Fire Management *today*

Volume 69 • No. 3 • 2009

Looking Ahead, Working Together

Disaster Response Partnerships
Coping with Change
Fire Ecology in Public Schools
Federal-Local Cooperation

United States Department of Agriculture
Forest Service

Coming Next...

Fire response seldom involves only one agency or affects only one group of stakeholders. The next issue of *Fire Management Today* (69[4] Winter 2009) will feature articles on cooperative efforts to manage fire on international, national, and local levels. Examples include U.S. contributions to fire recovery efforts in Australia, the logistics of U.S. military support of firefighting missions in the United States, the Forest Service's loan of wildland firefighting equipment to a local fire department, and how volunteers organized by the Nebraska Forest Service are reaching out into rural communities to educate landowners about fire prevention.

Other articles in the issue address on-the-ground aspects of fire management: modeling smoke distribution in anticipation of prescribed fires, measuring fuel moisture for its affect on fire intensity, and training firefighters in an intensive academy setting.

Erratum

In *Fire Management Today*, vol. 69(2), the article *Assessing Changes in Canopy Fuels and Potential Fire Behavior Following Ponderosa Pine Restoration*, the crowning index maps on page 50, Figure 4, were inadvertently switched. The map under "1996/97" illustrates conditions in 2003 and the map under "2003" illustrates conditions in 1996/97. View the corrected figure in the online version of 69(2), located at <http://www.fs.fed.us/fire/fmt/fmt_pdfs/FMT69-2.pdf>.

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On the Cover:

Mapping plow line disturbance with GPS in a pine flatwoods community at Savannas Preserve State Park, Florida. See the article "Plow Line Disturbance From Wildfire Suppression in Two Florida State Parks." Photo: Jeffrey T. Hutchinson.

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

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

Firefighter and public safety is our first priority.

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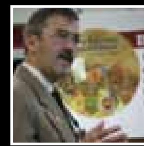

by Tom Harbour
Director, Fire and Aviation Management
Forest Service, Washington, DC

Fire Management into the Future

Today, as I formulate this article, wildfires are burning in Arizona, California, New Mexico, and Texas. Earlier in the year, we've assisted in or managed fire suppression efforts in Oklahoma, Florida, and South Carolina. Another fire season is certainly upon us. So, what's different about this fire season? What's the same? And what does fire management look like as we look into the future?

We need to use better-defined protocols for managing wildfires and the tools that help us evaluate risk and make better risk-informed decisions during fire incidents

What's Different?

This year, we've received new guidance for the implementation of the Federal Wildland Fire Policy. While the policy itself has not changed, the implementation guidance has been updated. That guidance established two categories of fire: prescribed fire and wildfire. Prescribed fires are defined as those with planned ignitions, while wildfires are those started from unplanned ignitions. Unplanned ignitions include the naturally caused ignitions formerly referred to as wildland fire use. The new guidance allows for management of any naturally caused wildfire for resource benefit so long as that management response is supported by the respective unit's land and resource management plans. All human-caused fires, however, will continue to be suppressed using the safest, most efficient, effective means.

The Forest Service created the Wildland Fire Decision Support System (WFDSS) to provide incident-level support to fire managers under the "two kinds of fire" framework. WFDSS is an array of decision support applications that calculate risk and probability and predict what may happen on a fire—providing fire managers with tools to determine the safest, most efficient, effective management options within applicable land and resource management plans.

What's in the Future?

What changes do I see in our future? To address the subject, I consulted the Quadrennial Fire Review (QFR). The QFR is an interagency assessment of current and future strategies and capabilities and identifies core mission points, future trends, and forces driving those trends. It is not a policy document and does not make policy recommendations.
The first QFR was found to be an extremely accurate reflection of developments that have brought us to our current position. In January 2009, the second QFR was published. In it, I see the success of our future fire management efforts in promoting:
- Fire-adapted communities,
- Fire-adapted ecosystems, and
- Fire-adapted business practices—how we operate.

What's the Same?

What's the same is our ongoing commitment to long-term cooperation, management, and safety. We need to continue to work with existing partners, develop new partners, and make those partnerships as effective as possible. We need to continue our work to accomplish much-needed fuels projects to enhance the safety of communities and our firefighters when wildland fires happen. We need to promote the creation of fire-adapted communities and elevate a widespread understanding of fire—how to live with fire and our responsibilities prior to, during, and after fire incidents.

We need to use better-defined protocols for managing wildfires and the tools that help us evaluate risk and make better risk-informed decisions during fire incidents. The WFDSS tools will help managers identify and focus on high-value objectives where success is likely, making the best use of available firefighting resources.

