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Treating Fuels and Using Wildfire at Scale

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On the Cover:

Laura Spellman, a member of the Redding Interagency Hotshot Crew, uses a drip torch as part of a burnout operation on the 2018 Mendocino Complex Fire on the Mendocino National Forest in California. USDA Forest Service photo by Cecilio Ricardo.

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Firefighter and public safety is our first priority.

GUIDELINES
for Contributors

Increasing the Use of Planned and Unplanned Ignitions

Prescribed fire on the Flathead National Forest, part of the Southwestern Crown of the Continent Project. USDA Forest Service photo.

By Hutch Brown

This issue of *Fire Management Today* focuses on the future of wildland fire management in the United States. Forest Service staff and partners offer their perspectives on how land managers will successfully manage wildland fire in the coming years. The issue closes with a guest article by author Stephen Pyne, who suggests that "the sum of anthropogenic fire practices" has replaced the Pleistocene Epoch of ice with an epoch of fire.

For the past 20 to 30 years, a wildfire crisis has been building in the West as wildfires have grown in size, duration, and destructivity despite highly effective suppression responses by the USDA Forest Service and others in the wildland fire community. In response, Federal land managers have carried out fuels and forest health treatments on a rising scale, yet treatment levels have not kept pace with the rising scale of wildfire risk (Ager and others 2021a). Recognizing the mismatch, Forest Service scientists devised a national Fireshed Registry to model the way that ignitions burn across broad landscapes and expose homes and other buildings to wildfire (Ager and others 2021b).

CONFRONTING THE WILDFIRE CRISIS

In January 2022, based on the Fireshed Registry and other cutting-edge tools and technologies (Ager and others 2021c), Forest Service Chief Randy Moore joined Agriculture Secretary Tom Vilsack in releasing the Wildfire Crisis Strategy to reduce wildfire risk (see the article in this issue describing the strategy). The strategy articulated the need for a new land management paradigm: stepping up the pace and scale of fuels and forest health treatments to match the scale of wildfire risk across western landscapes.

On badly overgrown forested landscapes across the West, part of the solution is to restore a semblance of the original fire-adapted landscape in three steps:

1. Using mechanical means to reduce the forest to something approaching historical stocking levels;
2. Using prescribed fire to further reduce fuels (such as through pile burns) and to reintroduce fire effects into the system; and
3. Using planned and unplanned ignitions, repeated at suitable intervals over time, to re-create a patchy fire-adapted landscape.

In the past, Congress has funded the corresponding fuels and forest health treatments on the national forests and grasslands through annual appropriations alone. In fiscal

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year 2020, for example, the actual appropriation for the hazardous fuels budget line item, according to the Forest Service's latest budget justification, was about $445 million. However, research suggests that far greater areas need to be treated just to keep pace with rising wildfire risk (Ager and others 2021b, 2021c).

NEW FUNDING SOURCES

In November 2021, Congress passed the Infrastructure Investment and Jobs Act, better known as the Bipartisan Infrastructure Law. The legislation invested about $5.5 billion in natural-resources-related infrastructure, including a 5-year investment of about $3 billion in restoring ecosystems and reducing wildfire risk. The Forest Service worked with Tribes and partners to select 10 landscapes for initial investments using funding under the Bipartisan Infrastructure Law. In April 2022, the Forest Service announced that the 10 western landscapes would receive an initial investment of $131 million in fiscal year 2022. In late 2022, the Forest Service released an update showing progress made in the initial 10 project areas.

> **For the past 20 to 30 years, a wildfire crisis has been building in the West.**

In August 2022, President Joe Biden signed the Inflation Reduction Act into law. The act made $5 billion in additional funding available to the Forest Service over 10 years, including $2 billion for fuels and vegetation treatments on the national forests and grasslands. In late 2022, the Forest Service selected an additional 11 western landscapes for fuels and forest health treatments through funding under the Inflation Reduction Act. Through both sets of new legislation, Congress has increased funding for fuels and forest health treatments in firesheds and high-risk areas across the West.

REINTRODUCING FIRE INTO FIRE-ADAPTED LANDSCAPES

Now it's time to deliver. Implementation of the Wildfire Crisis Strategy hinges on safely and effectively reintroducing wildland fire into fire-adapted landscapes at scale. To succeed, land managers must be able to operate within a cultural and institutional framework that is conducive to the use of wildland fire at the scale of large landscapes across the West. The articles in this issue focusing on the use of planned and unplanned ignitions show what needs to be done.

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The Evolution of Cross-Boundary Fuels Treatments

Jennifer Croft

Looking back at the events that have shaped Federal fire policy, it is fair to say that large fire events are reactive change agents. There has always been conflict between managing the ecological function of ecosystems and protecting life and property. The additional influences of global warming, species migration, extended droughts, and urban sprawl into the wildland environment have amplified the need for change in how land managers balance the human dimension with science.

The evolution of cross-boundary fuels treatments starts with Indigenous burning knowledge. Tribal peoples have always used landscape-level burning practices to manage, protect, and relate to their surroundings, a keystone element of Indigenous culture. Pioneer expansion into the West changed the role of fire across western landscapes by creating additional boundaries, limitations, and fear of fire in general (see the sidebar, “Evolution of Cross-Boundary Fuels Treatments Timeline”).

Prescribed fire in ponderosa pine, part of the Kootenai Valley Resource Initiative Project on the Idaho Panhandle National Forests. USDA Forest Service photo.

Jen Croft is an applied fire ecologist for the Forest Service, Fire and Aviation Management, Washington Office, Washington, DC.

Evolution of Cross-Boundary Fuels Treatments Timeline

1871–Peshtigo Fire

Protecting Timber Supply

Pioneer expansion replaces cultural burning by Tribes. Peshtigo Fire (1871)—2,500 fatalities, 1.2 million acres (0.5 million ha) burned. With insufficient resources to suppress all fires, the emphasis is on protecting communities, timber, and other resources. Backcountry fires are ignored.

1905–1930

Prevent and Protect Era

Big Burn (1910)—89 fatalities, 3 million acres (1.2 million ha) burned. Forest rangers establish fire suppression protocols, focusing on community protection and suppressing backcountry fires when possible. Tribal burning practices are limited to Indian reservations.

1930–1970

Fuel Breaks, 10 a.m. Policy, Smokey Bear

Civilian Conservation Corps gives fire managers the capacity to construct access roads and fuel breaks and to suppress large fires. Policy set to suppress all fires by 10 a.m. next morning. Smokey Bear campaign begins.

1970–1990

Backcountry Fire Use, Yellowstone Fires

Natural ignitions in national parks and wilderness areas are allowed to play their historical role in fire-dependent ecosystems. The ensuing spread of some large fires in Rocky Mountain and Yellowstone National Parks undercuts public support.

1990–2014

NFP, WUI, SPLATs, Federal Fire Policy

The 2000 fire year—fuel buildups lead to extreme fire behavior across large areas. The National Fire Plan (NFP) resets Federal fire policy, mobilizing more resources and fuels treatments to protect the wildland-urban interface (WUI). Land managers begin strategically placed landscape area treatments (SPLATs).

2014–2021

Cohesive Strategy, Shared Stewardship, PODs, QWRAs

The wildland fire community adopts a National Cohesive Wildland Fire Management Strategy of learning to live with wildland fire, in part through cross-boundary treatments to restore fire-dependent landscapes under Shared Stewardship agreements. Fire managers use potential operational delineations (PODs) and qualified wildfire risk assessments (QWRAs) to improve suppression success.

2022

WCS, Fireshed Registry, Equity, Climate

The Forest Service launches a Wildfire Crisis Strategy (WCS) to work with partners across shared landscapes to reduce wildfire risk to communities, watersheds, and other values. A new Fireshed Registry identifies landscapes with the highest potential for wildfire and associated risks. The strategy and registry incorporate census and environmental data to ensure that communities are supported equitably and landscapes are evaluated for climatic changes.

WAR ON WILDFIRE

Following great fatality fires, such as Peshtigo (1871), the Big Burn (1910), Cloquet (1918), Tillamook (1933), and Mann Gulch (1949), support for using wildland fire as a management tool diminished. Smokey Bear (launched in 1944) and the "10 a.m. Policy" (1935–1978) gave America the mindset of being at war with wildfire, and the practice of using fire became part of a war of wildland fire suppression.

Decades of suppression led to an increase in fuel loadings, a decrease in ecosystem diversity, and the emergence of large-scale insect and disease issues. Such adverse impacts reminded land managers of the role of wildland fire in fire-dependent ecosystems, a role that Indigenous people had understood all along: wildland fire is not our enemy. As the fire ecologist E.V. Komarek noted, **"The Earth, born in fire, baptized by lightning since before life's beginning, has been and is a fire planet."**

EVOLVING APPROACHES

Federal fire managers in the 1970s recognized a need to reduce stand densities, restore the role of wildland fire in fire-dependent ecosystems, and increase the use of fuel breaks to support suppression efforts. The initial paradigm focused on stand-level treatments, cleanup after timber sales, and wildland fire use in wilderness areas.

However, fear of free-ranging fires in wilderness and perceptions that the Government was "letting fires burn" without any intervention soon restricted the ability of land managers to use prescribed fire across landownership boundaries. The effects of the Ouzel (1978) and Yellowstone (1988) Fires moderated public support for allowing wildland fire in national parks and wilderness areas. Loss of life and property on the South Canyon (1994), Cedar (2003), Trigo (2008), and Wallow (2011) Fires demanded a more unified approach to suppression efforts.

The 2000 fire season, with more than 7.4 million acres (3.0 million ha) burned nationwide, instigated the

Aftermath of the 2021 Bootleg Fire, Fremont-Winema National Forest, OR, showing the range in fire effects across fuels treatments. A thinning-only treatment showed moderate- to high-severity fire effects (lower third of the photo). Thinning followed by prescribed fire resulted in low fire severity (middle third of the photo). No treatment resulted in high-severity fire with pockets of stand replacement (top third of the photo). USDA Forest Service photo.

National Fire Plan, which started laying the groundwork for a more integrated wildland fire management response and collaborative mitigation planning. Fuels programs were ramped up, including prescribed burning across larger landscapes and cross-boundary projects under the Wyden Amendment.

The Wyden Amendment, part of legislation passed by Congress in 1999, allowed the Forest Service to enter into cooperative agreements with other Federal, State, Tribal, and local governments and nongovernmental entities to protect natural resources across landownership boundaries. Under the Wyden Amendment, Federal land managers were expected to collaborate with adjacent landowners, develop strategically placed fuels treatments to interrupt fire spread, and identify locations at high wildfire risk.

ECOLOGICAL DEGRADATION

The departure of conditions from historical fire regimes has resulted in abnormal wildfire intensity and severity on scales that have exceeded all expectations. Large fires used to be few and far between, and now there are multiple large fires in multiple geographic areas at the same time. Fire potential indices set new records every year.

Current fire footprints, fire behavior, and fire severity are like angry parents who have asked their children to clean up their rooms several times. Mother Nature is now using wildland fire to clean out forests in ways that far exceed fire's historical ecological role. High-severity wildfires are destroying entire watersheds, habitats, and communities in the process. The result in fire-dependent ecosystems is loss of critical habitats and diversity, increase in nonnative species, and extensive loss of life and property.

INCREASING FUELS TREATMENTS

Recognizing the need to reverse the widescale loss of ecosystems and communities, land managers are now taking collaboration to the next level, bearing in mind that fuels treatments are not designed to stop wildfires. The primary intent is to reduce fire severity, create safe conditions for suppression response, and improve safe evacuation routes for the public. Side benefits of fuels treatments include modifying fire behavior to result in favorable fire effects, creating a mosaic of species and stand densities on a landscape level, thinning trees and pruning branches, and allowing a fire to play its ecological role.

Since fire doesn't stop at national forest boundaries, fuels managers are now working across landownerships, in part to combat climate change and improve equity for communities at risk from wildfire. Shared Stewardship agreements, initiated in 2018, build on the National Cohesive Wildland Fire Management Strategy finalized in 2014. The strategy dovetails with initiatives like the Joint Chiefs' Landscape Restoration Partnership, Collaborative Forest Landscape Restoration Program, Tribal Forest Protection Act, and Good Neighbor Authority.

AN ALL-LANDS APPROACH

The era of working across all lands, including private lands, and formulating a joint prioritization process with State foresters, Tribal elders, and local communities has arrived. Forest Service Research and Development has given land managers the ability to assess conditions at multiple scales with multiple tools and to incorporate multiple perspectives. In early 2022, drawing on its expanded capacities and partnership authorities, the Forest Service launched its Wildfire Crisis Strategy to address the wildfire crisis in the West at scale.

Land managers are now tasked with increasing the pace and scale of fuels treatments on both National Forest System lands and other landownerships. Treatments will focus on "firesheds" (delineated blocks of landscapes about 250,000 acres (100,000 ha) in size that are evaluated for the potential fire effects to life, property, and resources) across Federal, State, Tribal, and private lands landscapes with communities, watersheds, and other values at risk. All treatments will be based on partnerships to restore resilient landscapes and improve partner capacity, taking the effects of a changing climate into account.

Agency leaders, community members, and key stakeholders will strive to steward the whole across all lands. The new paradigm will be based on sharing knowledge, capacity, and long-term planning among practitioners, stakeholders, and policymakers. Planning will include underserved communities; communities at risk; and State, Tribal, nongovernmental entities, and private landowners. Working with partners, land managers will have opportunities to overcome traditional constraints like funding and capacity. Land managers will be expected to look beyond fence lines, manage for ecosystem resilience rather than historical ecosystems, and build on joint capabilities instead of operating in agency silos.

DYNAMIC NEW ERA

As Federal land managers move into this dynamic new era, I would encourage all of us to look at the past developments that landed us here and change the way we respond to fire across the landscape. Change is always scary, but we are now living in a fire-dominated environment. We need to accept such tradeoffs as enduring a few weeks of prescribed fire, thinning forests for ecological rather than economic values, and expanding the scale of our treatments across boundaries. If we don't, Mother Nature will take care of it on her own terms.

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Area of ponderosa pine treated to reduce fuels and restore forest health and resilience near South Lake Tahoe, CA. USDA Forest Service photo by Cecilio Ricardo.

Using Wildfire to Our Advantage

Francisco (Frankie) Romero

Federal fire policy emphasizes the need to use both management-ignited prescribed fire and naturally occurring wildfires to our advantage—that is, to produce more favorable land management and public safety outcomes. The scientific literature overwhelmingly supports the idea of using wildfires to our advantage whenever opportunities arise, but the social and political aspects of our wildland fire response make the use of wildfire much harder in practice than in theory. A short video, Understanding the Fire Paradox: Why We Need Fire To Prevent Fire, offers a great discussion of the friction between opposing views of fire as either adversary or ally.

WILDFIRE CRISIS STRATEGY

The Forest Service has launched a Wildfire Crisis Strategy to confront the growing threats from wildfire. At the heart of the strategy is improving the resilience of America's forests by:

- Reducing hazardous fuel accumulations on 20 million acres (8 million ha) of National Forest System (NFS) lands;
- Helping partners treat 30 million acres (12 million ha) across non-NFS lands; and
- Maintaining reduced fuel loads beyond the 10 years.

Frankie Romero is the fire use program manager for the Forest Service, Fire and Aviation Management, Washington Office, Washington, DC.

The treatments will make wildfire response safer and more effective, communities more fire adapted and better able to withstand wildfire, and landscapes more resilient and better able to withstand and recover from wildfire.

The Wildfire Crisis Strategy relies on mechanical thinning to help create conditions that will allow us to introduce the use of prescribed fire on a much larger scale than ever before. Although thinning and prescribed fire are the foundation of our strategy, our long-term plan for success also depends on using naturally occurring wildfires as a resource management tool. Figure 1 illustrates our ambitious goal of reducing wildfire risk by increasing the pace and scale of fuels treatments across the NFS, including managed wildfire burning in a beneficial fashion—that is, in a way that is characteristic for fire-adapted forest types such as ponderosa pine.

Across the NFS, about 2 million acres (800,000 ha) burn each year, a number that has been steadily rising over the last 20 years. Postfire evaluations of fires started by lightning indicate that about 500,000 acres (200,000 ha) burn on average each year in a characteristic way, helping to maintain healthy, resilient forest conditions (fig. 1). As we approach our goal of treating an additional 20 million acres (8 million ha) of national forest land over the next 10 years, we can expect wildfires to increasingly burn across landscapes with improved fuel conditions, so a growing proportion of the 2 million acres (800,000 ha) burned by wildfire annually will show favorable fire effects. The improved conditions created by wildfires will increase our annual accomplishment of "activity acres"—areas in a preferred condition for tempering wildfire risk through regulating the quantity and structure of flammable vegetation.

IT COMES DOWN TO TRUST

Getting the landscape into physical condition to accept wildfire is one thing. An entirely different challenge is building the community support and political will needed to expand both prescribed fire and our use of wildfire to reduce future wildfire risk.

In using naturally ignited wildfires to reduce fuels, we often refer to "social license" to mean a community's willingness to accept a higher level of short-term risk in exchange for reduced wildfire risks in the longer term. Stated simply, what we are talking about is earning people's trust. Here is a partial list of the factors that stakeholders might consider in evaluating whether to trust the wildland fire community to act in their best interest in using wildfire to our advantage when conditions allow:

- Are we selective in how and when we chose to use this tool, or do we just come across as flame-happy firebugs?
- Have we conducted a thorough scientific analysis, and do we understand where and when using the tool is prudent as well as where and when it is not?
- Are the security and other benefits we expect to gain from using wildfire worth the associated risks and costs as compared to not using wildfire to our advantage?
- Will we adhere to parameters and constraints developed by rigorous planning and analysis, or do we have a tendency to just "wing it"?
- Are our actions predictable, or do we tend to surprise people and catch them off guard?

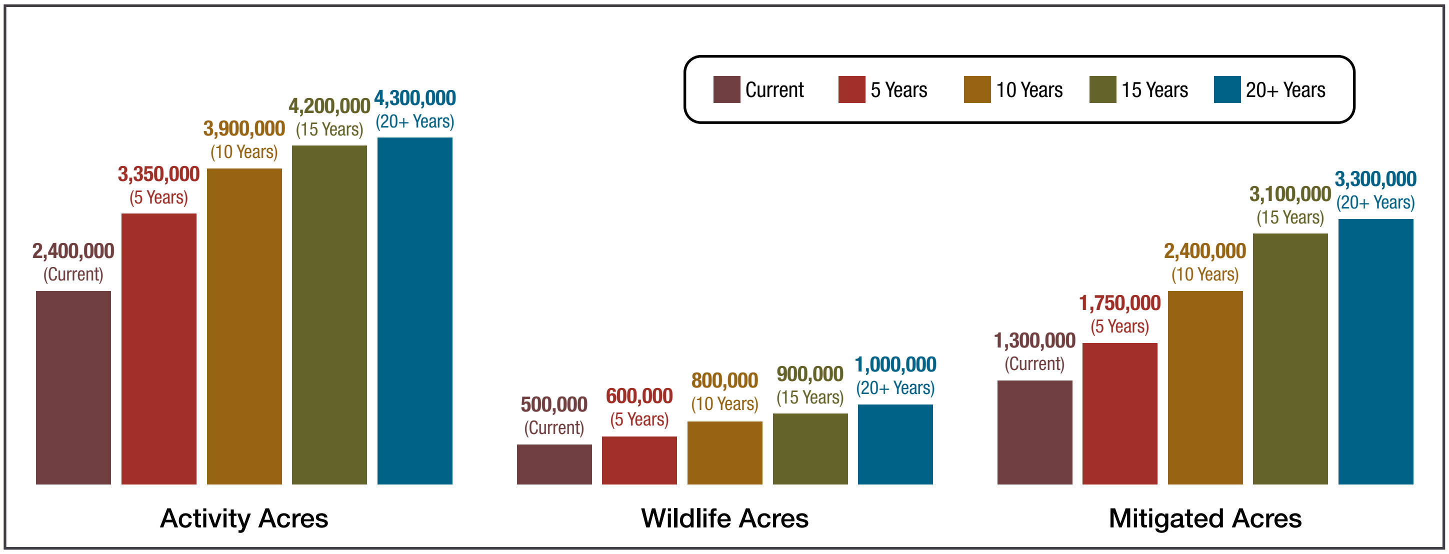

Figure 1—*Trajectory of rising fuels and forest health treatments produced annually to achieve the goal of creating and maintaining an inventory of 30 million mitigated acres (12 million ha) over 20-plus years. Activity acres reflect the individual actions taken by managers to improve fuel conditions, such as mechanical thinning and prescribed fire. Mitigated acres reflect areas in their preferred condition to receive wildfire; it can take three or more activity acres (for example, thinning, then piling and burning, followed by broadcast burning) to produce a single mitigated acre. Wildfire acres reflect wildfires that burn in a characteristic fashion, which contributes to mitigated acres; at present, the combination of 2.4 million acres (1 million ha) of management activity with about 500,000 acres (200,000 ha) of favorable wildfire effects results in about 1.3 million mitigated acres that contribute to the 30-million-acre (12-million-ha) goal.*

ARE WE SELECTIVE IN USING WILDFIRE?

One of the most important steps in garnering public support is to put forth a credible plan. The plan should define where and when we might use wildfire to future advantage. The plan should also name the places and conditions under which the opportunities are too few or the consequences of failure too great to attempt to use wildfire to our advantage.

To have these conversations with our partners and stakeholders, we need to create a common understanding of the situation, and a map is a good place to start. National and regional wildfire risk products are already available, such as Wildfire Hazard Potential, Wildfire Risk to Communities, Firesheds and the Fireshed Registry, and more. Planning processes such as quantitative wildfire risk assessments and potential operational delineations are especially useful in providing a focal point for partners and stakeholders to use in discussing fire danger and opportunities to intervene across the landscape.

In some cases, these mappable products require effort and expertise to produce, but we usually see easily accessible products. For example, the Map Viewer function on the Risk Management Assistance Dashboard includes useful layers, such as suppression difficulty index, potential control locations, potential operational delineations, snag hazard, and ground evacuation time, just to name a few.

