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Wildfire Triage: Targeting Mitigation Based on Social, Economic, and Ecological Values

Fire-adapted landscapes in the West can benefit from wildfires, but can also experience significant damage and destruction to buildings, communication and energy systems, watersheds, and other highly valued resources and infrastructure. (Photo by John Rieck)

SUMMARY

Evaluating the risks of wildfire relative to the valuable resources found in any managed landscape requires an interdisciplinary approach. Researchers at the Rocky Mountain Research Station and Western Wildland Threat Assessment Center developed such a process, using a combination of techniques rooted in fire modeling and ecology, economics, decision sciences, and the human dimensions of managing natural resources. The method combines predictive mapping of the distribution and intensity of wildfire with locations of highly valued resources. By soliciting input from experts, the response of each resource to different fire intensity levels is estimated and categorized. Combining the likelihood and intensity of fire with the locations and predicted responses of key resources across a landscape allows scientists and managers to determine the areas and assets most likely to experience significant change due to fire. This framework accounts for resources that respond negatively to burning as well as those, like fire-adapted ecosystems, that benefit. Identification of the areas where fires pose low risk to sensitive resources and might be left to burn promotes ecosystem health while minimizing costs of fire suppression. This highly versatile process has been employed at multiple (regional to national) scales while earning encouraging feedback from decision-makers. Work is currently underway to enable managers to employ the process in numerous jurisdictions.

The adage that "hindsight is 20/20" may seem especially fitting during the days and weeks after a wildfire threatens or destroys valuable resources. Each field season land managers face tough decisions of where to implement prescribed burns, timber sales, thinning projects, and other efforts designed to mitigate hazardous fuel conditions and reduce the risk of uncharacteristic wildfire [fire that does not occur within the time, space, and severity patterns of the historical natural fire regime] with constrained budgets and personnel limiting their capacity. Yet managers also realize that fire is an inherent part of the forest life cycle in most ecosystems, and can have benefits. But with every lost home, stream choked by eroding sediment, charred acre of critical wildlife habitat, or day of smoke-induced air quality advisories comes retrospective scrutiny of the chosen course of action.

In response to the ballooning costs of wildfire suppression, resource damage, and land rehabilitation, pressure on land management agencies has mounted from the Office of Management and Budget, General Accounting Office, Office of Inspector General, Congress, and general public to maximize and document the effectiveness of fire management programs in reducing risk from wildfires to natural and social resources. Some resource managers have incorporated predictive tools like fire probability mapping into their decision-making processes. While identifying areas where fires are likely to occur is an important step, these techniques did not historically support a refined estimation of the tangible impacts, both good and bad, of wildfires burning in areas with diverse resources. Understanding the likelihood as well as the potential benefits and costs of wildfire is fundamental to evaluating fire risk and making informed management decisions.

AN INTERDISCIPLINARY PERSPECTIVE OF RISK

Advancements in fire simulation models and improving techniques for acquiring and managing geospatial data prompted researchers at the USDA Forest Service to develop an approach for identifying areas most in need of wildfire mitigation measures. The team included Matt Thompson, Dave Calkin, and Mark Finney from the Rocky Mountain Research Station, and Alan Ager from the Western Wildland Threat Assessment Center. Joe Scott of Pyrologix, LLC and Don Helmbrecht from the TEAMS Enterprise Unit of the Forest Service were also instrumental. Members of the group were able to capitalize on recent developments in their respective fields, which span fire modeling, fire ecology, climate sciences, economics, decision sciences, and the human dimensions of natural resource management, to produce a streamlined methodology for evaluating fire risk at a wide range of spatial scales. "There was a constellation of great work done in a variety of related fields that we drew upon to make our approach to assessing wildfire risk possible," says Thompson. "As a key example, the science needed to develop the Wildland Fire Decision Support System [WFDSS, an interagency system for developing and documenting decisions for wildfire events] really set the stage for our efforts with wildfire risk assessment. Further, the ArcFuels system significantly advanced the incorporation of risk assessment into spatial analysis and fuel treatment planning."

The wildfire risk assessment process helps prioritize the protection of diverse resource types.