We have a fire doctrine that promotes an informed, shared-learning culture in which firefighters avoid unnecessary risk and that encourages keen awareness and observation, knowing the leaders' intent at all times, and assisting with adaptable decisionmaking in unexpected situations. Our doctrine is the heart of safe, effective fire management in this increasingly complex world of fire management. It's important that we continue to concentrate on the speed, agility, and focus associated with the fire doctrine at all times.

Successes and Challenges

The continued success of our efforts depends greatly on our commitment to risk management and safety within our workforce and work practices. This requires continued investment in that workforce to meet and maintain the highest standards in the vital work we perform.

We work in a hazardous environment—it's a fact. The Federal Wildland Fire Management Policy, WFDSS tools, and existing doctrine can help us to minimize that hazard and be safe, efficient, and effective in our jobs; but it is incumbent upon us, both as an agency and individually, to remain aware of the environment in which we work and look for ways to maintain safe practices in every aspect of our work.

In May of 2009, we mourned the loss of fellow firefighters Tom Risk, Mike Flynn, and Brian Bliss when Neptune Aviation Services Tanker #42 crashed while responding to a wildfire in New Mexico. We must always remember these firefighters and those we have lost before them, dedicating ourselves daily to safety and managing the risks we take in every action. ■

Further Information

InciWeb may be accessed at <http://165.221.39.44/>.

Forest Service employees may access Tom Harbour's Blog by accessing <http://fsweb.wo.fs.fed.us/>, clicking on *FS Blog*, entering e–authentication, clicking on the tab labeled *Directory of Blogs*, and then click on *Tom's Blog*.

Hired for Fire: Wildland Fire Management Projects Putting People To Work

Mary Carr

Wildland fire management is out front in economic recovery efforts as the Forest Service helps put people back to work through the American Recovery and Reinvestment Act of 2009 (ARRA, colloquially coined the "stimulus bill").

The ARRA provides $1.15 billion to the Forest Service for work on the Nation's forests with a focus on providing and retaining jobs. Congress appropriated $650 million for Capital Improvement and Maintenance and $500 million for Wildland Fire Management. Of the $500 million for Wildland Fire Management, Congress directed $250 million to be used on Federal lands and $250 million on State and private lands.

Fire management projects funded through AARA include removal of dense underbrush and other hazardous vegetation from crowded forest lands. The intent of such work is to help protect communities from large, unnaturally severe fires and to contribute to the restoration of fire-adapted ecosystems by diminishing the rate, severity, and size of wildland fires.

Related projects promote the use of biomass generated from fuels reduction projects as a way to contribute to renewable energy production. A biomass utilization team is working to improve estimates of woody biomass and to develop integrated systems and technologies for biobased products and bioenergy.

Mary Carr is a technical publications editor with the Forest Service, Ecosystem Management Coordination, Publishing Arts, in Olympia, WA.

Funds for wildland fire management will be used to thin dense stands of trees such as this, not only reducing hazardous fuels but also resulting in biomass that can be used as a source of clean energy. Photo: Tom Iraci, Forest Service, Pacific Northwest Research Station.

More than half the initial projects proposed for the Forest Service's billion dollars of funding through the ARRA were for wildland fire management.

Most of the jobs created by these projects are in the private sector, with a small proportion of specialist positions (such as contracting and engineering) gained in the Forest Service to help facilitate and coordinate the program. Some projects also incorporate assistance from rural community partners and other cooperators.

In addition to creating or saving some 10,000 jobs with Wildland Fire Management Funds, Forest Service economic recovery efforts overall also address Capitol Improvement and Maintenance Projects that will repair and improve roads, facilities, trails, administrative sites, and the ecosystems and watersheds affected by them.

As of September 2009, the U.S. Secretary of Agriculture had

Small-diameter materials removed during hazardous fuels reduction work will be piled and chipped for use as fuel for boilers under funding from the American Recovery and Reinvestment Act of 2009. Photo: Forest Service Eastern Region.

Firefighters string fire in a precise pattern on the Chadron Creek Prescribed Burn, Nebraska National Forest, NE, 2005. Reducing the rate, severity, and size of wildland fires is a major focus of the Forest Service's economic recovery efforts. Photo: Kelly Stover, Buffalo Gap National Grasslands, SD.

Most jobs created by wildland fire management economic recovery projects will be in the private sector.

released more than $429 million of Wildland Fire Management funds for hazardous fuels projects, invasive species projects, wood-to-energy grants, and forest health projects. These projects are on Federal, State, private, and tribal lands.