Planning to use wildfire to our advantage can take time and effort, but it accomplishes two important things:

1. It illustrates the extraordinary level of wildfire risk and the pressing need to do something about it, which can become the basis for action; and
2. It demonstrates professionalism and attention to detail, improving our performance by making us better informed managers, all of which raises the level of trust: Who wouldn't want smart, competent performers working for them?

OPEN THE TOOLBOX SO EVERYONE CAN SEE INSIDE

As fire managers, we recognize the complexity of the fire environment and the variety of response options we might choose on any given fire. This complexity can make us reluctant to speculate about a specific course of action on any future fire, and in meetings and conversations we might too often say, "It depends" (without providing further clarity or examples). Many of us learned from our prescribed-fire mentors that we want the least restrictive parameters possible that will still meet the objectives, so leaving as many options open as possible is a habit we've formed because we hate to see an opportunity pass us by.

Contrast that approach to experience in congressionally designated wilderness areas, where the use of wildfire was first introduced in the 1970s. In the early days of experimenting with wildfire response options other than immediate suppression, we created plans that specified criteria under which we would or would not pursue the use of fire to achieve resource management objectives. Because the idea of using wildfires to our advantage was so novel, a necessary step in gaining trust was to establish sideboards to help show that our approach was not just "anything goes." Over the years, as the use of wildfires became more accepted and managers discovered that they might have missed opportunities to make gains, we began to view the sideboards as overly restrictive and as a barrier to success. Today, as a result, we often see a preference for minimal criteria in making decisions about selecting from among various options for wildfire response.

One downside of having an expansive window of opportunity is that others cannot judge whether we are acting rationally or irrationally, which makes it harder for them to trust us. Not having an understandable plan with associated criteria makes the decision-making process appear secretive, mysterious, and obscure.

We don't have to create plans with inflexible thresholds that require specific actions even if they make no sense. But if we fail to provide insight into the process managers use and the considerations they take into account, then trust will falter. If someone is

The Camillo Fire in 2015 near Flagstaff, AZ, used by the Coconino National Forest to remove down and dead forest fuels, increased community safety and lessened the threat of severe wildfires. Andrew Hostad, fire prevention supervisor for the Flagstaff Ranger District, tests the fire's success in burning off pine litter. USDA Forest Service photo by Deborah Lee Soltesz.

holding a box with something important inside that will affect you, wouldn't you want to see for yourself what's in it?

One of the best examples of providing a clear description of all the tools in the wildfire response toolbox is the longstanding Alaska Interagency Wildland Fire Management Plan. For years, the interagency partners in Alaska have chosen every strategic option available, from using firefighting assets to quickly control the most threatening fires to protecting values such as structures but taking little or no action to control a fire's growth. The Alaska example demonstrates that we can retain a broad range of response options if we can present them in a way that makes our thought process understandable to others, building trust without limiting our options.

IT'S OKAY TO TAKE A STRIKE

Fire managers have a bias for action: we hate to see an opportunity go to waste. But we can lose trust if we jump at every opportunity without making sure that our stakeholders understand the rationale. We don't have to hit a home run on every pitch, so it's okay to take a strike once in a while in order to set ourselves up for later success.

Take the example of the 2017 Pinal Fire (see the article by Mary Lata in this issue). In 2015, a lightning fire ignited on the Tonto National Forest near Globe, AZ, under what managers thought were ideal conditions for using a wildfire to reduce future risk. But the local communities did not understand the reasons for a "box-and-burn" approach to achieve a larger fire footprint under moderate burning conditions. Rather than move ahead with the plan, the Forest Service decided to suppress the fire but highlighted it as an opportunity lost that stakeholders might not want to pass up again. In 2017, after 2 years of monthly meetings with fire chiefs, community meetings, and communication with elected officials and other interested parties, the Forest Service was able to successfully carry out the 7,500-acre (3,000-ha) Pinal Fire.

Figure 2—*The footprint of the 2017 Pinal Fire in Arizona (left, above the road) moderated the effects and behavior of the 2021 Telegraph Fire (right, below the road), where there had been no fire for over 10 years. USDA Forest Service photo by Mary Lata.*

In 2021, when the Telegraph Fire burned through the same area with greater intensity, the Pinal Fire footprint played a major role in reducing its impacts on the community of Globe (fig. 2).

NO SURPRISES ABOUT RISKS AND CONSEQUENCES

Even after we explain to constituents how we can use wildfire to our advantage, not everyone might agree, and various stakeholders will have different tolerance levels for risk. We should make sure that everyone understands that every action (or inaction) has consequences and that no option is entirely free of risk. Local communities and other stakeholders face a choice:

1. They can accept the losses associated with taking calculated risks under well-conceived plans in hopes of reducing future risks in an increasingly volatile climate; or
2. They can accept the losses associated with a strategy of deferring risk until the inevitable wildfires arrive—hotter, more dangerous, and more damaging than ever.

DO WE HAVE "ENOUGH STUFF"?

One area for improvement is in the organizational capacity to carry out the response strategy we choose because fire responders are in increasingly short supply. In his 2022 Letter of Intent for Wildland Fire, Forest Service Chief Randy Moore stressed the importance of taking into consideration the strain on the workforce in making our wildfire response decisions during periods when capacity is stretched thin. Chief Moore directed that any decision to "use fire for resource benefit" be approved by a regional forester during national or regional preparedness levels 4 and 5 (PL 4/5).

To be clear, the Chief's intent is not to discourage managers from doing the right thing in the right place at the right time with the right resources. Rather, the goal is to raise the level of stakeholder trust in our commitment to support a safe and effective national fire response when resources are stretched thin and shortages are causing problems across the entire wildland fire system.

One worry is that decision makers will simply refrain from considering opportunities to use wildfire to our

Using fire to reduce wildfire risk in mixed-conifer forest in 2013. USDA Forest Service photo.

advantage during PL 4/5. A decision to exclude the use of wildfire for resource benefits might rest on the assumption that such a wildfire response requires a larger commitment of resources than other response options. That assumption might be correct; however, it might also be the case that mounting a suppression response would detract even more from our ability to support the larger fire response effort. Is committing dozens of firefighters and aircraft to contain a fire in a remote wilderness area confined by natural barriers really the best way to manage fatigue, reduce exposure to hazards, and maximize firefighter availability?

Remember the call to "stop, think, and talk" before acting. It may be unwise to assume that managing a wildfire for resource benefits puts the most people at risk and expends the most response capacity. Depending on the situation, that might or might not be the case. It might be wiser to leave our options open and select the strategy, depending on the situation, that is most likely to succeed in a constrained environment where we lack enough personnel and equipment to do everything we might prefer.

It would also be a mistake to restrict such assessments of alternatives to naturally occurring wildfires where a resource objective might be pursued. Working within the limits of our capacity is a consideration on every wildfire, regardless of cause or objectives being pursued. The rationale for favoring strategies that require fewer resources and reduce the ongoing strain on an overextended workforce should apply to any large fire, particularly on fires with a full-suppression objective and with no feasible containment date in sight. At national PL 4/5, there is simply not "enough stuff" to go around to allow for an effective full-suppression response on every large fire; therefore, it only makes sense to consider response options other than full suppression. A response that includes the pursuit of resource objectives might alleviate the strain on the workforce better than simply hoping that if we just keep ordering "enough stuff," it will eventually show up.

HOW ELSE CAN WE IMPROVE?

As a learning organization, we continually ask ourselves: “How can we raise our game and do things better?” Here are some ideas for improving relationships and trust with our stakeholders while boosting our performance in using wildfire to gain advantages in a safe and effective manner.

- **Always have a control plan.** How do you intend to stabilize and control the incident? The wildfire you are managing doesn’t have to be as small as possible, but if you cannot describe the intended footprint or confinement area and how you plan to achieve it, then you will have trouble building trust.
  - » If you are depending on weather or a “season-ending event” to put out the fire, then say so and provide the data you used to show that the odds are in your favor.
  - » If you are holding the fire at the road and letting one side burn to the old fire scar, then say so and draw it on the map, showing what you expect the fire size to be and how long it will take to stabilize the event.
- **Never say that your plan is to monitor.** The purpose of wildfire response is not to watch the fire. Our intent should be to stabilize and control the incident while meeting land management and other objectives defined by the line officer. Monitoring might be a tactic for telling us when to take action, but it is not a strategy for stabilizing or controlling a wildfire.
  - » Emphasize the intent to reach a particular end state and how monitoring is helping you achieve the intent. For example, “We expect the fire to go out on its own at a few acres in size; but if it grows beyond that, then our plan is to use roads to control it at about 100 acres (40 ha). We are monitoring the fire to determine whether we will need more firefighters to hold the fire along the roads.”
  - » Consider removing “Monitor” as a strategy in ICS-209 and replacing it with “Confine” and “Confine/Contain” as strategic options. Monitoring does not convey a particular end-state intent, whereas contain or confine/contain does.
    - *Confine* is a wildfire response strategy of restricting a wildfire to a defined area, mainly by using natural barriers to restrict the spread of the fire under the prevailing and forecasted weather conditions. Some response action might be required to augment or connect natural barriers (such as fireline construction, burnouts, bucket drops, etc.).
    - *Contain* refers to actions to restrict or inhibit fire spread, with firefighters constructing fireline or using roads, trails, or other landscape features to restrict and stop fire spread.
    - *Confine/Contain* is a wildfire response strategy that employs a combination of both containment (that is, suppression) actions and confinement strategies that restrict fire spread but do not require a lot of action by firefighters.

MAKING TRADEOFFS

One thing is for certain: removing tools from our wildfire management toolbox won’t help improve our situation. In the years to come, as we better understand the trajectory and impacts of our warming climate, we will need every tool available to solve problems, including the ability to respond to wildfires in a way that offers opportunities and seeks advantages. There is no such thing as a no-fires future, so we face a choice: Do we want to engage wildfire by fighting it until it inevitably defeats us? Or, do we want to try to curb and manipulate it in ways that reduce but not eliminate its adverse consequences?

As Gifford Pinchot, the first Forest Service Chief, once said, “Unless we practice conservation, those who come after us will have to pay the price of misery, degradation, and failure for the progress and prosperity of our day.” Pinchot was talking about conserving natural resources, but his words apply to natural processes as well, including the wildland fire legacy we leave to the next generation. Unless we practice the judicious use and strategic control of wildfire when burning conditions allow, then those who come after us will pay a much higher price in terms of property losses, degraded natural resources, and human loss and suffering caused by wildfire because we saw the need to focus on our own immediate safety and prosperity. ■

A Long-Term Strategy To Reduce Wildfire Risk

Hutch Brown

In January 2022, the Forest Service released the Wildfire Crisis Strategy to reduce wildfire risk to lives, homes, communities, and natural resources, with a focus on the areas at highest risk in the Western United States. The implementation plan involves greatly expanding fuels and forest health treatments through partnerships and collaboration across shared landscapes. This article summarizes the strategy, giving its context and rationale.*

RECOGNIZING THE WILDFIRE CRISIS

In the 1990s, growing recognition of rising wildfire risk led to more congressional funding for hazardous fuels treatments (such as prescribed fire and forest thinning) to reduce wildfire risk. The fire year of 2000, when more than 7.4 million acres (3.0 million ha) burned for the first time since the 1960s (Oswalt and others 2019), precipitated a sharp rise in congressional allocations

Aftermath of the 2021 Caldor Fire at South Lake Tahoe, CA. A fuels treatment (foreground) gave firefighters the time and space they needed to keep the fire from burning into homes and unburned forest (background). USDA Forest Service photo by Cecilio Ricardo.

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* *The author, working with Forest Service scientists at the Rocky Mountain Research Station and under the direction of Forest Service leaders in the agency's Washington Office, served as lead writer/editor for the strategy.*

for treatments under a National Fire Plan adopted by the Clinton administration (USDA Forest Service 2019). The 5-year average annual area treated on the National Forest System, including wildland fire use, rose from 1.871 million acres (0.757 million ha) in 2005 to 3.14 million acres (1.27 million ha) in 2011 (USDA Forest Service 2019). In 2008, in Emmitsburg, MD, representatives from across the wildland fire community came together to begin formulating a National Cohesive Wildland Fire Management Strategy, finalized in 2014. The strategy embraces a vision of learning to live with wildland fire, in part by restoring healthy, resilient, fire-adapted landscapes through prescribed burning, forest thinning, and other fuels and forest health treatments (USDA and DOI 2014).

Nevertheless, the level of fuels and forest health treatments has not kept pace with growing wildfire risk. Congressional funding for hazardous fuels treatments declined in the 2010s before rising again and leveling off at about $430 million per year in fiscal years 2018–19 (USDA Forest Service 2019). After 2013, the 5-year annual average area treated across the National Forest System never again exceeded 2.8 million acres (1.1 million ha). Dillon and others (2015) found more than 460 million acres (186 million ha) at moderate to very high risk from wildfire, almost a quarter of the contiguous United States.

As a result, wildfires and fire years have worsened. In 3 of the last 7 years, more than 10 million acres (4 million ha) burned nationwide (NIFC 2021), an area more than six times the size of Delaware. Megafires—fires larger than 100,000 acres (40,000 ha)—have become so common that the National Interagency Fire Center has stopped tracking them as exceptional events. The scale and destructivity of such fires have far outpaced the scale of efforts to protect lives, homes, communities, and natural resources. In 2018, the greatest American wildfire disaster in a century—the Camp Fire—demolished the community of Paradise, CA, taking 85 lives. The 5-year average annual number of structures destroyed by wildfires nationwide rose from 2,873 in 2014 to 12,255 in 2020 (NICC 2021), a fourfold increase in just 6 years.

UNDERSTANDING THE CRISIS

In short, the Nation faces a growing wildfire crisis, especially in the West. Many western landscapes are at grave and growing risk from wildfire due to a combination of accumulating fuels, a warming climate, and expanding development in the wildland/urban interface. After more than a century of rigorous fire suppression, most western forests have excessive fuels (Stephens and others 2018), with cascading effects on forest health (Arno 2017; Keane and others 2002). Climate change is exacerbating the fuels problem by lengthening the fire year, reducing precipitation and snowpacks, and increasing the frequency and extent of hot, dry weather (Abatzoglou and Williams 2016; Williams and others 2019). In addition, communities continue to spread into wildlands (Radeloff and others 2018), elevating the wildfire risk to lives, property, and infrastructure (Ager and others 2021a). In 2021, for example, the Dixie Fire destroyed much of the historic mining town of Greenville, a community surrounded by heavy fuels on the Plumas National Forest in California.

Given the wildland fire trajectory in the West, many watersheds and vast parts of the wildland/urban interface are now at risk from megafires that can spread for 10 to 30 miles (16–48 km) or more across multiple landownerships and forest types within days or even hours. Forest Service researchers have identified hundreds of communities where the predicted risk from wildfire

Smoke lingers over infrastructure damage on the 2014 King Fire in the California Sierra Nevada. USDA Forest Service photo.

is higher than it was for Paradise—potential disasters waiting to happen (Ager and others 2019, 2021a; Barclay 2019). Without a major expansion of fuels and forest health treatments and more "hardening" of communities through Firewise and similar measures (BAH 2015; Harbour and others 2009), the devastation of recent fire years in the West could become the norm.

SHIFTING THE LAND MANAGEMENT PARADIGM

In recent years, the Forest Service has treated on average about 2.7 million acres (1.1 million ha) per year for hazardous fuels across the Nation (USDA Forest Service 2019), whether through forest thinning, prescribed burning, or other means (table 1). Many fuels and forest health treatments have worked. A wildfire entering a treated area has often dropped from the canopy to the forest floor and slowed its rate of spread, buying firefighters time to evacuate people and protect homes, communities, and infrastructure. By moderating fire behavior, treatments can also ensure that a wildfire benefits a forest ecologically rather than damaging soils, habitats, watersheds, and other elements of forest health.

But annual funding for treatments has been limited and uncertain, and patterns of placing treatments have never approached the necessary scale. Federal land managers have sized and placed their treatments based on limited funding rather than on the needed locations at the right scale. Treatments have been further limited by the challenge of coordinating funding and capacity to do the work across landownership boundaries. The scale of work on the ground has not matched the need, and it will take nothing less than a paradigm shift to protect the Nation's western communities.

In response, the Forest Service has established a strategy for increasing fuels and forest health treatments by up to four times current treatment levels in the West (Ager and others 2021b). Working with partners, the agency plans to thin western forests and return low-intensity fire to western landscapes in the form of both prescribed and natural fire, ensuring that forest lands and communities are resilient in the face of the wildland fire that fire-adapted landscapes need. By ramping up treatments and using the best available science, our partners will embrace a new land management paradigm: placing treatments more strategically and at the scale of wildfire risk

Table 1.—*Forest Service hazardous fuels treatments nationwide, average annual acres treated, by treatment type, fiscal years 2015–19.*

Treatment type	Acres treated	Percentage total [1]
Fire		
Prescribed fire	1,301,971	47.4%
Using wildland fire	642,585	23.4%
Nonfire		
Thinning	401,383	14.6%
Biomass removal	154,172	5.6%
Machine pile	95,231	3.5%
Lop and scatter	68,632	2.5%
Grazing	34,620	1.3%
Crushing	19,959	0.7%
Chipping	16,330	0.6%
Chemical	9,865	0.4%
Mastication/mowing	2,586	0.1%
Total	**2,747,334**	**100.1%**

Source: USDA Forest Service (2019). | [1] *Does not add up to 100 due to rounding.*

TREATING KEY FIRESHEDS

Under the new paradigm, the Forest Service will focus on treating key firesheds (Ager and others 2021c)—large, forested landscapes with a high likelihood that an ignition could expose homes, communities, and infrastructure to wildfire. Firesheds, typically about 250,000 acres (100,000 ha) in size, are mapped to match the scale of building exposure to wildfire. The bulk of building exposure originates from a relatively small number of firesheds in specific locations, often in forests adapted to frequent low-intensity wildland fire, such as ponderosa pine or mixed conifer. The strategy will first target the firesheds that represent the highest community exposure—the firesheds most capable of generating large wildfire disasters and with the highest probability of fuels reduction success.

Figure 1 shows western firesheds with a high potential for exposing buildings to wildfires. As the map suggests, a broad body of science has already located the communities at highest wildfire risk and the specific firesheds that are the primary source of building exposure to wildfire (Ager and others 2019, 2021a, 2021b, 2021c). By targeting the source of exposure in these specific areas and working with partners and stakeholders to set common goals across shared landscapes, strategically placed treatments can reduce wildfire impacts not only on homes and communities but also on air quality, municipal watersheds, wildlife habitat, and other values at risk.

To reduce wildfire risk to communities and other values, science suggests the need to restore fire-adapted conditions on 35 to 45 percent of a fireshed through a range of fuels and forest management activities, including forest thinning and prescribed fire, followed

Highest Exposure Firesheds

This map reflects the highest exposure to communities from wildfires originating on all lands in the West. Community exposure is a critical factor considered under the strategy, within the broad context of other factors including existing Tribal and state plans, watersheds, equity, climate forecasts, and partner priorities.

🟥 Highest Exposure Firesheds

🟩 National Forest System Lands

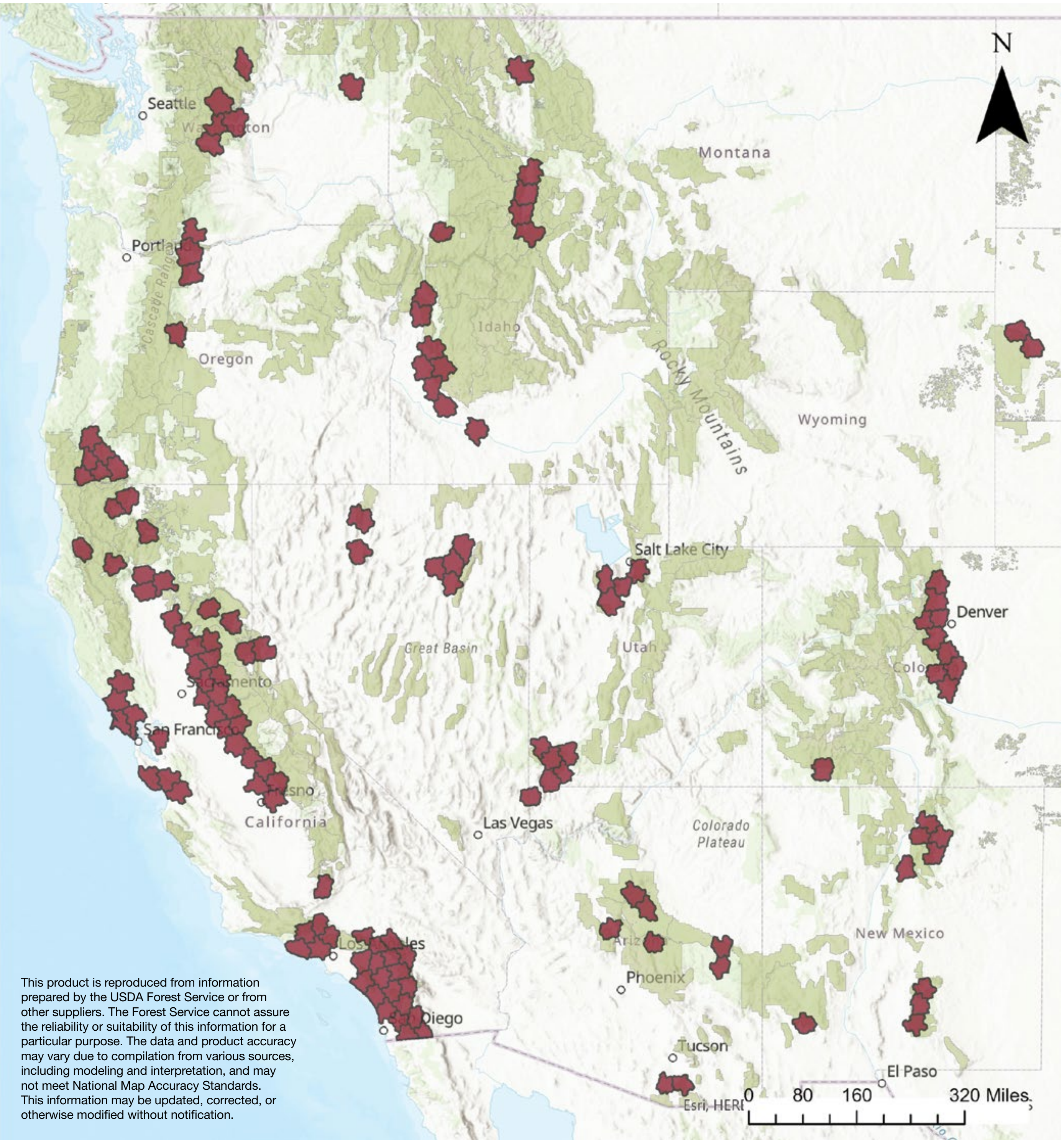

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Figure 1—*The map shows western firesheds with the highest exposure to buildings from wildfires originating on lands across all jurisdictions, public and private. Source: Forest Service, Rocky Mountain Research Station, Missoula, MT.*

by maintenance treatments at intervals of 10 to 15 years. Many national forests in the South and elsewhere have successful prescribed fire programs that can serve as models.

