing smoke exposure for personnel.
- Using flanking attack as opposed to head attack (where appropriate) in heavy smoke situations.
- Checking fire behavior forecasts for smoke and inversion potential.
- In heavy smoke, giving up acres to gain control.

Implementation

Many techniques can help reduce the exposure of personnel to heavy smoke, such as:

- Rotating people out of the heaviest smoke area, possibly the single most effective method.
- Locating camps and incident command posts in areas that are not prone to inversions.
- Minimizing snag falling, consistent with safety concerns, to avoid putting heavy fuels on the ground that will require mopup.
- Changing firing patterns and preburning (blacklining) during less severe conditions, thereby reducing exposure to smoke.
- Using retardant, foam, or sprinklers, thereby reducing the workload and exposure time for holding crews. ■

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.

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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.

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

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