Targeted projects are already underway, and most will be completed within 2 years.

For updated lists of stimulus-funded wildland fire management projects and for other fire management news, visit:

- The Forest Service economic recovery Web site at <http://www.fs.fed.us>,
- The USDA Web site at <http://www.usda.gov/recovery>,
- The National Interagency Fire Center (NIFC) Web site at <http://www.nifc.gov/>, or
- Your State fire management agency. ■

Response Partnerships During Disasters: Emergency Support Function 4

Gordon Sachs

Wildland fire agencies respond to more types of emergencies than only wildland fire. They also respond to hurricanes, tornadoes, floods, earthquakes, terrorist attacks—any type of natural or manmade disaster or emergency could result in a request for Federal wildland fire resources. Thus, the Forest Service, U.S. Department of Agriculture, may be called on to support response to and management of situations that involve multiple agencies.

A structure exists to guide such multiagency interactions. When an event results in a Presidential declaration of emergency or major disaster, the response is coordinated under the National Response Framework. Under the National Response Framework, the Forest Service serves as the Coordinator and Primary Agency for Emergency Support Function 4 (ESF4). During all types of disasters and major emergencies, ESF4 is the primary link between the wildland fire community and the U.S. Department of Homeland Security, Federal Emergency Management Agency (FEMA). The Forest Service coordinates and staffs ESF4 with the support of the U.S. Department of the Interior and the U.S. Fire Administration and serves as the face of wildland and structural firefighting resources to FEMA and other involved agencies.

Gordon Sachs is a disaster and emergency response specialist for Fire and Aviation Management in the Forest Service Washington Office.

The purpose of ESF4 is to provide Federal support for the detection and suppression of wildland, rural, and urban fires resulting from, or occurring coincidentally with, an incident requiring a coordinated Federal response for assistance.

There are six Departments or agencies identified as Support Agencies to ESF4 to provide technical support, assistance, and expertise in specific areas related to firefighting operations. In addition to the U.S. Department of the Interior and the U.S. Fire Administration, these support agencies are the National Weather Service, U.S. Environmental Protection Agency, the U.S. Department of Defense, and the U.S. Department of State. Their roles related to ESF4 are identified in the ESF4 Annex of the National Response Framework.

Emergency Support Function 4

The purpose of ESF4 is to provide Federal support for the detection and suppression of wildland, rural, and urban fires resulting from, or occurring coincidentally with, an incident requiring a coordinated Federal response and assistance. Under the National Response Framework, ESF4 manages and coordinates Federal firefighting activities by mobilizing firefighting resources in support of State, tribal, and local wildland, rural, and urban firefighting agencies. Often, these resources are mobilized to support Federal or State entities with situations that do not involve wildland fire.

Forest Service Washington Office, Fire and Aviation Management, Disaster and Emergency Operations Branch, is the day-to-day link to FEMA and provides the national ESF4 coordinator. Each Forest Service region and area has a designated ESF4 coordinator to work with their FEMA region(s). As support agencies, U.S. Department of the Interior bureaus and the U.S. Fire Administration have ESF4 coordinators to maintain a close working relationship with the national ESF4 coordinator.

During a disaster or emergency, ESF4 may be staffed at all levels of FEMA operations (figs. 1 and 2):

- The National Response Coordination Center (NRCC) at FEMA headquarters in Washington, DC;
- A regional response coordination center (RRCC) in any of the 10 FEMA regions;
- A joint field office (JFO) established in any State affected by a disaster or major emergency;