Wildfire risk is an all-lands problem affecting multiple landownerships across firesheds. Under the Wildfire Crisis Strategy, the Forest Service envisions greatly reducing wildfire exposure in the areas at highest risk by working together with partners to:

- Treat 20 million acres on the National Forest System in the West (over and above the current level of treatments with appropriated funds, which will continue);
- Treat 30 million acres of other Federal, State, Tribal, and private lands in the West; and
- Develop a plan for long-term maintenance beyond the 10 years.

Treatments are vital in America's eastern forests as well, and the Forest Service remains committed to sustaining the health, diversity, and productivity of all forests nationwide by continuing ongoing treatment levels, including in the South, Midwest, and Northeast. Current levels of fuels and forest health treatments will continue in these regions as well.

WORKING THROUGH PARTNERSHIPS

No single entity can rise to the challenge alone, and partnerships will be key. The Wildfire Crisis Strategy is based on decades of work in raising national awareness of the wildfire crisis and in creating national frameworks for reducing wildfire risk through partnerships and collaboration across shared landscapes (see the sidebar). Preconditions for success include building on partnership frameworks nationwide to:

- Expand workforce capacity in Federal and State agencies as well as in local, Tribal, nongovernmental, and other organizations to coordinate and accomplish the needed work; and
- Mobilize a large multijurisdictional coalition, including broad public and community support for the work, at the scale necessary to make a difference.

Some projects in identified firesheds are "shovel ready"—ready to go, lacking only the necessary funding to begin. The Forest Service will work with partners to launch such projects early on while also building the needed workforce capacity and public support for complementary cross-boundary treatments in later years. After altering the wildfire trajectory in the most critical firesheds on the National Forest System, the Forest Service will work with partners to scale treatments on national forest land to match the rate of treatments on adjoining lands.

At the core of the Cohesive Strategy is the vision of learning to live with wildland fire, which dovetails with the 10-year strategy. Working with partners, the Forest Service will continue to help communities in the wildland/urban interface create defensible space around homes and infrastructure. In addition, the partners will need public support for wildland fire prevention as well as support from homeowners and communities for fuels and forest health treatments at the pace and scale needed to reduce wildfire risk.

Communication will be key. Through better communication, land managers can gain community support for using both planned and unplanned ignitions to reduce long-term wildfire risk despite short-term tradeoffs such as temporary smoke in the air. Community groups can also play a role in forest health collaboratives and other partnerships to help accomplish cross-jurisdictional treatments themselves.

FILLING THE FIRE DEFICIT

At its core, the wildfire crisis in the West is a crisis of forest health and protecting forest health is at the heart of the Forest Service mission. Deprived of wildland fire, many fire-adapted western forests are in poor and declining health. Degraded and overgrown, many are prone to disastrous wildfires that

Historical Context for the Wildfire Crisis Strategy

2000: Historic Fire Year—More than 7.4 million acres burned, the most in more than a decade.

2000: National Fire Plan—Set five national goals, including reducing hazardous fuels through increased funding for fuels treatments.

2001: 10-Year Strategy/Implementation Plan—Increased treatments and established community wildfire protection plans. Updated in 2006.

2003: Healthy Forests Restoration Act—Improved the regulatory framework for extending the area of fuels treatments on Federal lands.

2010: Collaborative Forest Landscape Restoration Program—Funded landscape-scale collaborative projects nationwide to reduce wildfire risk.

2014: National Cohesive Wildland Fire Management Strategy—Committed the entire wildland fire community to restoring fire-adapted ecosystems, building fire-adapted communities, and responding safely and effectively to wildland fire.

2018: Omnibus Bill—Provided off-budget fire funding in heavy fire years; stopped funding transfers from nonfire programs.

2018: Shared Stewardship Initiative—Provided for agreements with States to work with stakeholders across shared landscapes to reduce wildfire risk.

2021: White Paper on Reducing Wildfire Risk—Based on cutting-edge science, outlined a 10-year framework for scaling up investments to reduce wildfire risk.

2021: Infrastructure Investment and Jobs Act—Authorized unprecedented levels of investment on Federal lands to protect communities from wildfire and improve resilience in America's forests.

The 2019 Ikes Fire on the Kaibab National Forest in Arizona backing slowly downhill. The low-intensity fire was allowed to play its natural role of reducing litter, deadfall, and other ground fuels in ponderosa pine woodland. USDA Forest Service photo by Brandon Oberhardt.

threaten lives, homes, communities, and natural resources. This is a national emergency, and it should be treated as such by investing in treatments in the same way that the Nation invests in disaster response—but before the disaster occurs.

That means returning wildland fire to the land. Ironically, the wildfire crisis in the West—the *surplus* of fuels, smoke, horrendous wildfires, and lives, homes, and communities at risk—is actually a *deficit* of the right kind of wildland fire across western landscapes. The Nation needs a new land management paradigm devoted not to shrinking the area burned each year but to making it grow through the right treatments, in the right places, at the right time, and at the right scale.

ACKNOWLEDGMENTS

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Collaborative Forest Landscape Restoration Project Outcomes: An Overview

Lindsay Buchanan and Jennifer Croft

Wildland fire management is a common and complex challenge across public and private lands. The Collaborative Forest Landscape Restoration Program (CFLRP), established by Congress in 2009, has illustrated the benefits of sustained investments in restoring fire-adapted landscapes to reduce wildfire risk to communities, watersheds, and other values. Drawing on a 10-year CFLRP summary, this article outlines lessons learned (see also USDA Forest Service 2020a, 2020b); then we summarize outcomes from three sample CFLRP projects.

OVERALL RESULTS

There are 24 CFLRP projects currently underway. From 2010 through 2019, the projects treated 3.8 million acres (1.5 million ha) of hazardous fuels, including 1.6 million acres (0.6 million ha) with prescribed fire and another 1.6 million acres (0.6 million ha) with mechanical treatments. In fiscal years 2013–19, CFLRP projects comprised 11 percent of the acres treated on the National Forest System and 9 percent of the Forest Service's restoration-related spending while accomplishing 19 percent of the agency's total hazardous fuels treatments. In 2019

Prescribed burn, part of the Southwestern Crown of the Continent Project on the Lolo, Flathead, and Helena-Lewis and Clark National Forests in Montana. USDA Forest Service photo.

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alone, CFLRP projects accounted for 15 percent of the Forest Service's prescribed fire treatments.

Data and monitoring indicate that CFLRP treatments have reduced wildfire risk. In a survey of CFLRP practitioners, 80 percent of the respondents reported that treatments reduced the threat of wildfire and improved ecological conditions (Schultz and others 2017). Annual project reports have documented how treatments have created and maintained resilient forest stands, helping wildland firefighters better manage wildfires. Monitoring has indicated the effectiveness of fuels treatments: wildfires in treated areas have been dramatically less intense than in untreated areas. CFLRP projects have also documented desired conditions for restored natural fire regimes and reduced the risk of uncharacteristically severe wildfire at both the project and landscape scales. At the 10-year mark, over 80 percent of CFLRP practitioners surveyed said that treatments had achieved their objectives for fire regimes.

In 2019, Forest Service researchers did a deeper analysis of fuels treatments on five CFLRP projects. Analysts performed wildfire simulations and risk calculations on landscape conditions before and after treatments (2012 and 2019, respectively) for all five areas. In general, all study sites showed a decrease in average burn probability and expected annual area burned, a decrease in predicted flame lengths, and a decrease in flame lengths greater than 6 to 8 feet (1.8 to 2.4 m).

From 2010 to 2014, the Forest Service used the Risk and Cost Analysis Toolkit (R-CAT) to improve its understanding of cost savings using fire modeling. The initial R-CAT results indicated a high potential for CFLRP fuels treatments to reduce various components of fire management costs.

CFLRP projects typically prioritize treatments in areas of high or very high fire hazard and focus on maintaining desired conditions in areas of low fire hazard. High priorities listed by projects include:

- Forest restoration,
- Hazardous fuels reduction,
- Municipal watersheds and other infrastructure,
- Areas of high crown fire potential, and
- Alignment with other restoration and community strategies.

In general, CFLRP projects reported that managing wildfires for resource benefits can help maintain or restore the ecological integrity of a landscape and can also improve firefighter safety and effectiveness. Though effective, the use of unplanned ignitions requires extensive advance land management planning as well as work with communities to build understanding and acceptance, and it can involve changes in Forest Service business practices.

SAMPLE PROJECTS

In California's Sierra Nevada, former foes teamed up to show how environmental and timber industry interests could work together to ward off wildfire disasters through the Dinkey Landscape Restoration Project, launched by the Dinkey Collaborative on the Sierra National Forest in 2010 (Bliss 2020). A century of wildland fire suppression had prevented naturally occurring wildfires from reducing dense growth on the forest floor, leading to forests clogged with excess fuels. Add to that the loss of large old trees to timber harvest and their replacement with dense stands of smaller even-age trees, and the result was forests prone to drought and wildfire. In recent decades, drought driven by climate change has dried up many of these overly dense forests in the Sierra Nevada, making them vulnerable to lethal bark beetle attack and turning tens of thousands of acres on the Sierra National Forest into tinder.

From 2010 to 2019, Federal, local, and private partners pooled their resources and spent about $30 million on treating overgrown conifers, hardwoods, and chaparral across the 154,000-acre (62,000-ha) CFLRP landscape for the Dinkey Landscape Restoration Project. Fuels and forest health treatments resulted in a more resilient and sustainable landscape by balancing ecological imperatives, industry interests, and outdoor recreation. Experts foresaw a time when such treatments at scale might help California's forests better withstand the high winds and hot temperatures that have led to explosive fire years across the West.

One payoff came in fall 2020, when the Creek Fire ignited under hot and dry conditions near Shaver Lake on the Sierra National Forest. At one point, the fire swept across 15 miles (24 km) in a single day. Ultimately, the fire burned almost 380,000 acres (15,000 ha) of mixed-conifer forest. But rapid fire spread and extreme fire behavior all but stopped when the fire reached treated areas on the Dinkey CFLRP project (fig. 1). There, the flames dropped from the canopy and moved along the surface, charring the bases of trees but leaving the overstory intact.

The fire effects stood in stark contrast to areas to the north and west, where high-severity wildfire had left much of the landscape looking like a "nuclear site," according to the owner of a nearby sawmill. Strategic placement of thinning and prescribed burning treatments through the Dinkey CFLRP project improved forest health, reduced hazardous fuel accumulations, and restored resilience. Using science as its guide, the Dinkey Collaborative brought partners together to support treatments to reduce the risk of catastrophic wildfire.

Dinkey Collaborative & Creek Fire Perimeter

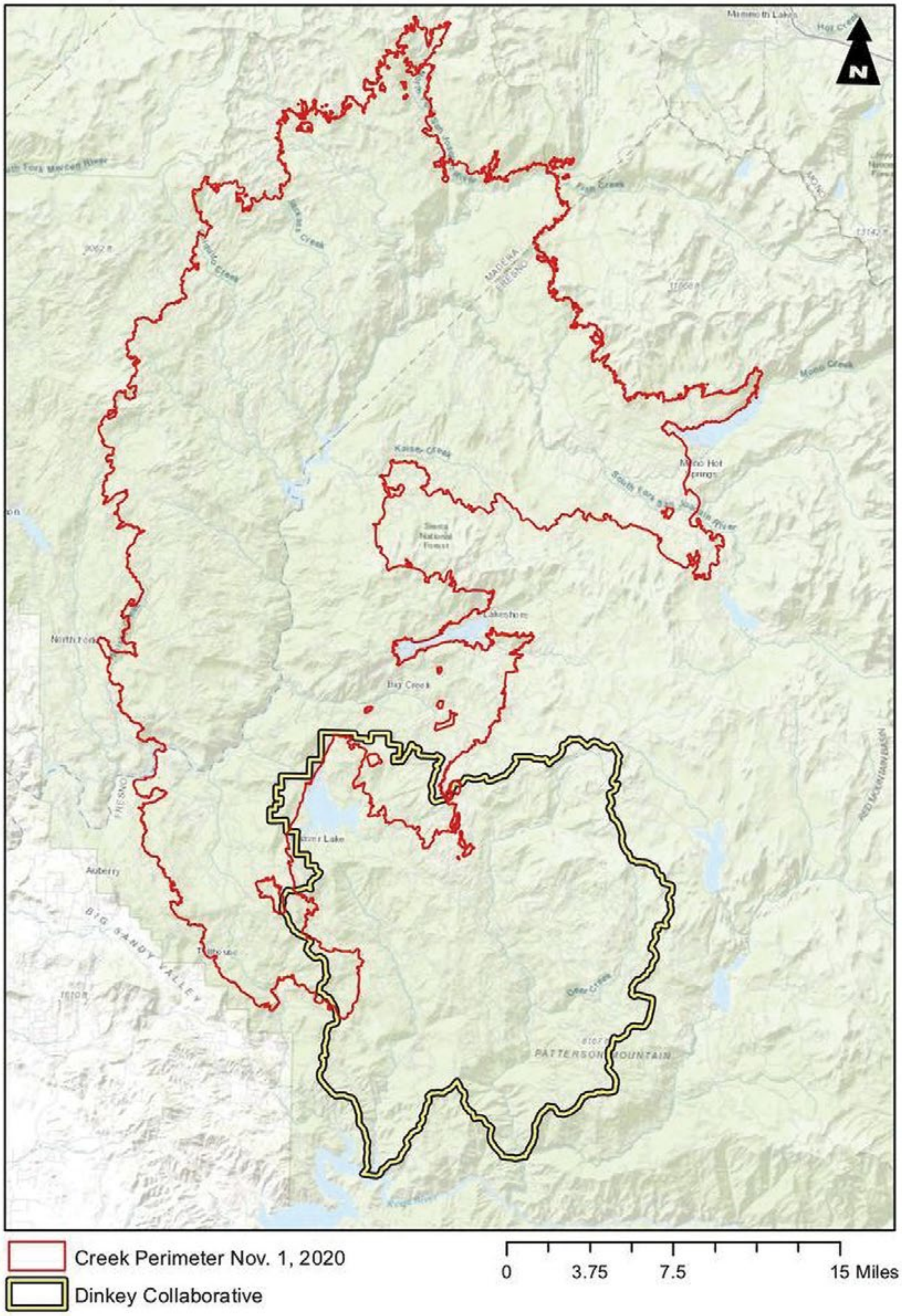

Figure 1—*The 2020 Creek Fire perimeter (red) in relation to the Dinkey Collaborative Forest Landscape Restoration Program project perimeter (double line). Fuels and forest health treatments near Shaver Lake on the northwestern project perimeter gave firefighters time and room to stop the blaze. USDA Forest Service map.*

Until the advent of fire exclusion in the 20th century, ponderosa pine and other forest types were shaped by low-intensity blazes, with the flames clearing underbrush but rarely killing mature trees. Forests across the West are now so overgrown that they are powder kegs for explosive fire behavior. Work by the Deschutes Collaborative Forest Project in central Oregon, where towns and subdivisions sit in a green ocean of ponderosa pines and other conifers, shows the effectiveness of forest thinning and prescribed burning (Robertson and Buchanan 2021; Selsky 2017). It also shows how loggers and environmentalists—once bitter enemies—can join forces.

Established in 2010, the Deschutes project spans an area of 257,000 acres (104,000 ha), much of it on the Deschutes National Forest. The partners have focused on treating areas at risk from wildfires near homes and communities in the wildland/urban interface. Treatments have included thinning and burning a section of the Deschutes National Forest outside the tourist town of Sisters, a community of about 2,500 on the eastern slope of the Cascade Mountains.

In August 2017, lightning started the Milli Fire in a remote wilderness area about 9 miles (14 km) from Sisters. Driven by high winds, the fire ultimately roared across 24,000 acres (9,700 ha), threatening Sisters and other communities. About 40 percent of the area within the Milli Fire perimeter fell within the CFLRP landscape, and when the fire reached treated buffer zones, it dropped from the canopy to the ground and slowed its rate of spread, allowing firefighters to corral it. In treated areas, crown fire activity mostly changed to surface burning or showed little or no spread (USDA Forest Service 2017).

Partners in the Deschutes Collaborative Forest Project meet to discuss fuels and forest health treatments in ponderosa pine in central Oregon. USDA Forest Service photo.

"Our treatments functioned just as they were supposed to when the fire came through," said Nicole Strong, the former outreach chair for the Deschutes project. "The fire, once it entered the treated area, hit the ground and made it safe for firefighters to come and fight the fire to lower its intensity. Because of the treatments, we were able to save the communities, and the trees are still alive."

Outreach and public education served the community well (USDA Forest Service 2017). Even before the Milli Fire was out, the Deschutes Collaborative showed a video highlighting the effectiveness of collaborative forest restoration in reducing wildfire impacts and protecting values at risk. The postfire consensus was to continue treatments adjacent to high-priority areas and to build on previous investments.

The Southern Appalachians are a biodiversity hotspot, with fire-adapted species and forest types shaped by millennia of wildland fire. In North Carolina, much of the vegetation on the Pisgah National Forest is in oak/hickory and oak/pine forest types historically adapted to frequent low-severity fire, including planned ignitions by American Indians and European settlers (USDA Forest Service 2014). Local residents, in speaking of Bald Knob (a high point on the Pisgah's Grandfather Ranger District), still say that "the mountain needs to burn" (Cross and others 2015).

Since 2012, partners in western North Carolina have been working together through the Grandfather Restoration Project to increase prescribed burning and other management practices on more than 40,000 acres (16,000 ha) on the Grandfather Ranger District, about 30 miles (50 km) east of Asheville, NC. Using a structured prescribed fire prioritization process, the partners identified high-priority areas for restoring fire-adapted forest ecosystems while benefiting a variety of native plants and animals. Project components have included multiple prescribed fires.

In summer 2015, a lightning strike near the top of Bald Knob started a slow-spreading wildfire. The ignition point was in oak/pine forest with a heavy understory of blueberry, rhododendron, and mountain laurel, all highly flammable. The rugged backcountry terrain limited firefighter access, but the surrounding area had a rich history of both planned and unplanned ignitions. The resulting changes in fuel loading and fuel structure allowed the Forest Service to use a confine/contain strategy to manage the fire for resource benefits while minimizing risks to firefighters and surrounding homes. The local fire history gave firefighters plenty of opportunity to focus on protecting private lands by improving old roads and natural barriers as needed.

The Lake James prescribed burn in January 2015, part of the Grandfather Restoration Project on the Grandfather Ranger District of the Pisgah National Forest. The prescribed fire footprint was instrumental in allowing project managers to use the Bald Knob Fire in August 2015 for resource benefits. USDA Forest Service photo.

The Bald Knob Fire ultimately burned about 1,200 acres (500 ha). The planning and prioritization process for fuels treatments enabled a wildfire response that restored fire-adapted ecosystems while providing for firefighter safety and community protection. The Forest Service was able to protect all homes and infrastructure in the 22,000-acre (9,000-ha) planning area for the wildfire, while letting fire play its natural ecological role.

By using both planned and unplanned ignitions, the CFLRP projects have made measurable gains in restoring fire-adapted Appalachian ecosystems. Monitoring results show a change in understory composition, with a reduction in rhododendron and mountain laurel and more oak and pine regeneration. In recent fire years, the interaction of wildfire with prescribed fire units shows that the project is also reducing the risk of catastrophic wildfire. "With these recent fires," said Nicholas Larson, district ranger for the Grandfather Ranger District, "we are starting to reap the value of the restoration work under our Collaborative Forest Landscape Restoration Project" (Cross and others 2015).

PARTNERSHIPS AND COLLABORATION

Projects like Bald Knob, Deschutes Collaborative, and Dinkey Restoration are great examples of partnerships and collaboration. The Forest Service strives to improve relationships with all stakeholders involved and CFLRP projects capitalize on efforts to include all perspectives. Involvement by local residents, Tribal Nations, nonprofit groups, and partner agencies has resulted in positive outcomes that will strengthen landscape resilience on the National Forest System and protect nearby communities. CFLRP projects build on existing and planned investments to reduce wildfire risk at the landscape level, stewarding for the whole rather than limiting treatments to areas within administrative boundaries.

For examples of CFLRP approaches to treatment prioritization, techniques for using both planned and unplanned ignitions, and strategies for community engagement and partnerships, including strategies for dealing with smoke in communities, see Collaborative Forest Landscape Restoration Program Results and the appendixes in USDA Forest Service (2020a).

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Restoration Activities Help Firefighters Control the Rafael Fire in Arizona

Victor Morfin and Dick Fleishman

The Forest Service, joined by the State of Arizona and other partners, has conducted widespread restoration activities in and around the national forests in Arizona. Land managers reintroduced wildland fire to fire-adapted ecosystems through a combination of:

- Prescribed fire,
- A strategic approach to wildfire response, and
- Harvesting trees to resemble the structure and pattern of a resilient forest.