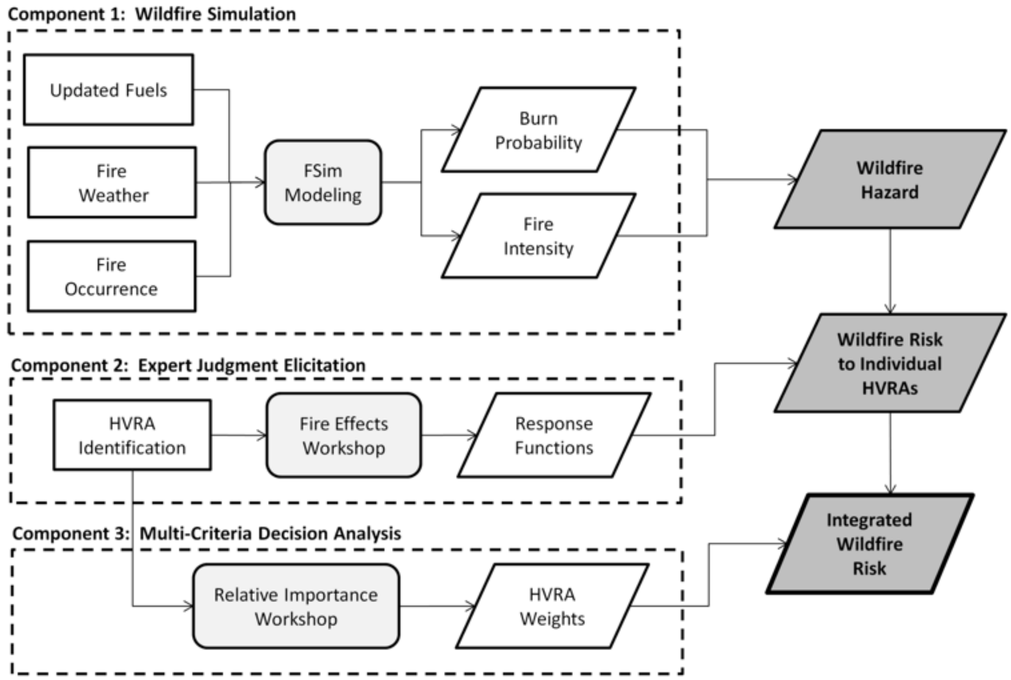
In a world of complex choices and tradeoffs, application of the wildfire risk assessment approach at spatial scales ranging from national- to National Forest-level can help reduce second-guessing by land managers. The assessment approach helps managers evaluate and compare the predicted tradeoffs of proposed fuel treatments and suppression strategies in an objective and transparent way. Considering the complications imposed by changing climates, unprecedented fuel loads, extensive exurban development, and diminished budgets, these characteristics are more than timely—they are essential.

The approach to wildfire risk assessment developed by Thompson and his colleagues boils down to a three-step process. Evaluating the likelihood and predicted intensity of wildfire across a given landscape of interest is the starting point. Next is the determination of what resources exist on that landscape, their values, and how they are likely to respond to fires of varying levels of intensity. The third and final step is to rank the value of each resource so that it can be weighted in the analysis based on its relative importance; in this final step, managers carefully consider the interests of stakeholders, partners, and the public. When this information is considered in concert, researchers and managers can compare the predicted environmental and social repercussions of different fire management scenarios and weigh the costs and benefits of various actions.

FORECASTING FIRES THROUGH SIMULATION

The foundation for the process is an innovative wildfire simulation system developed by Finney, called FSim, which models fire behavior across real-world landscapes. FSim estimates burn probabilities, fire size distributions, and

"The foundation of the process—the FSim model—estimates burn probabilities, fire size distributions, and fire intensity as functions of weather, ignition location, fuel structure, and topography..."



This flowchart illustrates a process that allows scientists and managers to determine the areas and assets most likely to experience significant change due to fire and therefore make informed management decisions about fuel treatment and fire suppression priorities. The acronym HVRA stands for "highly valued resources and assets." (Flowchart by Matt Thompson)

fire intensity as functions of weather, ignition location, fuel structure, and topography and maps those estimates in a pixelated landscape. The size of pixels typically varies from 90m by 90m for simulations at the scale of individual Forests or Regions, up to 270m by 270m for nation-level assessments. "The intent is to refine the resolution of the fire simulations based on the scale of the landscape of interest," says Thompson. "It's also important to consider the scale of the data being used in the fire simulations. Fine-scale fuels data give you the flexibility to simulate fire at higher resolution, but they are not generally available over large areas. There is also a tradeoff between higher resolution and the computing time needed to get your results."