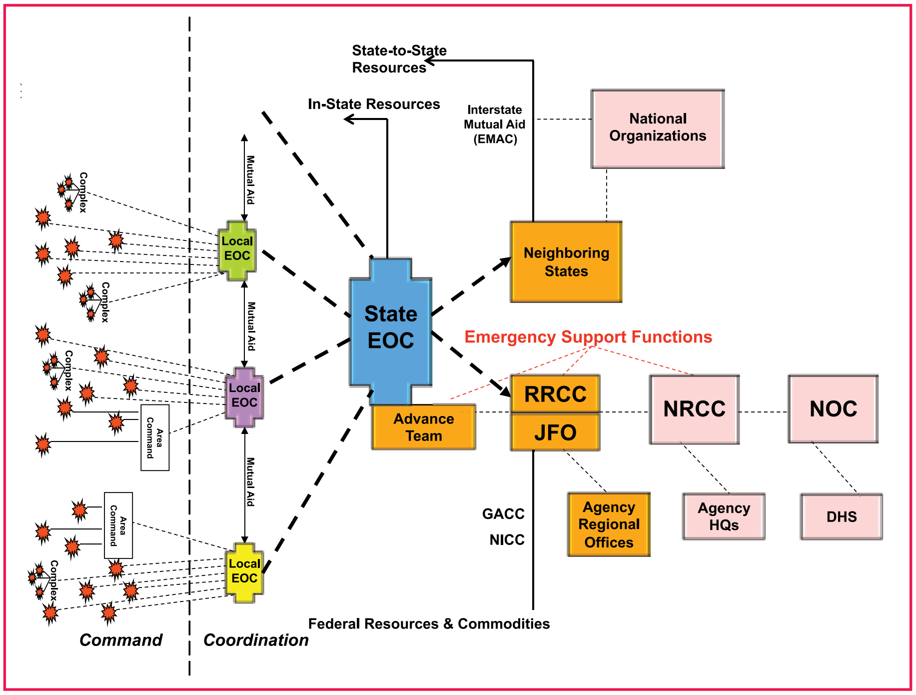

Figure 1—*Coordination of resources can be complicated during a presidential declaration of emergency or major disaster. The National Response Framework identifies the roles and structures of Federal agencies to provide support to States or other agencies through emergency support functions (ESFs). The National Response Framework identifies ESF4 as the coordinator for wildland, rural, urban, and suburban firefighting support. EMAC: Emergency Management Assistance Compact; ERT-A: Emergency Response Team-Advance Element; DRG: Disaster Readiness Group; NOC: National Operations Center.*

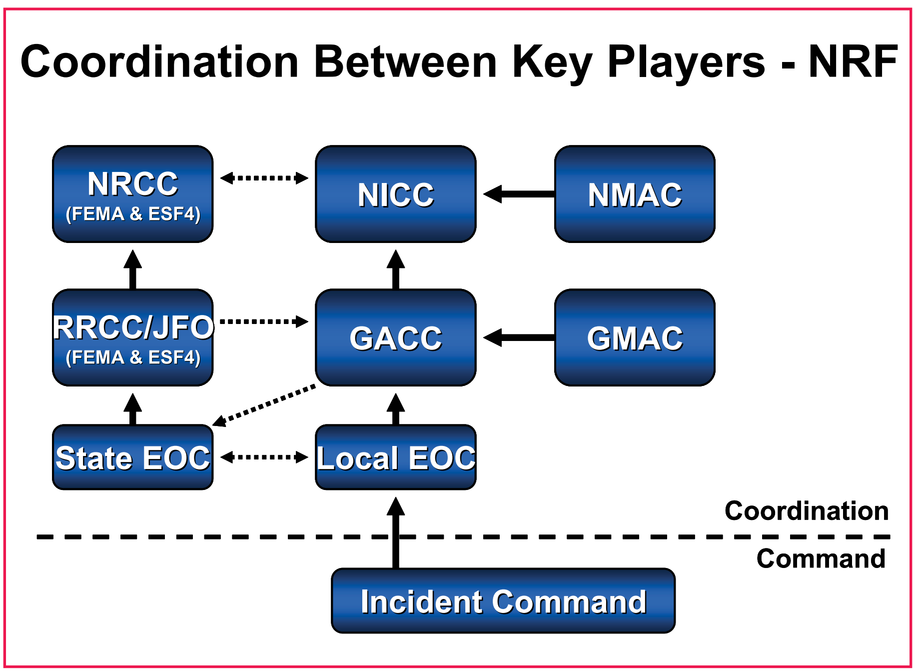

Figure 2—*ESF4 is the link between the wildland fire resource ordering process and FEMA funding mechanisms during a disaster response. Upon request for support from a State, FEMA provides ESF4 with a mission assignment, and if accepted, ESF4 notifies the geographic area coordination center. As with wildland fires, the geographic area coordination center mobilizes and coordinates firefighting resources at the geographic area level.*

- A geographic area coordination center (GACC);
- The National Interagency Coordination Center (NICC):
- A State emergency operations center (EOC); or
- A FEMA emergency response team (ERT) or incident management assistance team (IMAT).