Restoration treatments helped firefighters respond effectively to the Rafael Fire, which burned more than 78,000 acres (31,600 ha) in northern Arizona in June 2021. Restoration activities modified fire behavior, making it easier to conduct burnouts and control spot fires within treated areas. Overall, the decisions made—and actions taken—prior to June 2021 increased the probability of success and made it safer for firefighters to take effective suppression actions on the Rafael Fire.

Burnout operation in ponderosa pine on the Rafael Fire on June 27, 2021. Photo by Michelle Herrin.

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THE RAFAEL FIRE

Ignited by lightning, the Rafael Fire was first detected on June 18, 2021, in a remote area on the Prescott National Forest about 65 miles southwest of Flagstaff, AZ. The response objective was to control the fire before it could reach surrounding communities and infrastructure. However, hot, dry, and windy conditions prevailed; given the terrain and fire behavior, immediate control of the fire was not possible.

On June 20, the fire moved 9.5 miles northeastward onto the Kaibab National Forest and into the Sycamore Canyon Wilderness Area (fig. 1), remote and rugged terrain where direct attack was unsafe for firefighters. By June 22, the fire had crossed onto the Coconino National Forest, moving toward Flagstaff. Given the circumstances, fire managers selected a strategy to contain the Rafael Fire on favorable ground where prescribed fire, mechanical thinning, and past wildfires meant that fire behavior posed less danger and presented more advantages for firefighters.

EFFECTS OF WILDFIRE FOOTPRINTS

Wildland fire is common across the fire-adapted landscapes of northern Arizona. Over the years, the approach by land managers to wildfire response and containment has evolved.

The first set of wildfires to play a part in this story included the Taylor Fire (2009) on the east rim of Sycamore Canyon and the Slide Fire (2014), a human ignition west of Highway 89 and north of Sedona. The response to both wildfires had been to gain control as soon as practical; on the Slide Fire, firefighters used areas of prior fuels treatments and the road system to control the fire safely and effectively rather than trying to minimize the size of the fire, which would have been slower and put more firefighters at risk (for details, see the Southwest Fire Science Consortium's Slide Fire Field Trip in 2014).

In the years following 2014, the areas previously burned by the Taylor and Slide Fires gave fire managers opportunities to be more strategic in

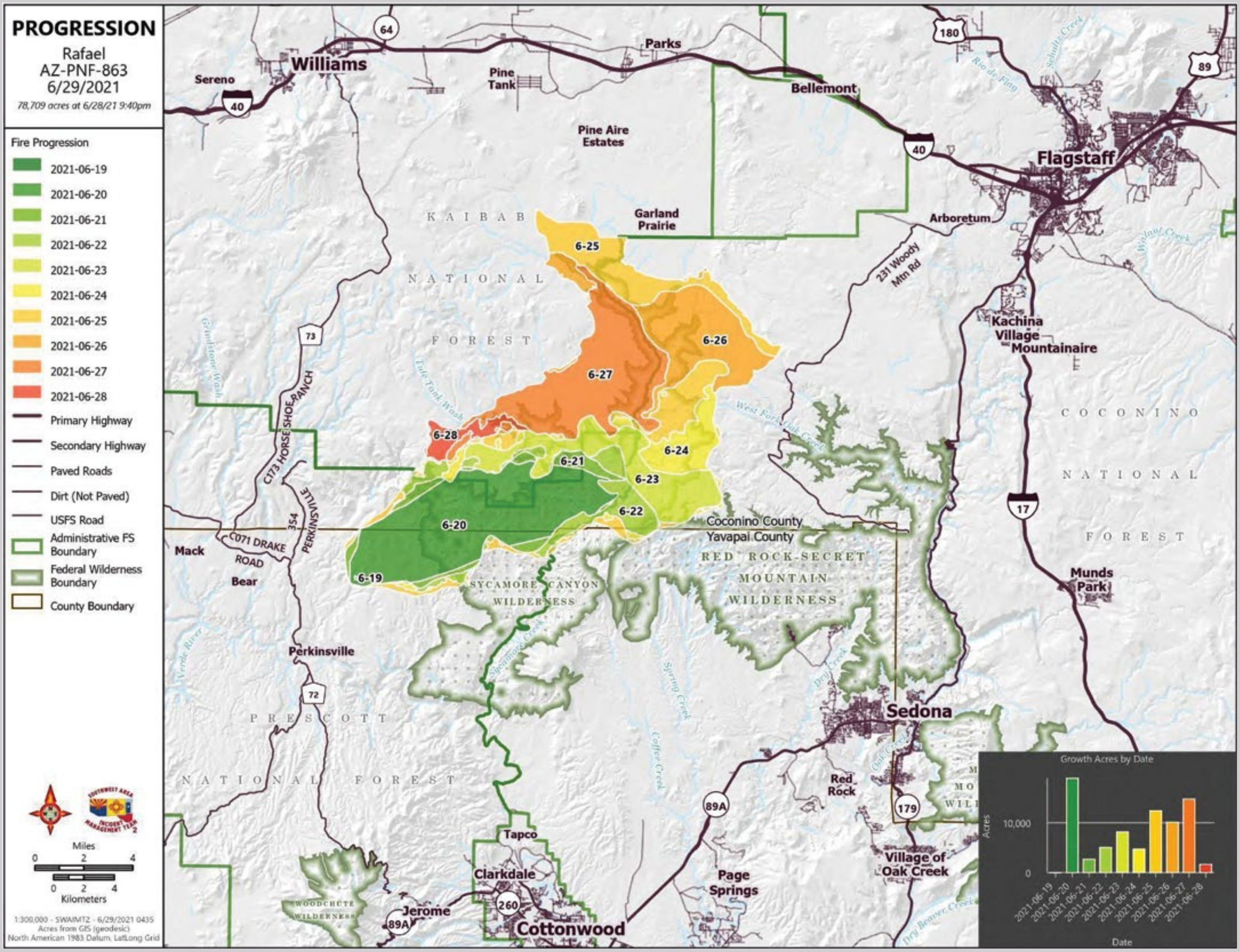

Figure 1—*Location of the Rafael Fire in June 2021 and fire progression by date. Note the proximity of communities on nearby highways. Source: InciWeb.*

their wildfire response. In managing the five subsequent fires west of Slide (Echo, Platypus, Rhino, Whiskey, and Sabre), firefighters used the Slide Fire footprint as a control feature to prevent fire spread to the east. For example, firefighters used burnouts and other indirect methods of containing the 2019 Whiskey Fire to allow the fire, as nearly as possible, to play its natural ecological role, in accordance with Federal wildland fire management policy (NWCG 2001, 2003; FEC 2009). The result was to reduce accumulated fuels while still ensuring a safe and effective wildfire response.

When the Rafael Fire reached the top of the Mogollon Rim on June 22–23, it encountered the substantial footprint of previous wildfires. True Brown, fire management officer on the Flagstaff Ranger District, was branch director for the Central West Zone Type 3 Incident Management Team managing the Rafael Fire at the time. According to Brown, the fire behavior moderated due to lack of fuels in the area, and firefighters were able to safely engage the fire at its edge. In addition, fuels reduction by previous fires (Whiskey and Sabre in 2019) allowed firefighters to easily line and control the frequent spot fires from the Rafael Fire.

EFFECTS OF MECHANICAL TREATMENTS

On June 24, the Rafael Fire reached areas of mechanical treatments under the Four Forest Restoration Initiative (4FRI). Under phase 1 of 4FRI, two projects had been completed: the KA Task Order in fall 2016, and the Pomeroy Task Order in summer 2017.

Both projects proceeded following environmental analysis under the National Environmental Policy Act (NEPA) conducted by the Kaibab National Forest, Williams Ranger District (the Frenchy NEPA project). The treatments replicated the structure and pattern of a restored ponderosa pine forest, leaving about 40 to 80 trees per acre. In such open forest, firefighters needed no fireline preparation before beginning burnout operations on the Rafael Fire. Such favorable conditions saved time and effort for firefighters and reduced the risk associated with using chainsaws to remove vegetation during fireline preparation.

Rafael Fire in Sycamore Canyon. USDA Forest Service photo.

An added bonus was that the treatments straddled the containment line. Treated areas in the black (outside the containment line) did not have heavy fuel loadings, making it easy to control any spot fires from burnout operations that started in the green (within the containment line). Furthermore, the mechanical treatments did not result in the typical windrow of heavy fuels adjacent to holding operations that becomes problematic on wildfires when we are holding the opposite side of the road that we hurriedly thinned. This reduces firefighter fatigue and exposure to hazards in fireline preparation and firing operations.

On June 24, teams carried out firing operations throughout the thinned project areas. According to Rick Miller, operations section chief for the Southwest Area Type 1 Incident Management Team 2 on the fire, crews were able to “light and go” without any need for fireline preparation. The mechanical harvests simplified burnout operations, making them safer and increasing the likelihood of success.

EFFECTS OF USING PLANNED AND UNPLANNED IGNITIONS

On June 24, fire crews began burnout operations at the northern end of the fire near the Raymond Boy Scout Camp, working both eastward and westward parallel to and above Sycamore Canyon. On June 25, fire crews completed a burnout along Forest Road 538 on the Coconino National Forest in an area adjacent to the 2019 Whiskey Fire, where low-intensity fire had been managed to play its natural ecological role of reducing fuels. According to Task Force Leader Matthew Mullin, who was working on the burnout with the Mormon Lake Hotshots, the burnout operation resulted in several small spot fires that where

Burnout operation in ponderosa pine on the Rafael Fire. USDA Forest Service photo.

easily contained because fuels had been previously reduced by the Whiskey Fire.

On June 26–27, fire crews burned out along road systems from White Horse Hills towards JD Dam, where the Kaibab National Forest had completed the Sunflower Prescribed Burn in 2017. Sunflower is one of many 4FRI projects completed following a NEPA decision based on the 4FRI Environmental Impact Statement. According to Rick Miller, operations section chief for the Southwest Area Type 1 Incident Management Team 2, fire crews easily contained several spot fires from the firing operation because of reduced fuels from the Sunflower project.

Overall, burnout operations consistently benefited from fuels reduction adjacent to the area burned. Fuels reduction resulted directly from large-scale prescribed fires on the Kaibab and Coconino National Forests and from intentional decisions to control wildfires in a manner that reduced hazardous fuels accumulations across the landscape.

BENEFICIAL EFFECTS

Incident management teams relied on an indirect suppression strategy (burnouts) to contain the Rafael Fire in Sycamore Canyon because it was not safe to place firefighters in the canyon. The burnouts had a much greater probability of success and lower firefighter risk because of past management decisions. Previous wildfires created a large buffer area of reduced fuels, as did mechanical thinning and prescribed burns. Mechanical treatments, along with the use of both planned and unplanned ignitions across the landscape, heightened the safety and effectiveness of control actions taken on the 2021 Rafael Fire.

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Effects of the 2017 Pinal Fire on the 2021 Telegraph Fire in Arizona

Mary Lata

In May 2017, the Pinal Fire burned 7,169 acres (2,901 ha) in the Pinal Mountains just south of Globe, AZ, about 80 miles east of Phoenix. When the Telegraph Fire burned though the same area in June 2021, its behavior and effects were significantly affected by the effects of the Pinal Fire.

The Pinal Mountains cover an area of about 46,000 acres (18,600 ha), mostly on the Tonto National Forest. The highest peak is 7,848 feet (2,392 m) in elevation, much higher than Globe's elevation of 3,510 feet (1,070 m). With rising elevation, vegetation types in the Pinals transition from chaparral to ponderosa pine and mixed conifer. The pine and mixed-conifer forests have historical fire return intervals of 2 to 10 years (Kaib 2001); the chaparral has a fire return interval of about 50 years (Wahlberg and others 2017).

From 1970 to 2017 (the year of the Pinal Fire), the Pinal Fire footprint had 116 fire starts. Totaling only 210 acres (85 ha), the fires were either suppressed or went out on their own. In the larger area of the upper Pinal Mountains, wildland fire activity between 1970 and 2017 was limited to about 225 acres (91 ha) of prescribed fire (in 2009) and about 700 acres (280 ha) of wildfire on the Mill 2 Fire (2010) and the Pioneer Fire (1985). By 2017, fuel loading in most of the Pinals was unnaturally heavy and contiguous.

BUILDING CONSENSUS ON FIRE USE

In July 2015, lightning started a fire in the Pinals. Fuel and weather conditions were ideal for using wildfire for desired effects in ponderosa pine; but many stakeholders were uncomfortable with

The 2017 Pinal Fire moderated the effects and behavior of the 2021 Telegraph Fire. The image shows the difference in the effects of the Telegraph Fire where the Pinal Fire had burned (to the left of the forest road, yellow line) and where there had been no fire for over 10 years (to the right of the forest road). USDA Forest Service photo by Mary Lata.

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using wildfire to treat the landscape, so the fire was suppressed.

The Globe Ranger District on the Tonto National Forest concluded that the Forest Service needed to bring more local stakeholders into the conversation. Over the next 2 years, district personnel increased communication with interested parties. They arranged community meetings, monthly meetings with fire chiefs, preseason fire preparedness meetings, and discussions with Gila County supervisors and other local elected officials.

POTENTIAL WILDFIRE OPERATIONAL DELINEATIONS

In fall 2016, the Tonto National Forest began working with the Rocky Mountain Research Station in Missoula, MT, to develop a fire planning process that would integrate:

- A map of landscape features that influence fire behavior based on historical fire perimeters, and
- Modeled outputs showing where fire was likely and with what behavior and effects.

The fire planning process mapped individual areas called potential operational delineations (PODs). Before a wildfire ignites, PODs allow fire managers to identify hazards and align short-term fire management with long-term landscape management objectives. In wildland fire management, PODs are used to:

- Coordinate fire response across ownerships,
- Communicate fire management objectives to out-of-area incident management teams, and
- Inform the public during ongoing fire operations.

The POD process became the beginning of strategic planning for the Pinal Fire. In spring 2017, during an annual preparedness exercise, the Pinal Mountains were identified as a high-priority area for wildfire treatment. Most of the area was in a "restore" category for PODs, meaning that there was a moderate risk of detrimental fire effects, but the desired effects and behavior were expected when conditions were right.

On May 8, a lightning strike ignited the Pinal Fire less than half a mile (0.8 km) from the location that had been used for the annual preparedness exercise 2 weeks before, and conditions were ideal for fire to produce the desired behavior and effects. Fire managers contacted the mayor, county supervisors, and local fire chiefs and found overwhelming support for the plan.

On May 10, the decision was made to use the Pinal Fire to begin reintroducing fire into the fire-dependent ecosystems of the Pinals. In public meetings at the Globe town hall and in nearby Miami, the incident commander (Andy Mandell) described the ecological benefits of the fire. He also outlined the role that the Pinal Fire footprint could play as a "catcher's mitt" to slow or stop future wildfires that might threaten homes in the lower portions of Kellner, Icehouse, and Six Shooter Canyons (fig. 1).

TELEGRAPH FIRE

In the runup to the 2021 Telegraph Fire, the Southwest saw extraordinary extended drought. During a 16-month dry period in 2017–18, shrubs and small trees lost leaves and twigs, going early into winter dormancy or never emerging. Leaf litter and dead woody

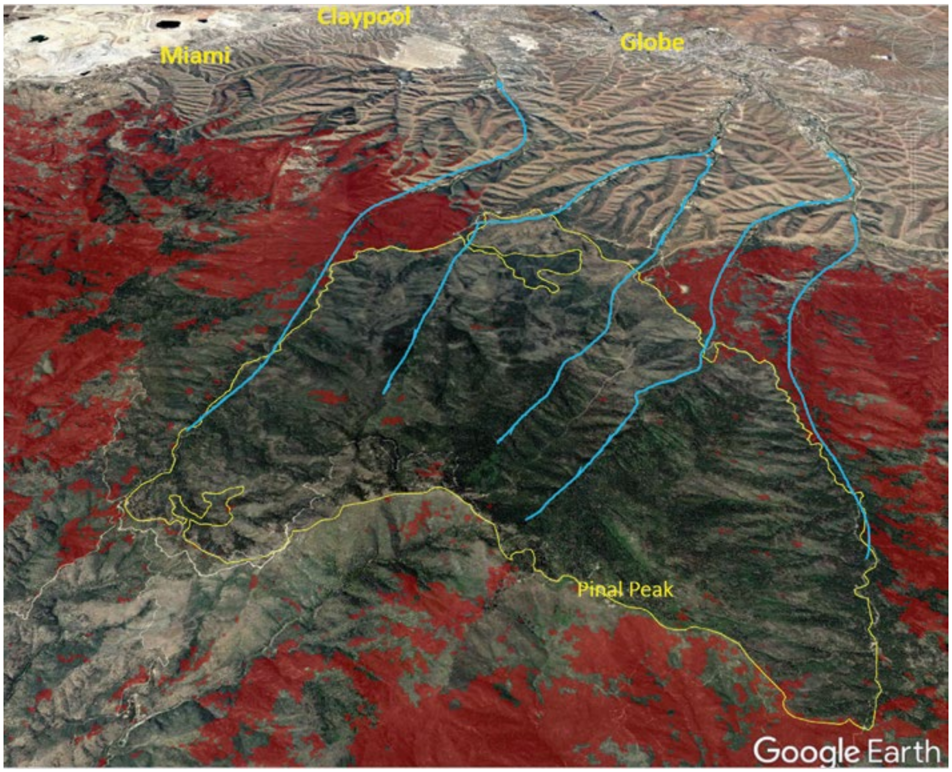

Figure 1—*Juxtaposition of the Pinal Mountains to local communities and drainages (blue lines) affected by the Pinal Fire. The Pinal Fire perimeter is in yellow (a "catcher's mitt" facing south); red patches indicate high fire severity from the Telegraph Fire. Inset shows location of the Telegraph Fire in south-central Arizona.*

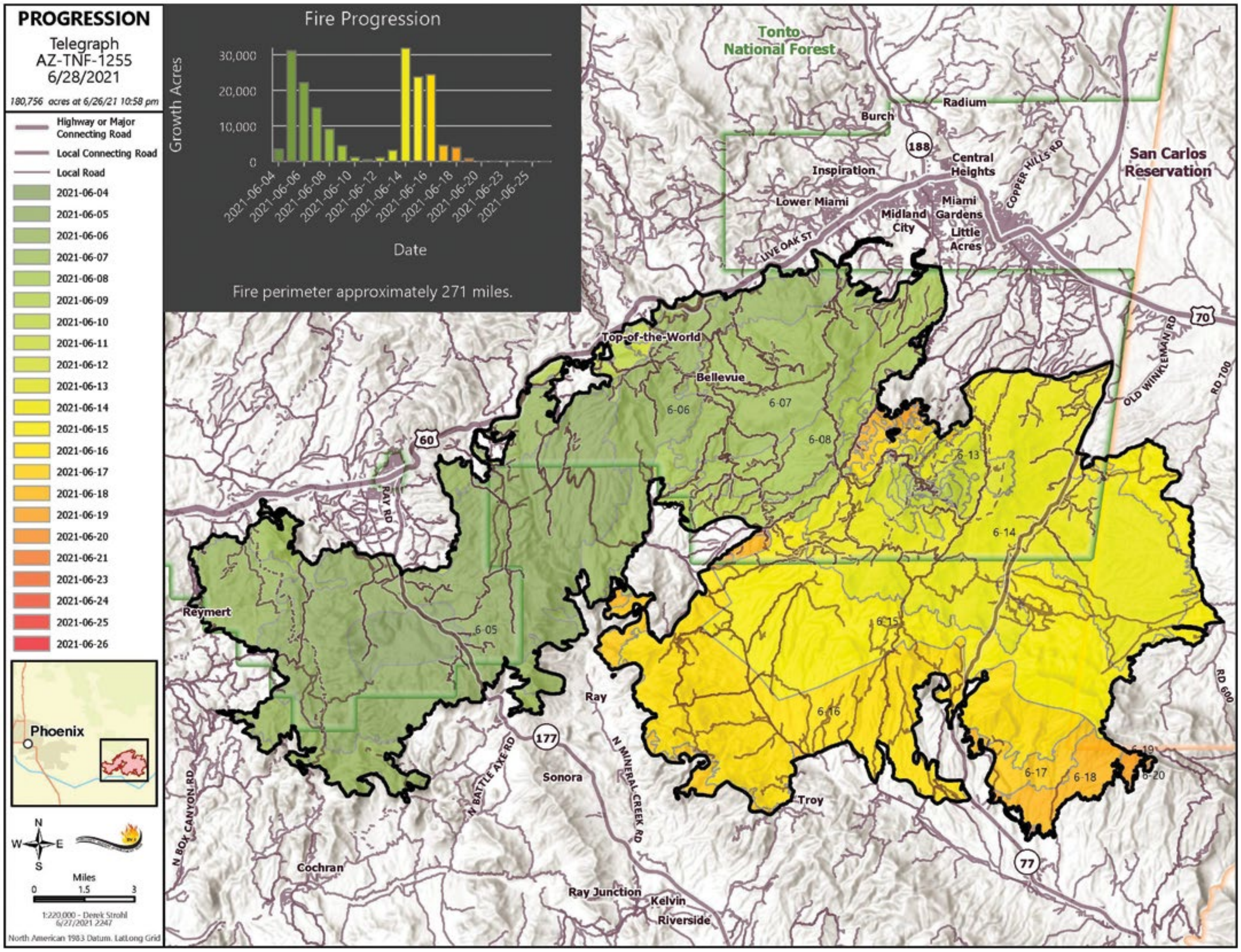

Figure 2—*Fire progression map for the Telegraph Fire in June 2021. The fire started on June 4 at lower left (darker green). By June 8, driven by winds, the fire had reached the area near Globe at upper center/right (lighter green). The footprint of the 2017 Pinal Fire forms a "catcher's mitt" (gray) penetrating the fire perimeter at top right. Source: InciWeb.*

fuel were abundant, with unusually heavy crops of contiguous fine surface fuels in 2019–20. By late spring 2021, manzanita and other small shrubs were dead or dying in patches, as were tree seedlings.