The set of values that FSim calculates for a given pixel quantifies the likelihood that the pixel area will burn in a given year and how intense the fire will be if it does. Estimates from FSim are generated by calculating distributions from repeatedly running fire growth simulations with varied weather and ignition locations. In the model, as in reality, fires behave according to a set of ground rules: spreading as elliptical waves, burning more intensely in areas with heavy and dry fuel loads, traveling vigorously upslope, and so on. Comparisons between FSim predictions and historical burn probabilities and fire size distributions indicate that the simulation results do a good job of reflecting reality.

Once the fire maps from FSim are created, they are combined with the locations of highly valued social, economic, and ecological resources. These merged data allow for easy identification of areas where valued assets exist in locations prone to fire. Detecting the high-risk locations where fire-sensitive resources overlap landscapes predisposed to intense burns is the basis for strategic use of fire mitigation and suppression resources. Of equal importance, mapping fire-adapted ecosystems simplifies the process of locating areas where fires pose low risk to sensitive resources and might be left to burn, thereby benefiting ecosystems and minimizing costs of suppression.

AN INVENTORY OF ASSETS

Any single resource in need of protection can be included in a fire risk assessment. However, data layers reflecting entire

Detecting the high-risk locations where fire-sensitive resources overlap landscapes predisposed to intense burns is the basis for strategic use of fire mitigation and suppression resources.

categories of highly valued features generally are used to ensure efficiency over larger spatial scales. In 2011, the research team completed an assessment of wildfire risk across the continental United States, identifying seven highly valued resource categories: residential structures, municipal watersheds, air quality, energy and critical infrastructure, federal recreation and recreation infrastructure, fire-susceptible species, and fire-adapted ecosystems. While this list is certainly not exhaustive of resources that could be impacted by fire, the categories were chosen to represent the major areas of concern nationally. "There are clearly a lot of important resources on the landscape that we care about and want to manage for," says Thompson. "But essentially you get diminishing returns with each added resource once you've captured most of the relative importance with several basic, broad categories." Thompson also points out that the resource categories are likely to be quite different at the Forest or Regional level compared to nationally. "At the national scale you have big picture categories, and as you move down to finer scales the important resources of interest become much more specialized," he says.

In some cases multiple resource types and data sets fall within a single category. For example, the "fire-susceptible species" value category in the national assessment incorporated a data layer for sage grouse habitat described by the Bureau of Land Management National Sage Grouse Mapping Team. It also included federally designated critical plant and wildlife habitat for 41 fire-susceptible vertebrate, invertebrate, and plant species that broadly represented the geographic distribution of federally listed threatened and endangered taxa. Data layers like these are available through many channels, depending on the scale and location of the risk assessment. Enterprise databases, data clearinghouses, and localized data sets can all prove useful for populating landscapes with key features.

Valued resources, like infrastructure, are given a higher relative weight by land managers in the wildfire risk assessment approach; this type of prioritization, when combined with fire risk mapping, allows for a more strategic and cost-effective approach to fuel treatment and fire suppression decisions. (Photo from inciweb.org)

THE GOOD, THE BAD, AND THE UGLY: HOW WILL DIFFERENT RESOURCES RESPOND?

Aside from knowing where on the landscape valued resources are located and the likelihood and predicted intensity of fire at those locations, it is important to understand how each resource will suffer or benefit in response to different levels of fire intensity. Limited understanding surrounding the effects of wildfire on some resources of interest can make this difficult. To address scientific uncertainty, wildfire risk assessment incorporates information gleaned through expert judgment elicitation. Expert-based approaches use the judgment of experts as a proxy for empirical data or predictive models.

This expert-based approach is used to determine "fire response functions." Fire response functions quantify, as a percentage, the amount of damage or benefit experienced by each resource at varying levels of fire intensity (flame length is considered a good proxy for fire intensity). For example, fire-adapted ecosystems were predicted to experience a strong benefit (+60%) at "low" fire intensity (flame length 0-2 feet). This would be reduced to a strong loss (-60%) at "very high" fire intensities (flames over 12 feet). In contrast, residential structures were assigned fire response functions reflecting a strong loss (-80%) at every fire intensity level.