Positions Within ESF4

ESF4 is staffed by qualified personnel from the Forest Service, U.S. Department of the Interior, and the U.S. Fire Administration. There are four ESF4 positions: ESF4 Primary Leader, ESF4 Support–Wildland, ESF4 Support–Structure, and ESF4 Support-Administrative (fig.3). U.S. Fire Administration employees fill the role of ESF4 Support–Structure to provide expertise on structural and urban firefighting. Persons qualified in each of the positions must complete an intense, 3-day ESF4 course and must demonstrate proficiency through trainee assignments and completion of a position task book.

When activated, ESF4 staff at the NRRC serve as the link between Forest Service and U.S. Department of the Interior leadership and FEMA leadership. Similarly, ESF4 staff at the regional response coordination centers or joint field offices serve as the link between Forest Service and Department of the Interior regions or State offices and FEMA regions. In addition to being the conduit linking the resource ordering process to FEMA funding mechanisms, ESF4 staff gather ongoing intelligence for the ESF4 agencies and FEMA about emerging details regarding the incident.

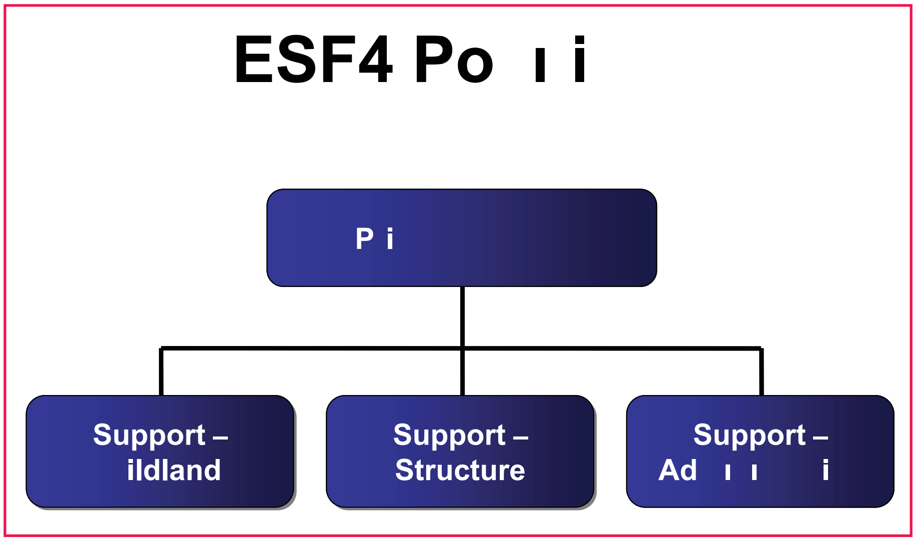

Figure 3—*ESF4 positions are staffed with qualified individuals from the identified agencies. The "ESF4 desk" is typically staffed in this basic configuration at the National Response Coordination Center and the regional response coordination centers and joint field offices and sometimes at the geographic area coordination center, depending on the type of emergency. NMAC: National Multi-Agency Coordination Group; GMAC: Geographic Multi-Agency Coordination Group.*

Tactical and Logistical Support

In addition to the primary ESF4 mission, the Forest Service and the U.S. Department of the Interior are also identified as support agencies to other emergency support functions. These agencies may provide secondary support identified in the National Response Framework when resources are available. For example, under these support missions, the Forest Service may be asked to provide:

- Transportation assets, such as aircraft;
- Radio communications systems and support personnel;
- Engineering, contracting, and procurement personnel and equipment to assist in emergency removal of debris;
- Planning support to multiagency coordination centers;
- Resources and supplies for evacuation shelters;
- Staff for establishing mobilization centers;
- Personnel, equipment, and supplies to support Federal health and medical teams;
- Cache equipment and supplies to support Federal urban search-and-rescue task forces;
- Technical assistance and logistical support at oil and hazardous materials spills; and
- Law enforcement and investigation personnel.

Additionally, FEMA can issue a direct mission assignment to the Forest Service or the U.S. Department of the Interior through ESF4 to provide support outside of that specifically identified in the National Response Framework. A mission assignment authorizes FEMA funding for resources in support of State or Federal agencies. Any mission assignments outside of the primary or support missions identified in the National Response Framework are closely scrutinized by ESF4 staff. When possible, ESF4 staff provide advisory services, guidance, and training to the requesting agency to help them build capacity rather than performing the task for them.