On the Globe Ranger District, foliar moisture is tracked for pointleaf manzanita (*Arctostaphylos pungens*) and turbinella oak (*Quercus turbinella*), two major contributors to extreme fire behavior. The 10-year average from April through June is 71 percent for pointleaf manzanita and 75 percent for turbinella oak; by mid-May 2021, pointleaf manzanita was at 53 percent and turbinella oak at 64 percent. With live fuels so explosively dry in the area and with elevated levels of fine surface fuels, the fire potential was extreme.

The Telegraph Fire was first reported to the Phoenix Interagency Fire Center on June 4 (fig. 2). The fire was human caused and was reported to be about 4.5 miles (7.2 km) south-southwest of Superior, AZ (fig. 2, lower left), at an elevation of about 3,900 feet (1,600 m).

At the time of ignition, the weather station in Superior recorded a temperature of 97 °F (36 °C), with the relative humidity at 9 percent and winds from the west gusting to about 14 miles per hour (23 km/h). Two hours later, the temperature had risen to 106 °F (41 °C), the relative humidity had dropped to 5 percent, and winds had reached 16 miles per hour (26 km/h), with gusts of up to 25 miles per hour (40 km/h) on ridgetops.

By 8 p.m., the fire had jumped Highway 177 south of Superior and was estimated at about 3,500 acres (1,400 ha). Driven by winds toward the east-northeast, the fire reached the Pinal Mountains by June 7, ultimately burning more than 180,000 acres (72,000 ha) before full containment on July 3 (fig. 2).

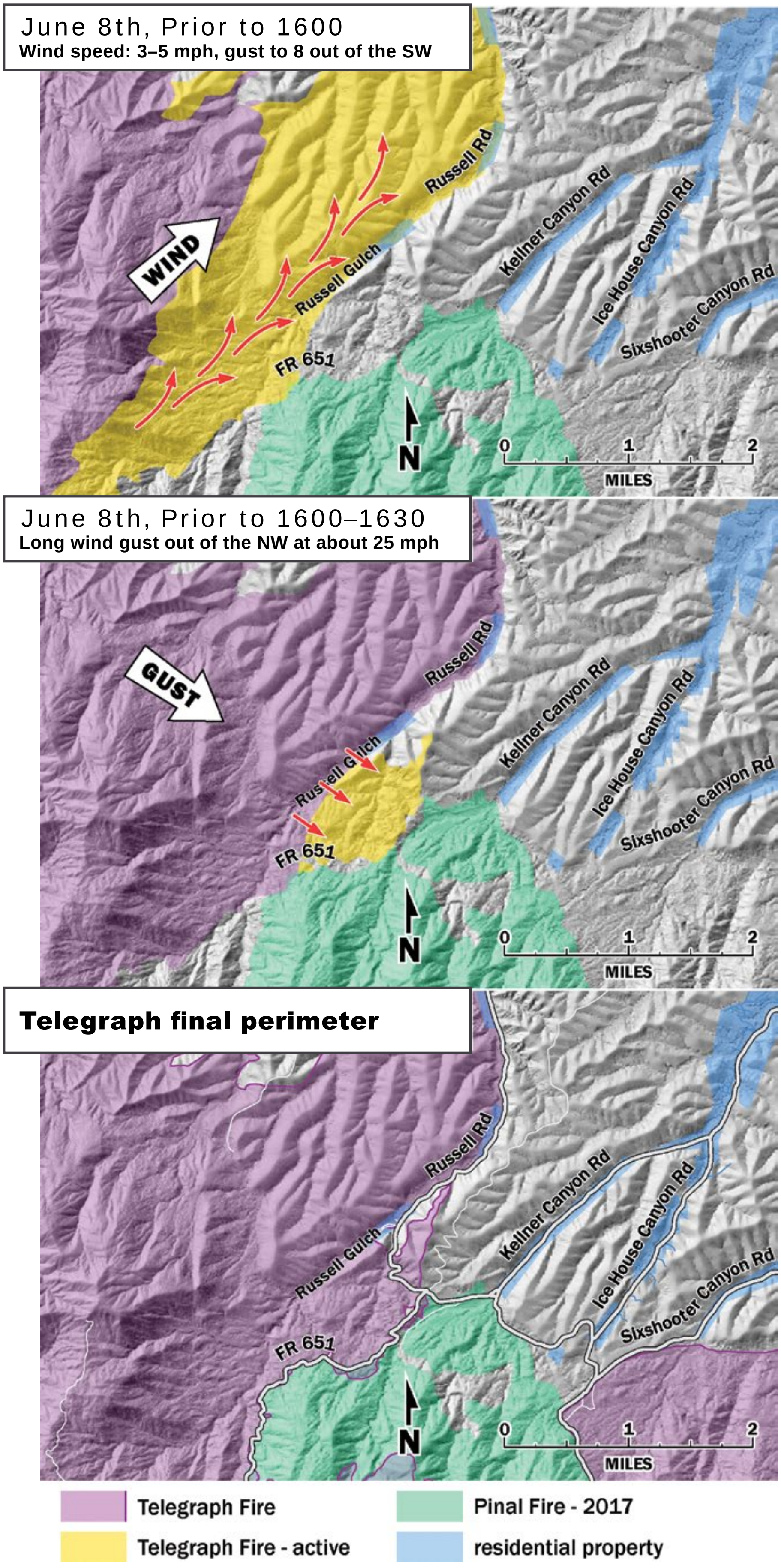

Figure 3— *Part of the Telegraph Fire in the Pinal Mountains in June 2021, showing area burned (purple) and active spread (yellow) in relation to the 2017 Pinal Fire (green) and residential structures in canyons (blue). The Pinal Fire scar moderated fire behavior on the Telegraph Fire, keeping the fire from threatening residential property. USDA Forest Service maps.*

FIRE BEHAVIOR

By the evening of June 8, one head of the fire was moving down Russell Gulch to the north-northeast from near the Sulfide del Rey Campground (fig. 3, top), while another head had wrapped around the north side of Madera Peak and was on the outskirts of Miami. Firefighters were fully engaged in protecting the lower portion of Russell Road, keeping the fire from jumping the road and moving east toward structures in Kellner Canyon.

At about 6:30 p.m., the wind shifted suddenly to the northwest, blowing hard enough to lift the hardhat from the division supervisor's head. What had been a flanking fire slowly moving to the northeast was now a headfire moving to the east/southeast (fig. 2, middle). When the fire hit Forest Road 651 and the Pinal Fire scar, it was a headfire burning uphill in chaparral that hadn't burned in well over 50 years, with 60-foot (18-m) flame lengths. All resources, including aircraft, were holding the fire in Russell Gulch, and no additional resources were available.

The 2017 Pinal Fire had burned small patches of chaparral with low to moderate severity. In these places, the Telegraph Fire jumped Forest Road 651 and burned into the Pinal Fire scar but soon ran out of fuel. The Pinal Fire had burned with high severity in most of the chaparral along Russell Road, so the Telegraph Fire exhausted its fuel and stopped.

Had the Pinal Fire not burned through the area, the Telegraph Fire would have jumped Russell Road to the north, where no resources were available to stop it from burning into homes in Kellner, Icehouse, and Sixshooter Canyons (fig. 2). The Pinal Fire scar was an effective "catcher's mitt" for that part of the Telegraph Fire. Without it, according to the division supervisor (Lata 2021), the Telegraph Fire "would have been a whole different beast. … [A] firefight was going on when [the main fire] hit Pinal, and there were insufficient resources to manage additional fire. … [Pinal] bought us enough time."

FIRE EFFECTS IN THE PINAL FIRE FOOTPRINT

Chaparral

Chaparral covers about 35 percent of the Pinal Fire footprint—the northern third, adjacent to areas with homes and infrastructure (fig. 2). Historically, when chaparral burned, it left 1,000- to 2,000-acre (400- to 800-ha) patches of high-severity effects, with most vegetation consumed (Wahlberg and others 2017). Chapparal has tended to burn with extreme fire behavior that is difficult to control.

In the first years following a fire, many shrub species produce sprouts 2 to 5 feet (0.6–1.5 m) tall. The new sprouts have higher fuel moisture, and it takes several years for sufficient fuels to build up to carry a fire. Chaparral is often called an "on/off fuel" because it mostly burns with high intensity or not at all.

When the Pinal Fire started in early May 2017, foliar moisture in the chaparral was too high for much of it to burn. It did ignite in places with a heavy dead/down component or where the wind lined up on a slope that was warm and dry; but the fire intensity was low, and when the wind died down or the heavy fuels burned out, the fire stopped its spread. By late May, however, the shrub foliage was drying out; flammability increased enough for the chaparral to burn in a mosaic of mostly high and moderate severity.

Forested Areas

The Telegraph Fire burned when conditions were much more extreme than for the Pinal Fire. Within the footprint of the Pinal Fire, however, the fire effects for Telegraph were well within the historical range of variation. Telegraph consumed surface fuels too moist to burn in the Pinal Fire, further decreasing the potential severity of future fires in the area. The Telegraph Fire maintained the mosaic vegetation patterns initiated by previous fires (Pinal, Mill 2, and Peak) in the Pinal footprint's mixed-conifer forests.

Ponderosa pine/evergreen oak is more complex than other ponderosa pine systems, it includes a vegetative subclass in which ponderosa pine is less dominant and the shrub cover is higher. This subclass is in fire regime III (Wahlberg and others 2017), with lower frequency and higher severity wildfires than for the matrix ponderosa pine (fire regime I).

On the Telegraph Fire, overall fire severity in forested areas within the Pinal Fire footprint was a little lower than on the Pinal Fire; however, much of the high severity in ponderosa pine on Pinal was in a single area that interfaced with chaparral. Telegraph burned with lower severity in the Pinal footprint than in adjacent areas, showing the moderating effects of the Pinal Fire on subsequent fire severity and intensity. Data collected before and after Pinal shows that the fire reduced fuel loadings to within historical ranges for the area (Lata 2017). Accordingly, conditions in the Pinal Fire footprint allowed fire managers to safely and effectively use aerial and ground ignitions to lower the intensity and severity of the Telegraph Fire, producing mostly beneficial fire effects where the Pinal Fire had burned.

Litter and Duff in Ponderosa Pine

Soil and duff moisture are important factors in soil heating (Lata 2006; Hungerford and others 1990). Locals reported up to 9 feet (2.7 m) of snow on Signal Peak over the winter prior to the Pinal Fire and 9 inches (23 cm) still on the ground in mid-March. During the first 3 days of the Pinal Fire, Pinal Peak got about a quarter of an inch (0.6 cm) of precipitation, sufficient to keep the soil moist to the touch just an inch or so (~2.5 cm) below the surface.

Litter burns more quickly and with higher intensity than duff, producing greater flame lengths that directly affect aboveground portions of plants. Duff burns mostly with smoldering combustion—at low temperatures and usually without flames—but the long residence time can transmit a lot of heat into roots, soil, and the air below closed canopies (Frandsen and Ryan 1986; Hungerford and others 1990).

Figure 4 shows the average prefire fuel loading for litter and duff for both fires

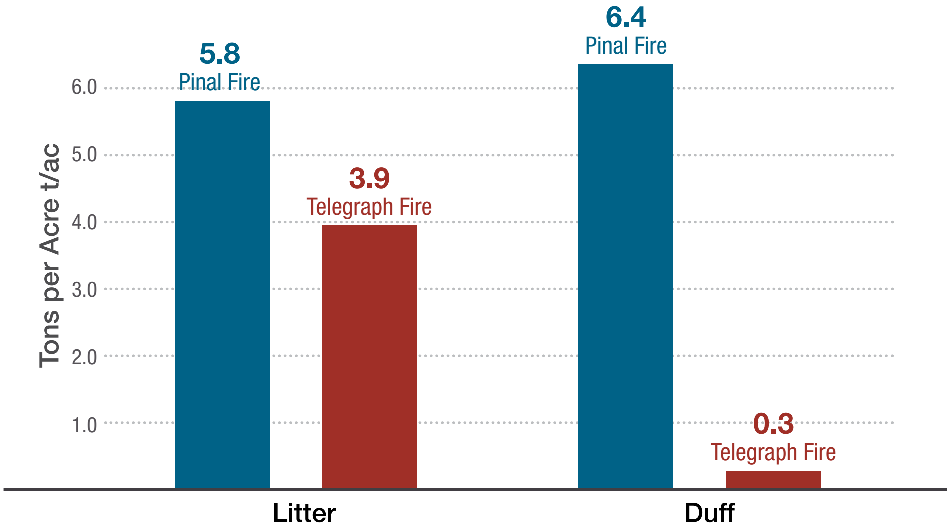

Figure 4— *Duff and litter loadings in ponderosa pine prior to the Pinal Fire (blue) and Telegraph Fire (red), in tons per acre. (Pinal numbers are averages from six transects, Telegraph from three).*

from transects in the ponderosa pine. It takes considerably longer for duff to develop than for litter to accumulate. The Pinal Fire reduced most of the litter and duff, burning under moderate conditions that resulted in mostly desirable fire effects. Though most of the duff burned, moisture near the soil surface would have minimized the heat transferred to soil by smoldering duff.

When the Telegraph Fire burned through the Pinal Fire footprint under much more extreme conditions, very little duff was available to burn. Young ponderosa pine litter burns quickly, transferring little heat into the soil; with very little duff, residence time would have been short and burned areas would have cooled quickly.

Fire Intensity and Soil Temperatures

Figure 5 shows three different combinations of fuel loading and burning conditions for the Pinal and Telegraph Fires based on the First Order Fire Effects Model (FOFEM 6.7). For each pair of graphs, the top graph shows soil heating (°C), with a red line indicating the temperature at the soil surface; the other five lines represent soil heating at depths of up to 16 centimeters below the surface. The bottom graph for each pair has a single line showing fire intensity (kW/m2). Each pair of graphs represents a different pairing of the conditions under which the Pinal and Telegraph Fires burned, including the fuel loading at the time.

The top pair (A) represents what happened on the Pinal Fire, with a higher fuel loading and moderate burning conditions. The conditions resulted in the lowest fire intensity and soil temperatures (less than 160 °C) and the second longest residence times (about 2.4 hours).

The middle pair (B) represents what would have occurred on the Telegraph Fire if the Pinal Fire had never happened. The model is based on fuel loading representative of the Pinal Fire and burning conditions at the time of the Telegraph Fire. The results show the highest fire intensity, the highest temperatures, and the longest

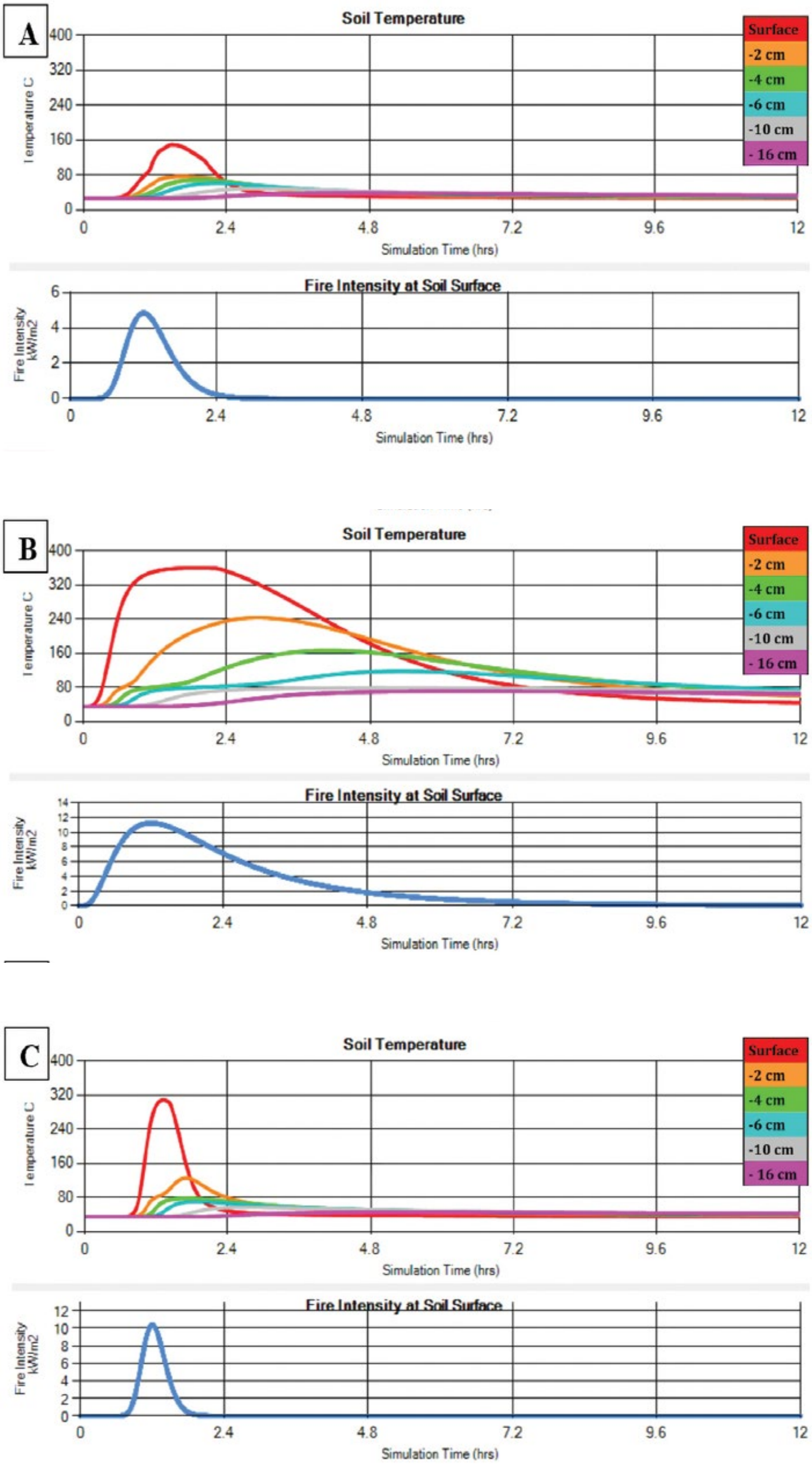

Figure 5— *Modeled fire intensity and soil heating (FOFEM 6.7). A: Pinal fuel loading burning under Pinal conditions. B: Pinal fuel loading burning under Telegraph conditions. C: Telegraph fuel loading burning under Telegraph conditions.*

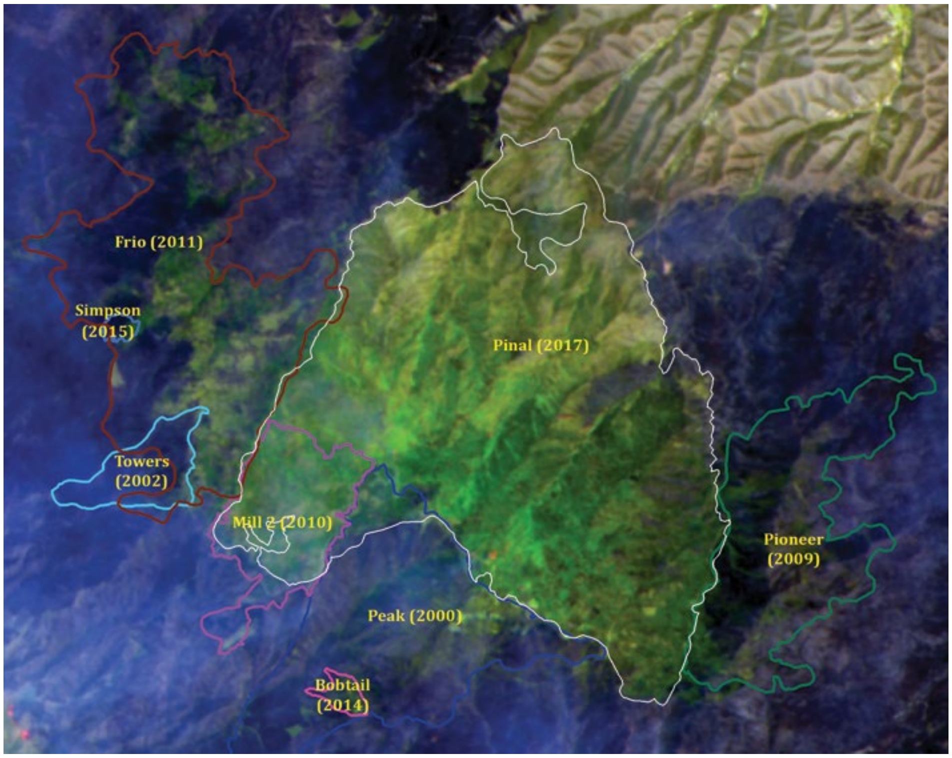

Figure 6—*Image of the Telegraph Fire taken on June 16 showing the perimeter of the Pinal Fire. Bright green areas indicate areas with low-severity fire effects, while the black shows high-severity fire effects. Moderation of fire severity is shown in the Pinal Fire footprint, along with some moderation to the east of the Pinal footprint (the 2009 Pioneer Fire) and to the west (the 2011 Frio Fire).*

residence times. Accordingly, the impacts on soils and vegetation would have been much greater than they actually were on either fire.

The bottom pair (C) represents what actually occurred on the Telegraph Fire, with Telegraph fuel loading and conditions. The fire burned with greater intensity and at higher temperatures than the Pinal Fire, but the reduced duff layer resulted in a much shorter residence time. Residence time is critical: a longer residence time allows more heat to transfer into the soil, tree boles, and roots, causing more damage than a much hotter fire with a short residence time.