According to Thompson, this step of determining fire response functions is an ideal time to capitalize on the local wisdom of resource specialists who, in many cases, know the resources on the grounds they manage better than anyone. "If you're looking at wildfire impacts to very specific resources, like the habitat of a wildlife species of conservation concern or a particular fishery, then there is no better information than the intimate local knowledge provided by specialists. In some cases they can tell you how they have seen fire affect that exact resource in the past. Experience like that really helps inform predictions for future fire events."

According to National Fire Ecologist Jim Menakis, the establishment of fire response functions is the most powerful aspect of this emerging risk assessment technique. "As an ecologist, the response

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function is what I like the most. When we look at the effects that fires have on some of our natural resources, it's clear that low intensity fires can be very important. By evaluating and accounting for the positive impacts of burns we can manage the fire for resource benefits and promote resilient, balanced, healthy forests," he says.

Once fire response functions are estimated for each resource, and resources are mapped to pixels with projected burn probabilities and fire intensities, the magnitude of anticipated fire-induced consequences can be assessed for the entire landscape. The result, measured in relative loss or benefit to the landscape, is referred to as the Net Value Change (NVC). Different proposed management strategies can be compared to determine how risk, or predicted NVC, is likely to be affected by different actions. Coming up with a common metric to compare landscape-level outcomes can be very helpful to managers. The next step is to consider which resources within those landscapes need priority protection.

PRIORITIZING RESOURCES BY VALUE

As individuals and as a society we value some resources above others, but from a management standpoint, trying to rank multiple resources in need of protection from fire can be one of the most daunting aspects of distributing mitigation efforts. Fortunately, the risk assessment framework lends itself well to establishing the relative importance of valuable resources.

In the assessment process, expert input informs the assignment of fire response functions (as described above), while leadership input, which represents both Forest Service mandates as well as the values and interests of the public, partners, and stakeholders, informs the ranking of highly valued resources. Thompson notes that because of these two parallel processes, "We hold two separate workshops for a given project, with the panel of resource specialists responsible for determining fire response functions, and the panel of Forest

Understanding the likelihood and the consequences of wildfire is fundamental to evaluating fire risk and making informed management decisions. (Photo by John Rieck)

"The response function is what I like the most. When we look at the effects that fires have on some of our natural resources, it's clear that low severity fires can be very important. By evaluating and accounting for the positive impacts of burns we can manage the fire for resource benefits and promote resilient, balanced, healthy forests."* – *Jim Menakis, Fire Ecologist

KEY FINDINGS

- Wildfire simulations continue to improve and allow for increasingly accurate estimates of the locations and intensities of future disturbance by fire.
- Emerging techniques for wildfire risk assessment now allow for refined predictions of how different types of resources will respond to fires and the use of that information to identify areas most at risk of serious damage.
- Researchers and land managers can establish locations where low intensity burns will have the highest net benefit and might be left to burn without suppression.
- Input from experts with specialized knowledge of the relative importance of highly valued resources and their expected responses to fire plays a central role in estimating fire risk.
- Focusing on risk to broad categories of valued resources for coarse-scale assessments and on more specialized resource types at finer resolution is an important characteristic that makes this approach well-suited for analyses at a wide range of spatial scales.

leadership informing the ranking of highly valued resources. The two panels work independently from one another."

Based on the input from leadership, valued resources are assigned a score, or weight, to describe their relative importance. Initially, for simplicity, three value categories were used: Moderate, High, and Very High. In the national assessment, the Moderate category included Class 1 air quality areas, recreation sites and campgrounds, national trails, and fire-adapted ecosystems. The High value category included low-density built structures, electronic transmission lines, oil and gas pipelines, energy generation plants, cell phone towers, ski areas, and critical habitat for fire-susceptible species. The Very High category consisted of non-attainment air quality areas, moderate- and high-density built structures, and municipal watersheds. Assignment of two resource types to the same category implies that they have similar social values to one another. In more recent applications, relative importance scores have been assigned, allowing for a more refined articulation of management priorities.

Coupling the scale of the predicted consequences (NVC) with the relative value of the impacted resources results in a "weighted NVC." This weighted NVC incorporates social values while facilitating comparisons of fire-induced changes across locations or resource types. In essence, the weighted NVC helps prioritize the protection of very diverse resource types; this can be a powerful tool to aid in decision-making by land managers.