Imagery taken during the Telegraph Fire shows some subtle and not-so-subtle differences in the effects that Pinal and previous fires had on the severity and behavior of the Telegraph Fire (fig. 6). In Figure 6, the bright green areas indicate areas with low severity, while the black shows high severity. The 2011 Frio Fire (west of the Pinal Fire) and the 2009 Pioneer Fire (east of the Pinal Fire) both moderated the effects of the Telegraph Fire somewhat.

MANAGEMENT IMPLICATIONS

Tree ring data, historical accounts, rates of woody encroachment, rates of fuel accumulation, lightning patterns, fire adaptations in plants, documented fire occurrences—all the evidence leaves no doubt that fire belongs in the Pinal Mountains. The interaction of the Telegraph Fire with the Pinal Fire and other past fires provides information on the needed fire frequency in the Pinal Mountains, and it starkly illustrates how not enough “good fire” inevitably leads to lots of “bad fire” on the landscape.

Historically, fires in chaparral were regulated by a mosaic of age classes mostly maintained by fire. The difficulty of controlling fire in chaparral that’s ready to burn is a major challenge for fire managers. When fire is withheld from chaparral, the fuel structure homogenizes, the fuel loading increases, and the potential for a large and intense wildfire grows. Observations by fire managers on the Tonto National Forest and monitoring of old fire scars suggest that it can take 8 to 15 years for chaparral to burn again after it has burned with high severity, depending on site-specific variables.

Fire in the forested parts of the Pinal Mountains has mostly been too infrequent to maintain the resilient fire-adapted landscapes typical of natural fire regimes. Data from Forest Inventory Analysis plots show that forested areas on the Tonto National Forest decreased by almost 25 percent from 1990 to 2013 (Makic and others 2022). The decline is mostly attributed to the historical suppression and exclusion of fires and the resulting shift in the character of fires that do burn. These fires are often uncharacteristically severe, resulting in the replacement of forested areas with chaparral-type ecosystems.

Since 2019, large fires have burned an additional 7 percent of the forested areas on the Tonto National Forest with high severity, mostly in forests that are disjoined from the larger, more contiguous ponderosa pine forests of the Mogollon Rim. For the remaining forests in the Pinals, a fire return interval of 10 years will probably be too long to avoid adverse effects under all burning conditions: Kaib (2001), based on data from 32 fire scars in the Pinal Mountains, determined that the natural fire return interval for the

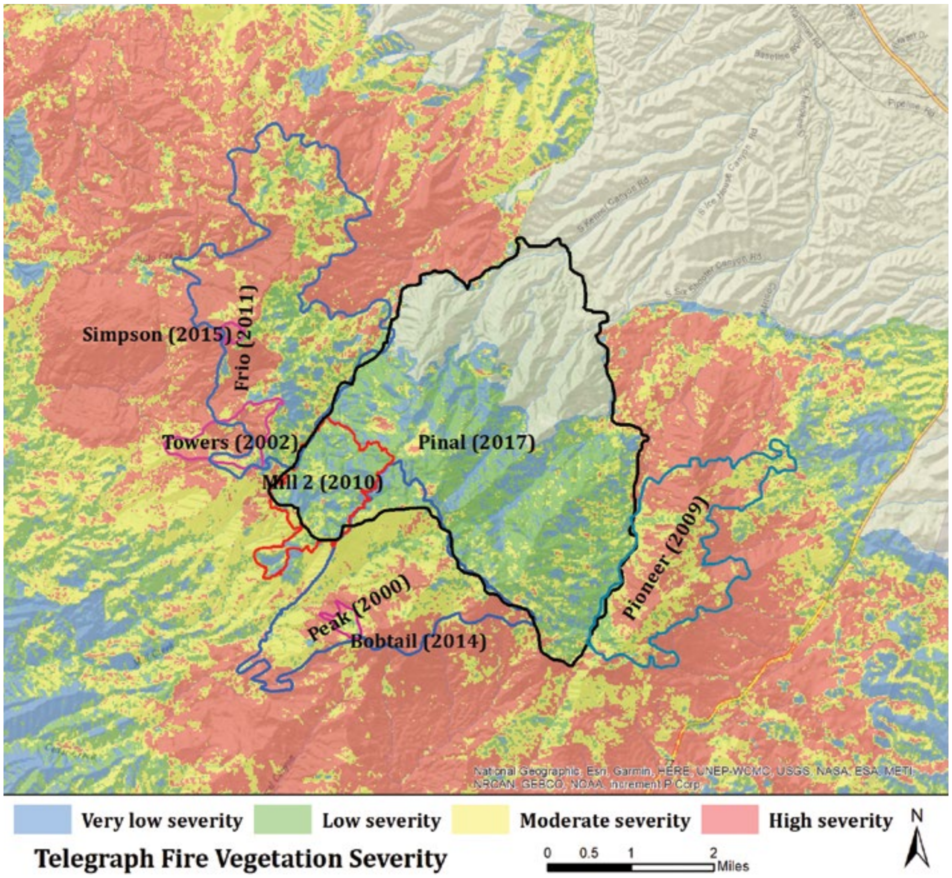

Figure 7—*Fire severity (for vegetation) on the 2021 Telegraph Fire was lowest (blue and green) in the fire scars of the most recent fires, with the 2017 Pinal, 2010 Mill 2, and 2011 Frio Fires showing the least severe fire effects in vegetation.*

Pinals was 2 to 10 years. The Telegraph Fire burned through all forested stands in the Pinals, and the severity of the corresponding fire effects was significantly lower in areas that had burned more recently (fig. 7).

Fire is an indispensable tool for regulating fuels. A fire return interval of not much more than 4 years could maintain the resiliency of the remaining forested vegetation in the Pinal Mountains. In addition to producing the desired effects, frequent fires that are mostly low in severity moderate subsequent fire behavior, expanding options for managing wildland fires. Effects in the footprints of the Frio and Pioneer Fires show that, on Pinal landscapes, a fire return interval of 11 years is too long if burning conditions are extreme.

The interaction of the Pinal and Telegraph Fires show that, in chaparral, the effects of high-severity fire will limit the size and spread of future fires for years. On the Telegraph Fire (outside of the Pinal Fire footprint), where shrub-dominated ecosystems burned with high severity, they will not reburn at all for at least 5 to 10 years and only under extreme conditions for an even longer period. Like the Pinal Fire did for the Telegraph Fire, such areas can serve as a "catcher's mitt" for adjacent areas that need fire, which can be managed with lower complexity and less risk.

ONLY A MATTER OF TIME

In the Pinal Mountains, with increasing fuel loads and multiple fire starts almost every year, it was only a matter of time before a fire that could not be suppressed would ignite on the cooler north aspects of Pinal and Signal Peaks, where most of the remaining forests in the Pinals are. The Telegraph Fire would likely have been that fire, causing much more damage than it did to forests in the Pinals, to homes and structures in the canyons, and to communities downstream that could have been affected by the fire itself or by ensuing flooding from the monsoon. But Telegraph stopped when it hit chaparral burned by the Pinal Fire, giving fire managers time to protect values along Russell Road. Telegraph also burned with much lower intensity and severity in forested areas within the Pinal Fire footprint than in less recently burned areas nearby.

Ecosystems are shifting in response to human impacts, including management actions, public activities, and climate change. The potential trajectories for the ecosystems managed by the Tonto National Forest are unclear, but working with natural fire regimes will be key to successfully managing public lands. Fire managers will continue to face the challenge of planning for desired fire behavior and effects on spatial and temporal scales that will effectively contribute to the health of entire fire-adapted landscapes.

The interplay of the Pinal and Telegraph Fires is typical of many areas across the country. Values at risk such as forests, streams, and wildlife are conjoined with values such as homes, infrastructure, historic/cultural sites, and communities; from a land management perspective, they cannot logically be separated. The relationship of a healthy ecosystem to the health and safety of communities is a critical factor in making decisions on how to manage wildland fire.

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Chumash Engine 802 crewmember cooling the fire's edge during a burn operation on Henness Ridge, Sierra National Forest, CA. USDA Forest Service photo by Kari Greer.

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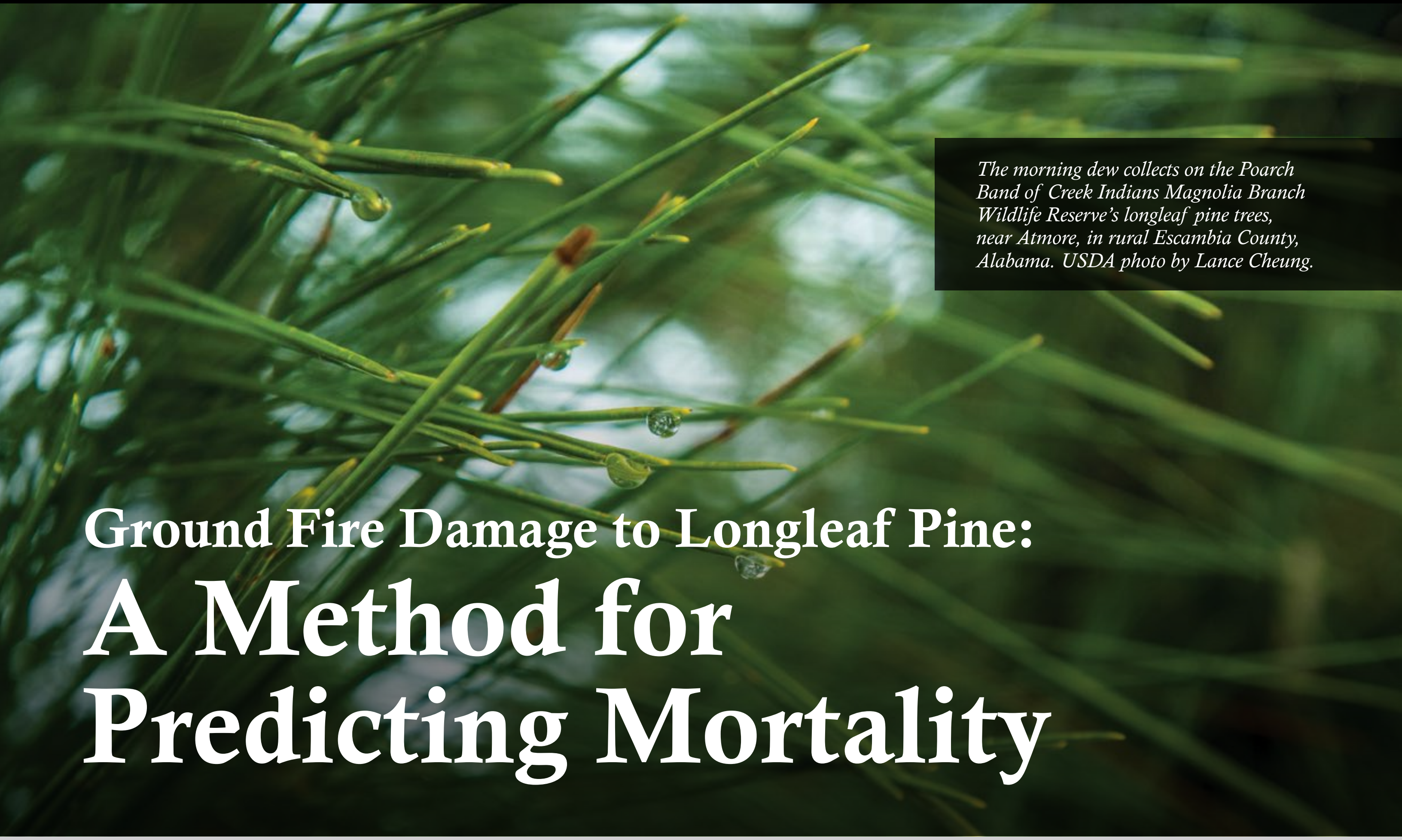

The morning dew collects on the Poarch Band of Creek Indians Magnolia Branch Wildlife Reserve's longleaf pine trees, near Atmore, in rural Escambia County, Alabama. USDA photo by Lance Cheung.

Ground Fire Damage to Longleaf Pine: A Method for Predicting Mortality

Crawford "Wood" Johnson and James Robert Meeker

Fire has played a significant role in the evolution of many conifer species by selecting for traits that confer resilience and encourage reproduction (He and others 2012). Longleaf pine (*Pinus palustris* Mill.) is an example in the Southeastern United States. It remains in a grass stage for multiple years, during which a sheath of long needles insulates the apical bud from heat during fires. During the grass stage, seedlings allocate resources to root development, providing the necessary energy for later rapid shoot growth.

As shoots grow, increasing bark thickness protects the underlying vascular tissue (the inner phloem, vascular cambium, and outer xylem) from the brief heat exposure generated by typically fast-moving surface fires (Chapman 1932; Wang and others 2016). These characteristics as well as the prevalence of recurring surface fires (every 1 to 10 years), which controlled competing vegetation and reduced surface fuel loads, historically favored the dominance of longleaf pine savannas on the Coastal Plain in the Southeast (Chapman 1932; Christensen 1981).

INCIDENCES OF TREE MORTALITY

In the absence of routine fire, forest litter and duff accumulate, particularly at the base of the larger trees that land managers aim to preserve (Kush and others 2004; Kreye and others 2020; Varner and others 2016). The reintroduction of fire into such long-unburned longleaf stands can, at worst, result in complete overstory mortality (Varner and others 2005; Varner and others 2007; Varner and others 2016). Although fire-related tree mortality often is a combination of bole and crown damage, it partly results from surface fires that do not reach the forest canopy. Smoldering combustion of organic matter within the duff layer during ground fires can destroy the fine roots growing there (O'Brien and others 2010) and generate sufficient heat over time to affect hydraulic conductivity and cause vascular tissue damage or necrosis (Hood and others 2018; Kreye and others 2017; Kreye and others 2020; Varner and others 2007; Varner and others 2016). Girdling of the stem and root collar prevents the translocation of photosynthates

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and stored carbohydrates needed to regenerate fine roots and otherwise support and maintain a viable root system. The crown and most of the bole might be unharmed, but the tree eventually dies from root starvation, lack of water, or a combination of physiological stress and insect and/or pathogen attack (Hood 2010; Hood and others 2018; Michaletz and Johnson 2007; Varner and others 2009).

Mortality following fire in such long-unburned areas typically occurs within the first 3 years (Kush and others 2004; O'Brien and others 2010; Varner and others 2005; Varner and others 2007). Efforts to model and predict postfire mortality include several measures of fire effects to individual trees and correlated physical tree characteristics (Hood and others 2018). Damage might not be immediately apparent; in the absence of crown scorch, vascular tissue damage at the base of trees has proven a reliable indicator in modeling postfire mortality of western U.S. conifers (Hood and others 2010; Ryan and Reinhardt 1988; Ryan and Frandsen 1991). Vascular samples are obtained with a drill and hole saw or increment borer at various aspects of the tree and samples are evaluated visually; generally, as the surface area of trees with dead vascular tissue increases, tree mortality increases (Hood and others 2007; Hood and others 2010; Ryan 1982). Such methods have not been used to predict mortality of longleaf or other southern yellow pines.

POSTFIRE TEST SITE

On October 31, 2017, a wildfire occurred overnight in the 1.7-acre (0.7-ha) Longleaf Vista Recreation Area on the Kisatchie National Forest (Natchitoches Parish, LA; N 31.475574°, W -92.999023°). The region was abnormally dry in the weeks leading up to the event, and a weather station 12 miles (19 km) away indicated a Keetch-Byram Drought Index (KBDI) value of 673 on that day (U.S. Drought Monitor maps; station 161803, Natchitoches, LA). Fires ignited in high KBDI conditions (600–800) can be expected to totally consume the duff layer and expose bare mineral soil (Melton 1996). The Longleaf Vista Recreation Area is mowed routinely and had not burned in recent memory, according to local ranger district personnel on the Kisatchie National Forest. The litter and duff layers were likely relatively deep and mounded at the base of trees prior to the fire.

On our initial visit on July 17, 2018, we found that the duff layer around the bases of trees had in fact been consumed, and internal sampling revealed browned cambia and resin-soaked xylem on several otherwise healthy trees (fig. 1). We observed no evidence of crown scorch and only minimal heights of bark charring on the 185 standing trees. In many cases, the entire organic layer had been eliminated around the bases of trees, exposing bare mineral soil and leading to a paucity of vegetative regrowth for as long as 21 months following the fire (fig. 2).

Thus, damage was most likely the result of the intense and prolonged heat created by the consumption of accumulated duff near and around the bases of the trees. This article reports the findings of a vascular tissue sampling method like that described by Hood and others (2007), as well as the noted presence/absence and severity of resin weeping, insect colonization, and other physical tree attributes as predictors of delayed mortality in longleaf pine in the 34 months following the ground fire.

METHODS

To determine the extent of damage and chronicle impending tree mortality, from July 27 to August 2, 2018, we tagged all pines greater than or equal to 4 inches (10.2 cm) in diameter at breast height. For each tree, we recorded:

- Tree species,
- Diameter at breast height,
- Crown canopy position,
- Vascular tissue damage, and
- Crown health status.

Crown health scores (0–4) were assigned based on percent crown fading

Figure 1—*Reddish-brown, resin-soaked cambium and outer xylem, indicative of potential basal girdling of a longleaf pine due to a duff-consuming ground fire. Also note the resin weeping, basal bark consumption, and bare mineral soil (lower right), indicative of a long-duration smoldering ground fire generating intense heat. USDA Forest Service photo by J.R. Meeker.*

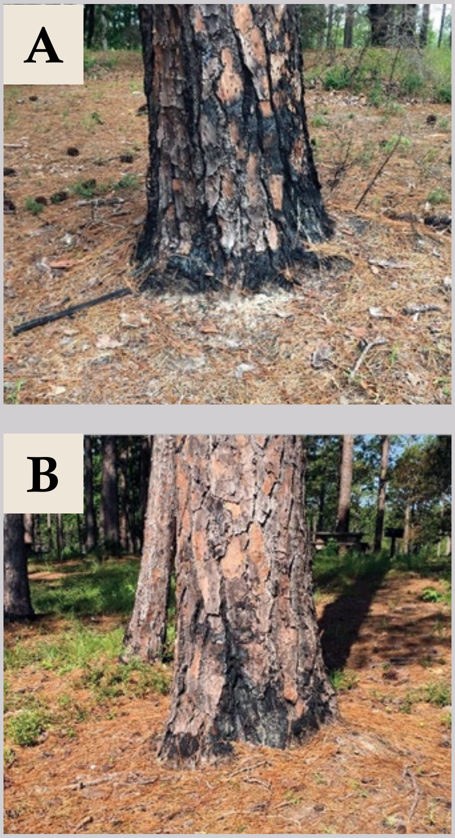

Figure 2—*Characteristic burn rings of a long-duration smoldering ground fire around the base of trees, exposing bare mineral soil and showing little if any new vegetative growth or regrowth (sprouting) 9 months following the fire, July 2018 (A) and 21 months following the fire, July 2020 (B). USDA Forest Service photos by J.R. Meeker.*

and dieback; a score of 0 denoted a healthy crown with no observable dieback, and a score of 4 was for a tree that was entirely red/fading.

To determine vascular tissue damage, core samples (to a depth of 4 inches (10.2 cm) in tree) were collected within 3 inches (7.6 cm) of ground level from each cardinal aspect using a 5.15-millimeter increment borer (Haglöf Sweden®) and scored as "H" if the inner phloem, vascular cambium, and outer xylem appeared normal and as "D" if the vascular tissue was red-brown in color and resin soaked (fig. 3) (after Hood and others 2007). Scores from each aspect were summed for a total tree vascular damage score (with a score of 4 denoting all four aspects damaged).

During our initial visit, we also recorded the presence or absence of the following in the basal 16 feet (4.9 m) of each tree:

- Resin weeping from bark fissures;
- Southern pine sawyer (SPS) (Coleoptera: Cerambycidae: *Monochamus* spp.) egg niches;
- Ambrosia beetle (AB) (Coleoptera: Curculionidae: *Scolytinae* and *Platypodinae* spp.) boring dust; and
- Black turpentine beetle (BTB) (Coleoptera: Curculionidae: *Dendroctonus terebrans* (Olivier) and/or Ips engraver beetle (Coleoptera: Curculionidae: *Ips* spp.) attacks.

Insect attacks were noted only when visible in the lower portion of the tree bole. Beginning July 27, 2018 (269 days postfire), 21 tree evaluations were conducted over the following 25 months to record tree crown health as a proxy for tree health. Evaluations were discontinued following the impacts of Hurricane Laura in the area on August 27, 2020.

ANALYSIS

We conducted categorical analyses to first test for meaningful associations between the tree variables measured on our initial visit and the final crown health score (as a proxy for overall tree health). Except for diameter at breast height, most measurements taken were either categorical (that is, variables such as sex or race with no intrinsic order, such as tree species, resin weep at a given aspect, and insect presence/absence) or ordinal (that is, variables that can be ordered numerically, such as crown class, crown score, and vascular damage score). The time to death (TTD)—that is, the number of days from the date of the fire—was converted from a numerical to a categorical variable with four categories:

Figure 3—*Basal core sample (July 2018) from a longleaf pine considered "damaged" following a long-duration smoldering ground fire. Note the resin-soaked outer layers of xylem in the right half of the sample. USDA Forest Service photo by J.R. Meeker.*

- 1 = dead at first visit (269 days post fire; July 31, 2018);
- 2 = death between days 269 and 468;
- 3 = death between days 469 and 1,017; and
- 4 = alive at day 1,017 (the day of the last visit, Aug. 13, 2020).

Categories 2 and 3 were chosen to evenly split into two categories the number of trees that died between visit 1 (day 269) and visit 4 (day 1,017).

We used TTD in contingency table tests for association—that is, crown score at visit 1 versus TTD; and total vascular damage score versus TTD. The total vascular damage score was ordinal but highly discrete, and days to death was truncated because most trees (143 of 185) either died before our first visit or lived beyond our last visit. Our statistical analyses for assessing relationships between variables were therefore methods suited to categorical and ordinal data.

To test for association between two variables where the row variable was strictly categorical and the other column variable was ordinal, we used the Cochran-Mantel-Haenszel (CMH) test for equality of row scores; and if both variables were ordinal, we used the CMH test for correlation (Cochran 1954). Analyses were performed using PROC FREQ of SAS (SAS v. 9.4) with OPTION CMH to obtain the test for correlation (CMH statistic 1) or for equality of row scores (CMH statistic 2). When excavations began, 24 trees were dead; these trees were excluded from analyses involving prediction of death based on information collected upon our initial visit (vascular damage, resin weep, and insect activity). Due to the very low numbers of shortleaf (5 percent) and loblolly (3 percent) pines, we combined these species with longleaf pine for all analyses.

Finally, we tested the variables for diameter at breast height, crown class, resin weep, and vascular damage to determine which would be the most useful predictors of latent mortality (and survival beyond the 2.7-year study period) using logistical regression (PROC GENMOD, SAS v. 9.4). We used backward elimination to identify the best predictors and omit unnecessary variables. The 24 trees that were dead when the study began were also omitted from regression analyses.

RESULTS

About 196 total living pines occupied the affected area prior to the fire. During the 268 days before our first evaluation at the end of July 2018, 11 trees were felled and removed; all 11 trees had been killed by the fire, according to ranger district personnel. The remaining 185 pines ranged in diameter at breast height from 3.8 to 31.0 inches (9.6–78.7 cm). Despite this wide range, tree diameter varied little, with an overall mean diameter (standard error (S.E.) ±1) at breast height of 13.4±0.34 inches (34.0±0.86 cm). The mean age (±1 S.E.) of three dominant/codominant longleaf pines cored at 12 inches (30.5 cm) above ground was 82±2.6 years (duration of grass stage unknown).

During the 34-month monitoring period following the ground fire, 77 pines (39 percent of the total) died. Nearly 70 percent of the observed mortality occurred within the first year, typically during the summer and fall months. The rate of annual tree mortality decreased over the duration of the study (fig. 4).

CMH tests of association indicated that tree survival 34 months after the fire was significantly related to the vascular tissue damage observed during our first visit (figs. 3, 5; $\chi 2 = 28.77$, df = 1, $p < 0.001$). The 25 trees with no observed vascular damage all survived to the last visit; of the trees with one, two, three, or four aspects of vascular damage, 9 percent, 25 percent, 39 percent, and 53 percent, respectively, had died by our last visit.

Although results indicated a strong relationship between basal vascular damage and tree mortality, vascular damage was not an infallible predictor. Five trees declared dead by the crown score on our first visit had fewer than four aspects of obviously damaged vascular tissue. Mortality was also significantly associated with resin weep ($\chi 2 = 25.30$, df = 1, $p < 0.001$), though this association was weaker than that between vascular damage and tree mortality. Crown class (dominant, codominant, and so on) was not associated with mortality ($\chi 2 = 3.57$, df = 1, $p < 0.0587$).

On our first site visit (7 months following the wildfire), we observed a

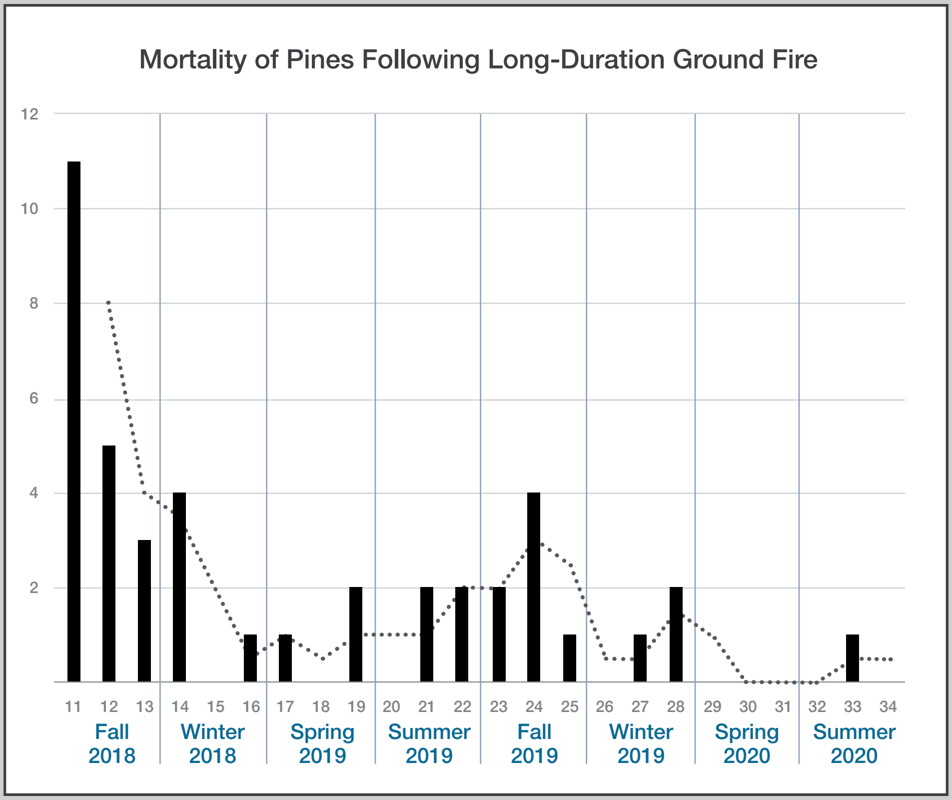

Figure 4—*Monthly mortality of pines (bars) and 2-month moving average mortality (dotted line) beginning 11 months following a long-duration smoldering ground fire (September 2018 to August 2020).*

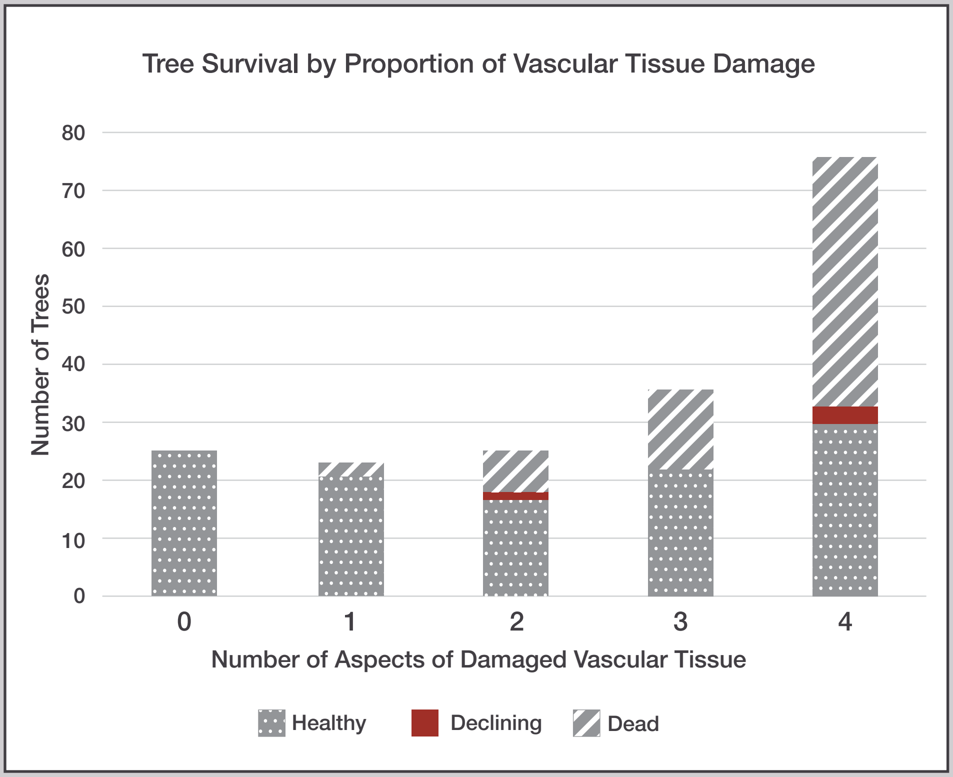

Figure 5—*Relationship between tree survival and vascular tissue damage by visual estimation 34 months following a long-duration smoldering ground fire.*

positive association of insect activity with vascular damage, including:

- SPS egg niches ($\chi2 = 15.06$, df = 1, $p < 0.0001$);
- BTB attacks ($\chi2 = 9.25$, df = 1, $p < 0.0024$); and
- AB attacks ($\chi2 = 13.11$, df = 1, $p < 0.0003$).

We observed insect activity on no more than 8 percent of the trees with no or one aspect of cambium damage. On trees with four aspects of cambium damage, we noted SPS niches as well as AB and BTB attacks on 26 percent, 21 percent, and 32 percent of the trees, respectively. Although we did not observe Ips engraver beetle attacks on any trees on our initial visit, each of the 13 trees with healthy crowns noted in previous evaluations that were later attacked and colonized by Ips (and died) had sustained vascular damage in three or more tree aspects. Failed Ips attacks were noted in only two cases, where vascular damage was observed in two and three aspects of the tree, respectively. No Ips attacks were observed in any trees sustaining no damage or damage in only one aspect.

For observations on our first site visit 7 months following the ground fire (omitting trees already dead), logistic regression analyses using backward elimination indicated that neither diameter at breast height ($\chi2 = 0.05$, df = 1, $p < 0.82$), crown class ($\chi2 = 3.12$, df = 1, $p < 0.37$), resin weep ($\chi2 = 0.45$, df = 1, $p < 0.50$), nor BTB attacks ($\chi2 = 0.90$, df = 1, $p < 0.34$) were significant predictors of mortality; therefore, we dropped them from the model. In our final model after backward elimination, the following variables provided the most predictive power of mortality (up to 34 months following the wildfire):

- Vascular damage ($\chi2 = 14.64$, df = 1, $p < 0.0001$);
- SPS egg niches ($\chi2 = 6.57$, df = 1, $p < 0.0104$); and
- AB attack ($\chi2 = 5.15$, df = 1, $p < 0.0233$).

> **Using a simple visual estimation method, we found that vascular damage/mortality is the best single predictor of longleaf pine mortality.**

DISCUSSION

Conifer mortality following fire damage can occur over a period of several years. Tools and methods for accurately predicting delayed mortality can assist in making appropriate management decisions. This article reflects the results of the first application of a rapid vascular sampling method, as well as the potential use of resin weeping and insect activity, as a tool to predict latent mortality in longleaf pine following a ground fire.

Using a simple visual estimation method, we found that vascular damage/mortality is the best single predictor of longleaf pine mortality 34 months following a ground fire—better than resin weep, insect activity, and physical tree characteristics.

Despite the significant positive correlation between apparently damaged vascular tissue and tree mortality, 58 percent of the total trees at the Longleaf Vista Recreation Area with four aspects of vascular tissue damage remained alive after the 34-month observation period. Possible explanations for this unexpected result include the duration of the postfire observation period and/or sampling error. Others report that most postfire mortality among southern yellow pines often occurs within the first 3 years (Ferguson 1960; Hanula and others 2002; Sullivan and others 2003; Varner and others 2005; Varner and others 2007), but a small percentage of the mortality could occur beyond 3 years (O'Brien and others 2010); few studies of southern yellow pines extend beyond 3 years. In studies of western U.S. conifers, ponderosa pine (Swezy and Agee 1991) and Douglas-fir (Ryan and others 1988) continued to die up to 5 and 8 years, respectively, following a wildfire.

At Longleaf Vista, our observation period ended due to the confounding effects of Hurricanes Laura and Delta, which might have prevented us from observing later additional mortality. The unexpected survival of trees with high proportions of vascular tissue damage might also be explained by sampling error, such as the misidentification of tissue health or the prevalence of undamaged tissue between the four small sample points for each tree, which represented a small proportion of the total tree circumference. Similar studies of delayed Douglas-fir and ponderosa pine mortality following wildfire, rather than relying on subjective visual scoring of tissue status, performed chemical analyses on collected cambium samples to detect dead tissue, a more objective measure (Ryan and others 1988; Ryan and Frandsen 1991). However, although this method would control for subjective sampling error, it would be costly and perhaps infeasible where large numbers of trees are involved.

Some have reported that large trees are more likely to die following a duff-consuming wildfire due to the greater depth of combustible material that accumulates at the base of trees (Ryan and Frandsen 1991; Varner and others 2007); others have reported no difference or opposite trends in some western U.S. conifers (Hood and others 2010). We observed a trend towards greater mortality of the larger diameter trees, yet we found no significant relationship between diameter at breast height, conductive tissue damage, and mortality. This lack of a strong difference might in part be attributed to the relatively uniform size of trees at the site we tested, reflected in the small standard error of the mean diameter at breast height (13.4±0.34 inches (34.0±0.86 cm)) and therefore similar duff accumulation depths at the bases of trees.

Most trees suffering severe vascular tissue damage from wildfire will die, but trees with less damage can recover. However, environmental factors such as drought, both before and after fire, can create additive or synergistic effects leading to mortality (Hood and others 2018; Kane and others 2017; Slack and others 2016). Conditions in central and northwestern Louisiana in the weeks before the fire were abnormally dry, and the region was in a moderate drought (with a Palmer Drought Severity Index of –2.0 to –2.9) during the normally wet winter months of 2017–18 and for a few weeks in July 2018; only then did conditions improve and remain stable for the duration of the study (U.S. drought monitor maps). The dry conditions preceding the fire enabled deep duff layer combustion, resulting in significant basal vascular damage and direct mortality of fine surface roots. In addition, the loss of the organic layer would have adversely affected soil moisture retention, physical structure, and chemistry (Neary 1999). Thus, some delayed tree mortality likely resulted from fire-caused damage to the basal vascular tissue and fine roots, coupled with the inability of trees to regenerate roots in a compromised soil environment during the persistent dry conditions in the months following the fire.

The effects of droughty conditions from late 2017 to mid-2018 might also have been exacerbated by insect and/or pathogen pressure. The Ips engraver beetles, SPS, and ABs associated with southern yellow pines are typically considered secondary pests that colonize severely stressed or dead hosts (Baker, 1972; Coster, 1969; Gandhi and others 2019; Munro and others 2019). Many of these species also are attracted to southern yellow pines stressed or killed following wildfire (Ferguson and others 1960; Hanula and others 2002; Haywood and others 2015; Menges and Deyrup 2001; Sullivan and others 2003). We observed attacks and colonization by *Ips calligraphus* (Germar) and BTB; we also saw the damage (dust/frass) produced by colonizing platypodine and xyleborine ABs on the lower boles of trees in close synchrony with fading crowns. Although it is difficult to say for certain whether damaged trees would have died in the absence of the observed insect activity, these agents certainly contributed to tree decline.

Other species of insects at Longleaf Vista that were not targeted for detection but could have played a role in pine mortality include *Ips avulsus* (Eichoff) and possibly *Hylastes salebrosus* (Eichhoff) and *H. tenuis* (Eichhoff) (Coleoptera: Curculionidae: Scolytinae). Ips avulsus attacks branches or small-diameter materials on weakened (or cut) southern yellow pines (Berisford and Franklin 1971) and can occasionally create small infestations in apparently healthy trees (Thatcher 1960). Trees weakened by the fire at Longleaf Vista would almost certainly have been attacked by this Ips engraver beetle, but the height of the trees prevented close observation prior to mortality.

Hylastes salebrosus (Eichhoff), *H. tenuis* (Eichhoff), *Pachylobius picivorus* (Germar), and *Hylobius pales* (Herbst) feed on the roots of weakened trees

*Forest of longleaf pine (*Pinus palustris) *in Green Swamp Preserve in North Carolina in early April. Adobe Stock.*

(Baker 1972; Wood 1982) and are known to be attracted to longleaf pine and other southern yellow pines following fire (Hanula and others 2002; Sullivan and others 2003). *Hylastes* spp. beetles also are associated with weakly pathogenic root fungi, which can play an adventitious role in fine root mortality following wildfire and other disturbances (Eckhardt and others 2004; Hanula and others 2002; Otrosina and others 2002; Sullivan and others 2003). Some or all of these biotic agents possibly contributed indirectly to the decline of trees at Longleaf Vista.

A COARSE PREDICTIVE TOOL

This is the first study to evaluate an ocular assessment of vascular tissue samples as a tool to estimate latent longleaf pine mortality following a ground fire. Although this method can be used as a low-cost coarse predictive tool, it might overestimate mortality within the timeframe reported here and does not provide the accuracy necessary to base management decisions on an individual tree basis. Future study of a rapid evaluation method of vascular tissue sampling in southern pines should focus on balancing increased sample intensity (per tree) with the corresponding sampling damage to the surviving trees and the potential use of chemical analysis for determining tissue necrosis.

ACKNOWLEDGMENTS

The authors thank Brian Strom for field assistance and subject matter discussions preceding this evaluation. We also thank Billy Bruce, Chris Steiner, Aaron Rachal, Karen Reed, Ben Parpart, Jaesoon Hwang, Alex Mangini, and Thomas Stokes for their invaluable field assistance. In addition, we thank the personnel of the Kisatchie Ranger District, Kisatchie National Forest, including former District Ranger Mike Dawson, Timber Management Assistant Kelly Boles, and Fire Management Officer Steven Staples for their support, information, and guidance in this monitoring study.

Using a simple visual estimation method, we found that vascular damage/mortality is the best single predictor of longleaf pine mortality.

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A cross-boundary prescribed burn on the Fremont-Winema National Forest and The Nature Conservancy's Sycan Marsh in south-central Oregon, October 2019. USDA Forest Service photo by Sarah J. Flanary.

Going 3D With Fuel and Fire Modeling: FastFuels and QUIC-Fire

Russ Parsons, Lucas Wells, Anthony Marcozzi, Rod Linn, Kevin Hiers, Francois Pimont, Karin Riley, Ilkay Altintas, and Sarah Flanary

Climate change, drought, insect outbreaks, and deteriorating ecosystem health have put the Nation's forests and wildlands on an increasingly unstable trajectory. Such developments are raising the stakes in—and adding uncertainty to—decision making in wildland fire and fuels management (IPCC 2022).

NEED FOR NEW MODELING

Fuel is the part of the fire behavior triangle that we can directly affect. So, we know that we need to get more proactive with fuels treatments and prescribed fire if we want to get a better handle on the fire situation. As we shift towards more prescribed fire and fuels treatments, information for fuel and fire managers also needs to shift.

One clear difference is that the time scale for asking questions becomes less immediate, allowing more time for identifying and quantifying differences between alternatives. In this context, we need more detailed information about fuels. In many cases, the options for how we treat (or burn) depend a lot on the fuels we have. Given a particular stand structure, composition, and condition, what could be done? How will a treatment alter fuel loads now and in the future? How will such changes alter fire behavior? Under what conditions? The greater detail needed to answer these questions adds complexity but also offers more tangible pathways to solutions.

With respect to prescribed fire, how we lay out the ignition over time and space has a profound impact on both the fire behavior and fire effects as well as how much smoke is produced and where it goes. Numerous factors affect fire intensity and plume dynamics in prescribed burns, so modeling should ideally help untangle complexity and expose risk-based tradeoffs in treating fuels and planning prescribed fires.

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At present, however, operational decision support systems in the United States are built on well-known but simple fire models primarily oriented towards suppression (Rothermel 1972). Though fast, the models do not account for a fire's physical processes and plume dynamics, and they operate at coarser detail with respect to fuels and fire behavior than is needed for prescribed fire and fuels treatment analysis (Hoffman and others; Parsons and others 2018).

Advanced-research, "full-physics," coupled-fire-atmospheric fire models (such as FIRETEC (Linn and others 2002) and the Wildland Urban Interface Fire Dynamics Simulator (WFDS) (Mell and others 2007, 2009)) address fire physical processes, fuel/fire interactions, and plume dynamics in sophisticated mechanistic detail, but their high computational demands make operational use difficult (Mell and Linn 2017). Recent developments of "reduced fire physics" models such as QUIC-Fire (Linn and others 2020) and the level-set formulation of WFDS (Bova and others 2016) enable faster-than-real-time calculations but still capture key aspects of plume dynamics, fire behavior, and smoke transport over much larger and more operationally relevant extents (Gallagher and others 2021). Although such models offer remarkable new possibilities, their application and use have so far been greatly limited by a lack of three-dimensional (3D) input data.

For several years, our research team has worked to close the gap between data and models. We started at the scale of individual trees and groups of trees (Caraglio and others 2007; Parsons and others 2011), then moved on to stand scales (Pimont and others 2016; Parsons and others 2018). The data needs of 3D fire models are substantial, and sophisticated methods are needed to translate trees into "voxels"—volumes that contain data, like pixels in an image. This translation process can work with a variety of formats; it typically uses modeling to extend data in different ways, either from a limited set of observations (such as a plot) to a larger modeled set (such as a stand) or to impute key attributes that were not directly measured (Pimont and others 2016; Parsons and others 2018).

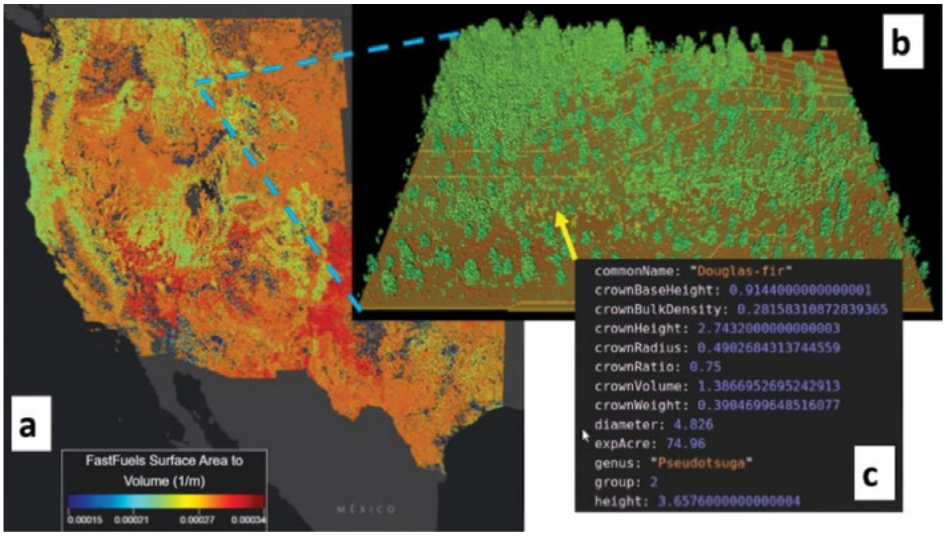
In 2018, our team developed a stand-scale platform called STANDFIRE (Parsons and others 2018), designed to make it easier to use 3D fire models at stand scales. STANDFIRE is a 3D fuel and fire modeling system that expanded on key developments in FuelManager (Pimont and others 2016) by linking the Forest Vegetation Simulator (Crookston and Dixon 2005), an empirical forest growth model, to both WFDS and FIRETEC. This linkage between forest fuel and fire models enables 3D fuel modeling and stand-level fire analysis for all major forest species in the United States using commonly available forest inventory data.