In the national fire risk assessment, the weighting of assets based on their importance helped identify Regions and resources expected to experience the greatest loss to fire. For example, non-attainment air quality areas – which were deemed of Very High importance and therefore heavily weighted – helped push California to the top of the list of National Forest System Regions expected to be impacted negatively by fire. It is important to note, however, that effective use of prescribed fire during appropriate timeframes can actually mitigate overall air quality impacts from wildfire. The relative value of habitat for fire-susceptible species was ranked below that of moderate- and high-density built structures and municipal watersheds but its weighted NVC value was predicted to exceed those other categories based on the widespread distribution of those habitats and the large scale of their anticipated loss to fire.

PUTTING THEORY INTO PRACTICE

The scalable nature of the risk assessment process makes it possible to take a step-down approach to allocating limited resources for fuel treatments. Analysis at the national scale helps identify Regions most in need of support. Assessment at the Regional level can help identify the National Forests where projects will have the greatest benefit. Finally, within a single National Forest, the process can be used to select among specific projects and sites. Menakis describes the approach as "a way to ensure we get the biggest bang for the buck." To date, fire risk assessment has been used to inform Forest-level management on the Beaverhead-Deerlodge National Forest, the Lewis and Clark National Forest, the Bridger-Teton National Forest, and the Pike and San Isabel National Forest, while generating positive feedback from managers. "One

Menakis describes the risk assessment approach as "a way to ensure we get the biggest bang for the buck" in terms of allocating limited resources for fuel treatments.

of the big reasons for the success in implementation so far is that Thompson and the research team have been fantastic when it comes to collaborating with the land managers," Menakis says.

Because fire risk assessment relies on scientific techniques that are still works in progress, completing an analysis at any scale is currently best accomplished through cooperation between managers and researchers. "The process is not, at this time, a black box that a manager plugs information into and gets an answer—nor should it be," says Menakis. "The approach relies on new methodologies and new science, but down the line this could be a key tool in managers' toolbox."

As the underlying science continues to be honed, and more managers become familiar with the fire risk assessment process, work is underway to help transfer capability from researchers to resource managers. Jessica Haas, Data Services Specialist with the Rocky Mountain Research Station, is leading the push to facilitate implementation of fire risk assessment by managers. "We have a prototype of a risk assessment program being tested now that is built to operate through the ArcGIS toolbox," she reports. "The debugging work is done and the users testing the program are getting good results. Part of the challenge is that fire behavior modeling is as much art as it is science and users need to have the experience necessary to understand fire behavior and critically evaluate simulation results for their landscapes," she says. Thompson also underscores the overarching objective of making the science fully accessible to the people who need it most—but not until the time is right. "We have worked closely with managers toward a process that is easily replicated, but we are at a point where each time we work through a new assessment we refine one aspect or another. One of the most encouraging developments is that we have a growing group of experienced professionals who know the steps needed to capture expert input to assign fire response functions and categorize highly valued resources by relative importance. People with these skills could be instrumental in helping to spread the process to other landscapes," he says. Considering the potential benefits to the Regions, Forests, and communities where fire risk assessment has not yet been applied, it may only be a matter of time before they are asked to do just that.

MANAGEMENT IMPLICATIONS

- Land managers will have increasing capacity for defensible, systematic wildfire risk assessments that can be used to guide decisions that will help maximize benefit from mitigation efforts.
- The limited resources available for fire suppression can be conserved by identifying, in advance, areas where fires pose low risk to valued assets.
- The wildfire risk assessment process provides highly customized and scalable decision support by allowing for input of local resource values and expert knowledge by local specialists and resource managers.

FURTHER READING

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MARK FINNEY is a research forester with the Rocky Mountain Research Station (Fire, Fuels, and Smoke Program) in Missoula, MT. He received a Ph.D. from the University of California, Berkeley. His research focuses on fire simulation for risk assessment and decision support; his research has advanced the understanding of fire behavior and practical management of wildland fires.

ALAN AGER is an operations research analyst with the Western Wildland Environmental Threat Assessment Center of the US Forest Service, located in Prineville, OR. Alan received a M.S. in plant genetics at the University of Wisconsin and a Ph.D. in forest genetics at the University of Washington. His current research interests include stress detection in forest trees, spatial modeling of wildfire, risk analysis, and a variety of operations research problems related to forest management.

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