However, forest inventory data is by nature drawn from plots, so it is not "wall to wall" (continuous) over larger areas. The stand-scale focus in STANDFIRE was useful for fuels treatment analysis, but the lack of "wall-to-wall" data over larger areas limited the use of advanced fire models. To build capacity to use these models to their full potential, we needed to close this gap.

CLOSING THE GAP

To provide data for use with advanced fire models over large areas, our team is currently developing a prototype fuel modeling platform called FastFuels, which substantially reduces the "data-to-models gap." FastFuels links STANDFIRE architecture to forest plot data from the Forest Service's Forest Inventory and Analysis (FIA) program, leveraging "wall-to-wall" TreeMap data built on statistical imputation and machine learning (Riley and others 2021) and other spatial data, essentially providing plot-level data details but at landscape scales.

Designed to work via high-performance computing or cloud servers with an automated "data-on-demand" model (focusing on a specific spatial area), FastFuels provides detailed 3D fuels inputs suitable for advanced fire models such as QUIC-Fire. Expanding our capabilities through partnership in a recent National Science Foundation project called the WiFIRE Commons, the team used our FastFuels architecture to build 3D voxelized fuels at 1 m3 resolution for the entire conterminous United States (fig. 1). The data can also be viewed interactively (*to use the interactive viewer, turn on the Forest Service FastFuels data in the menu in the upper right, navigate to a forested area, and click on the map*).



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crownBaseHeight: 0.9144000000000001
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crownHeight: 2.7432000000000003
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crownRatio: 0.75
crownVolume: 1.3866952695242913
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expAcre: 74.96
genus: "Pseudotsuga"
group: 2
height: 3.6576000000000004
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Figure 1—*FastFuels provides seamless fuels data for physics-based fire models as high-detail 3D arrays over vast areas, opening the door for operational use of advanced fire models to support fuels treatment and prescribed fire planning and implementation. Prototype data have been developed for the continental United States (a) and can be viewed interactively as 3D voxels (b). Voxel data are driven by underlying tree-list-level data (c).*

FastFuels is envisioned as a 3D fuels "superhighway," accelerating the use of 3D fire models by leveraging FIA databases and other available spatial data and then combining the data with cutting-edge modeling to enable the use of 3D fire models at landscape scales. In addition to providing voxelized (3D raster) data for 3D fire models, FastFuels retains individual tree attribute data, facilitating in-depth fuels treatment analysis and paving the way for stronger fire behavior/fire effects interactions. Similarly, FastFuels also seeks to facilitate use of data from new sources (such as lidar and unmanned aerial systems) and new techniques emerging in the fields of remote sensing and wildland fuels science. Along these lines, a series of specialized "on-ramps" are envisioned to enable rapid incorporation of detailed data for specific areas.

This team is currently working on on-ramps for both airborne lidar data (airborne laser scanning) and terrestrial lidar scanning data. The on-ramps concept enables us to update our baseline FastFuels data with more local and specific data. In this case, these on-ramps enable us to incorporate highly detailed fuels data over large areas (often tens of thousands of acres or larger) or extremely high detail for small areas (usually less than an acre), capturing both landscape and plot scales. These data on-ramps provide a means by which fuels maps can be more rapidly updated, and they also enable the use of existing lidar data to better effect in fuels and fire management.

FastFuels is currently configured to produce 3D fuels inputs for the fast-running 3D fire model QUIC-Fire (fig. 2). However, FastFuels is intended to support many modeling tools; it will be expanded to provide inputs for a larger set of fire models. An additional benefit of going 3D is that 3D fuels and fire behavior simulation outputs can be represented dynamically in videos or interactively with virtual reality. These capabilities will help in developing advanced firefighter training environments (fig. 3).

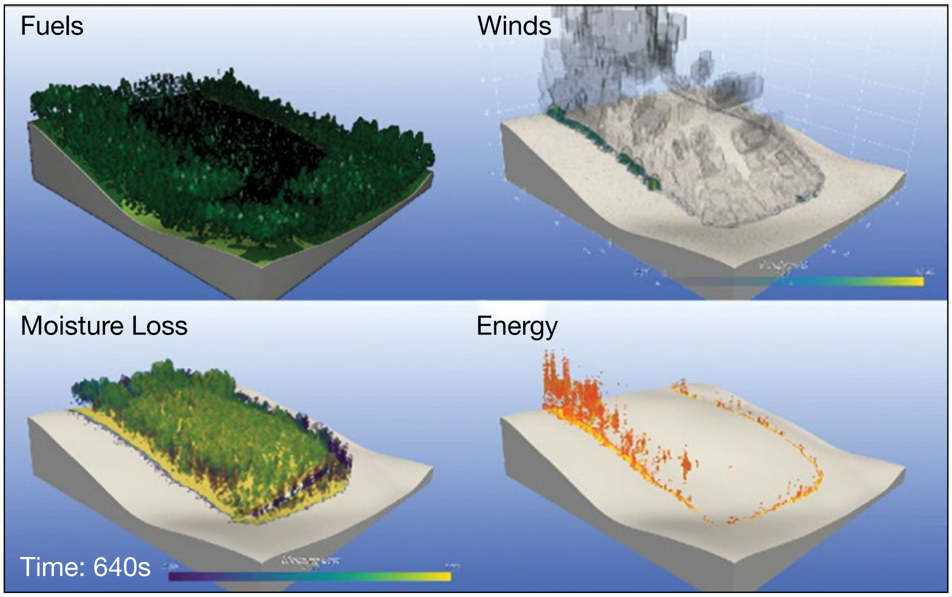

Figure 2—*Example of a 3D fire simulation with QUIC-Fire using FastFuels data. Panels show different aspects of the same simulation, including topography and fuel consumption (upper left), moisture loss (lower left), vertical energy to the atmosphere (lower right), and 3D plume and surface winds (upper right). Simulations are dynamic in space and time and can be viewed as videos. A link enables the user to view the FastFuels-QuicFire Demo video.*

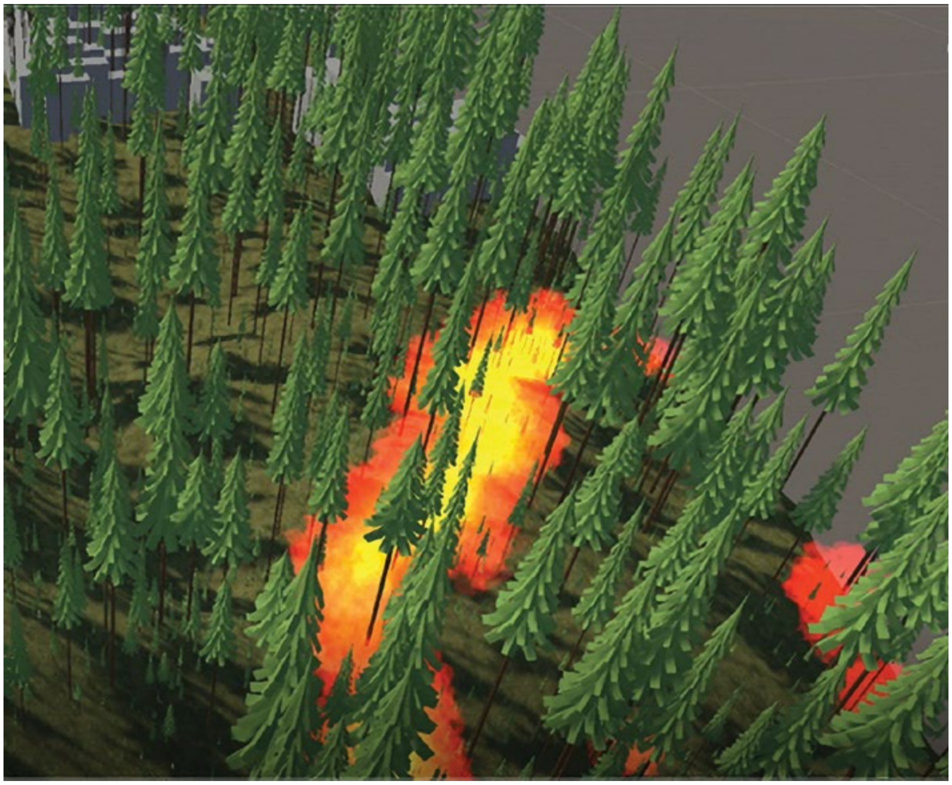

Figure 3—*3D immersive visualization in virtual reality, illustrating the connection between FastFuels data, dynamic 3D fire behavior, and virtual reality visualization using the Unity platform.*

NEXT STEPS

FastFuels is still in active development, and the development team is very excited about its potential. The team is currently creating tools to enable silvicultural detailed fuels treatments with FastFuels data, on-ramps to incorporate lidar data, and tools to enable detailed ignitions over space and time. We hope that these developments will accelerate innovation in—and the application of—advanced fire modeling.

FastFuels and QUIC-Fire are not intended to replace current systems but rather to complement and expand the existing toolbox for fuel and fire managers. The development team hopes to integrate these new tools into existing tool suites, such as IFTDSS (the Interagency Fuel Treatment Decision Support System). We also hope that having more interactive 3D visualizations of fuels and fire behavior will help improve firefighter training and communication with stakeholders making fuels management decisions.

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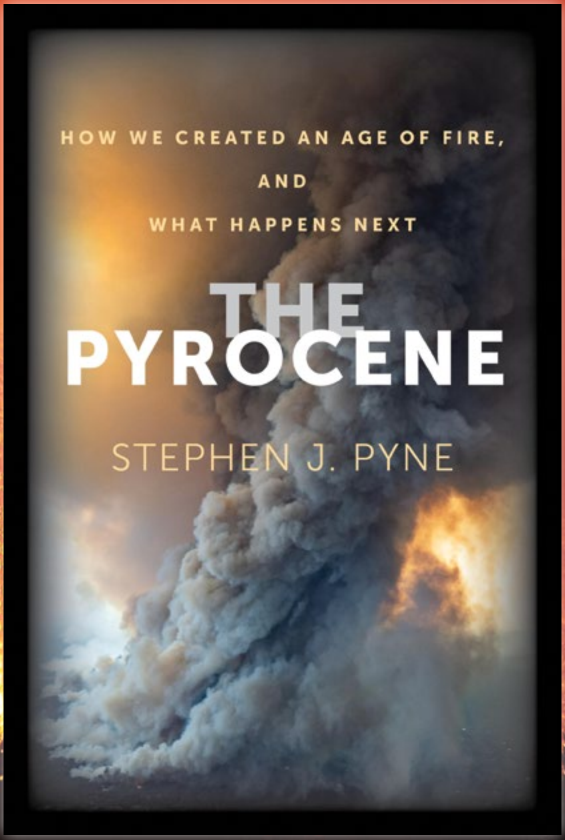
Erratum

Fire Management Today volume 80(1), in the article "COVID 'Shots: Hotshot Superintendents Reflect on the COVID Fire Year of 2020" by Emily Haire, showed an incorrect caption for the photo at right; the corrected caption follows.

Wyoming Interagency Hotshot Crew members cooking jerk chicken on the 2020 Lost Creek Fire in Oregon. The crew took to heart the challenge of becoming self-sufficient for meals through the use of a kitchen trailer, resulting in increased camaraderie and cohesion. USDA Forest Service photo by Kyle Miller.



Fire Age—or the Really Big Burn

Jacket cover for "The Pyrocene."

Stephen J. Pyne

The fires are getting bigger. A century ago, we had blowups and then campaign fires; next came fire sieges and megafires, and now we have gigafires. All these burn in living landscapes. It's not just that the fires are large in area but that they have a high percentage of high-severity burns. We've gone from a Big Blowup to a Big Blowback.

A similar expansion of scale is true for fire in its other expressions, especially the transition to the burning of fossil fuels (or lithic landscapes). Here, we've expanded from forges to combustion chambers and now to the planet as a crockpot. We've gone from fire as an event to fire as a geologic epoch.

FIRE AS A GEOLOGIC EPOCH

This is the premise behind the concept of a Pyrocene. The Pyrocene is the complement to the Pleistocene, the 2.6 million years just before the present, an epoch dominated by recurring ice ages. Those glaciations were characterized by climate change, ice masses (some continental), huge shifts in biogeography, periglacial landscapes (from permafrost to outwash plains), pluvial lakes, rises and falls in sea level, and mass extinctions. Ice created the conditions for more ice. Milankovitch cycles, based on planetary wobbles and orbital stretching that affected the intensity of sunlight, interacted with

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Steve Pyne is a fire historian, urban farmer, and emeritus professor at Arizona State University, Tempe, AZ. His most recent book is "The Pyrocene: How We Created an Age of Fire, and What Happens Next."

ocean currents and continents to serve as driver and pacemaker.

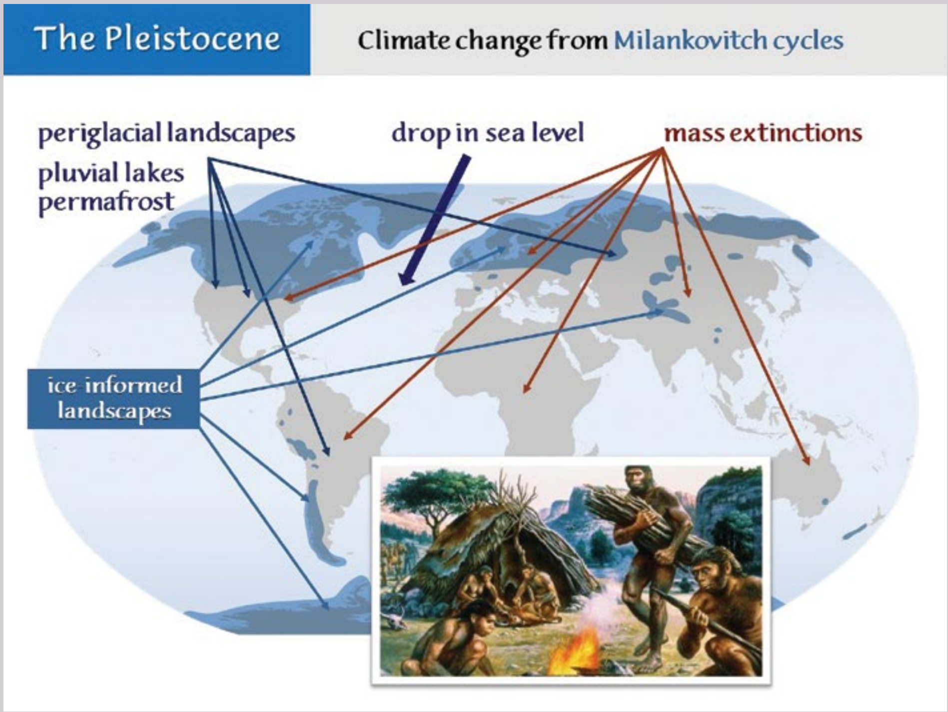
We have climate change, fire-informed landscapes, shifts in biogeography, peripyric phenomena (think massive smoke palls), collateral aridity, a rise in sea level, and mass extinctions. Fire creates the conditions for more fire. And while the Milankovitch cycles remain, along with the arrangement of oceans and land masses, overwhelming their rhythms is the sum of anthropogenic fire practices (aka fire intentionally lit, controlled, and used as a tool). These are erasing the landscapes informed by ice with those informed by fire.

Both epochs feature humans and their ancestors. Our genus emerged during the upheavals of the Pleistocene. Among its special capacities was the ability to manipulate fire. Our evolutionary ancestors' quest for fire was a search for fuels—for finding more stuff to burn and ways to burn it.

Today, only one type of human remains: us. We hold a species monopoly over fire's use, but we burn so much that our quest has become a search not for additional sources but for sinks. The waste of our combustion habits has overwhelmed the capacity of the Earth to absorb it without a disturbance profound enough to stall the cadence of the ice and replace it with fire. What began as a mutual assistance pact between humans and fire is looking more and more like a Faustian bargain.

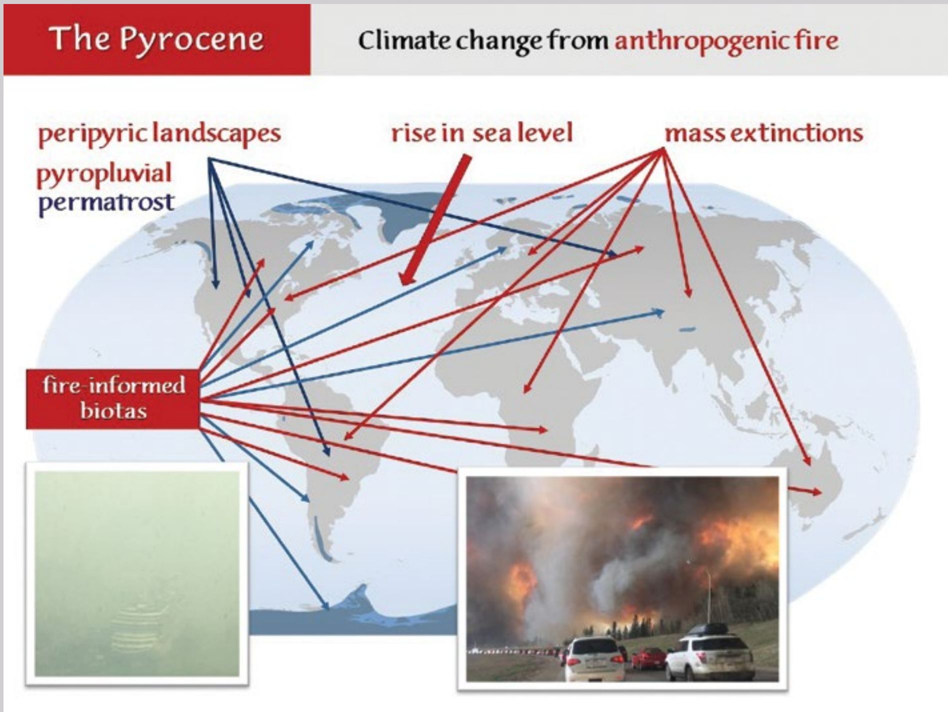
By my reckoning, the Pyrocene is synonymous with the Holocene, the epoch that began with the last interglacial period about 11,000 years ago. A fire-wielding creature met an increasingly fire-receptive planet (fig. 1). We have been steadily remaking the Earth ever since.

As even commentators in ancient times observed, we've transformed fire from a first-nature phenomenon (something that occurs naturally) into a second nature: something that became instinctive to us to use.



The Pleistocene with key attributes, including ancient hominids using fire.

Figure 1—*The transformation of fire from a first-nature phenomenon to a second nature has altered both the course of human development and the evolution of our global ecosystem. Adobe Stock photo.*



The Pyrocene with key attributes. Inset photo: The deadly fires that burned into Fort McMurray, Alberta, Canada, in 2016. Inset photo by DarrenRD.

BURNING LITHIC LANDSCAPES

We reached into the geologic past to find more combustibles. We began to burn once-living, now-fossilized biomass (aka fossil fuels), from what might be termed lithic landscapes. Unlike fires in living landscapes, these fires did not come with ecological checks and balances. They could burn day and night, winter and summer, through wet and dry. There were no sinks to soak up the emissions and so we released its byproducts into the future. Anthropogenic fire acquired afterburners. Add in the other byproducts of lithic landscapes, from petrochemicals to plastics, and we have made a third nature.

The fires of first and second nature competed—only one could burn at a particular place and time. Initially, the fires of third nature competed as well. By technological substitution and outright suppression, they replaced or removed fires in living landscapes. This had generally benign outcomes in houses and cities, but not in the countryside and wildlands. Eventually, by disrupting climate, they have acted as a performance enhancer on fire-prone places.

More than climate change, the transition to a fossil-fuel society affects how we live on the land, which is to say, land use. The issue is not whether climate change or land use is the underlying cause of our recent outbreaks of feral fire, but third fire that underwrites both—and how the three fires now occupying the planet collude. Paradoxically, megafires are a pathology of the developed world. Humanity's firepower is massive enough to replace the rhythm of the ice ages with a fire age.

Over the past century, societies have dealt with landscape fire as an episodic emergency, as something that can be resolved through temporary labor and incidental research. It should be clear by now that fire is systemic and needs to be addressed by institutions and with ideas that treat it as such. It isn't going away.

Even as we ratchet down our burning of lithic landscapes, we'll have to ratchet up our burning of living ones. Fire's management—now on a planetary scale—is not something that can be done on the side, as it presses against daily life or when convenient, as a byproduct of more fundamental processes. In the hands of humans, fire has become a cause, consequence, and catalyst. It is a prime mover of the Earth System today.

HUMANITY AND FIRE

We have a lot more fire in our future. We've shown we can use our firepower to disrupt the Earth. We now have to show we can manage it. Even those who consider the Earth beyond salvage and look to other worlds to start anew will leave the planet on plumes of flame.

To many commentators, that future appears not only dire but also strange, so much so that they despair of having a narrative by which to connect it to our past and an analogy by which to guide us into the future. In fact, we have a marvelous narrative: the epic of humanity and fire. And we have an apt analogy: we are creating the fire-informed equivalent of an ice age. ■

Fire Management today

GUIDELINES for Contributors

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

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

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

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

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