Incidents Involving the Emergency Support Function

Federal disaster response was tested heavily during fiscal year (FY) 2008 during both exercises and declared emergencies and disasters. Exercises involved many Federal Departments and agencies, and ESF4—with staff from the Forest Service, the U.S. Department of the Interior, and the U.S. Fire Administration—participated at both the national and regional levels. There were also nine ESF4 activations under the National Response Framework: three for fire emergencies and six for all-hazard emergencies. These activations were:

Southern California Fire Siege—Fires driven by the Santa Ana winds in September and October 2007 resulted in a fire situation that prompted a Presidential declaration of major disaster and the activation of ESF4 nationally

When activated, ESF4 staff at the NRCC serve as the link between Forest Service and U.S. Department of the Interior leadership and FEMA leadership. Similarly, ESF4 staff at the RRCC or joint field office serve as the link between Forest Service and U.S. Department of the Interior regions or State offices and FEMA regions.

and regionally. ESF4 received a mission assignment to "provide wildland firefighting resources to include structure protection urban interface resources through the wildland fire mobilization system to Federal, State, and local agencies in support of the 2007 Southern California Fire Siege." More than 125 engine strike teams and more than 300 miscellaneous overhead personnel were requested on a single mission assignment—the largest such request in history.

Texas Winter Fires—Unusually dry conditions throughout the winter and spring of 2007–2008 resulted in a presidential declaration of emergency for many counties in west Texas. FEMA activated ESF4 regionally to support the State of Texas with direct firefighting assistance. The Forest Service supplied more than 15,000 personnel days of fire suppression assistance over a period of more than 6 months.

Micronesia Drought/Flood—Drought conditions followed by salt water intrusion resulted in an emergency situation in the Federated States of Micronesia, a former U.S. Trust Territory. Under the National Response Framework, FEMA activated ESF4 regionally to provide a forester to serve as part of a preliminary damage assistance team to evaluate damage to local water supplies and food sources.

Midwestern Floods—In June, heavy rains resulted in significant flooding in many Midwestern States. FEMA activated ESF4 regionally to assist the State of Iowa with logistical support for hundreds of Federal, State, and local responders. Forest Service personnel assisted with the oversight of base camp establishment, selection of feeding sites, incident planning, and development of emergency purchasing processes and protocols.

Northern California Fire Siege—In late June, an unprecedented dry lightning storm started more than 1,000 fires in northern California. These and other fire outbreaks resulted in a presidential declaration of emergency for several counties in northern, central, and southern California. More than 20,000 firefighters were deployed to California during July, including firefighters from Canada, Australia, New Zealand, and Greece. ESF4 was activated nationally and regionally, and, for over a month, provided coordination between FEMA and the wildland fire community through operations at the California State Emergency Operations Center, two geographic area coordination centers, and the National Interagency Coordination Center.

Hurricane Dolly—In advance of Hurricane Dolly in late July, FEMA activated ESF4 nationally and regionally. This storm made landfall near South Padre Island, Texas, as a category 2 hurricane. Forest Service personnel maintained situational awareness and remained ready to evaluate requests for assistance made by FEMA or the State of Texas. Because of heavy wildland fire activity, few resources were avail-

Acronyms

As with any administrative function, FEMA has its own shorthand that all ESF staff must learn and use. The following are acronyms that speed communication—once you've learned them.

DHS	U.S. Department of Homeland Security
DOI	U.S. Department of the Interior
DRG	Disaster Readiness Group
EOC	(State) Emergency Operations Center
ERT-A	Emergency Response Team-Advance Element
ESF	Emergency Support Function
FEMA	Federal Emergency Management Agency
FS	Forest Service
GACC	Geographic Area Coordination Center
IMAT	Incident Management Assistance Team
JFO	Joint Field Office
MA	Mission Assignment
NICC	National Interagency Coordination Center
NOC	National Operations Center
NRCC	National Response Coordination Center
NRF	National Response Framework
RRCC	Regional Response Coordination Center
USDA	U.S. Department of Agriculture
USFA	U.S. Fire Administration

able to assist with this all-hazard response; fortunately, there were no requests that could not be filled.

Hurricane Gustav—This category 3 hurricane made landfall on September 2 near Cocodrie, LA, not far from New Orleans. FEMA activated ESF4 nationally and regionally prior to landfall. ESF4 received a mission assignment for 5 incident management teams, 14 hand crews, and numerous other resources. Forest Service personnel, coordinated through ESF4, were instrumental in supporting the aviation portion of the mass evacuation from the Gulf Coast region.

Hurricane Hanna—FEMA activated ESF4 in two regions to assist with planning for the possible impact of Hurricane Hanna on the East Coast. The category 1 hurricane was poised to strike in early September during the height of the response to Hurricane Gustav and during preparations for Hurricane Ike.

There are six Departments or agencies identified as support agencies to ESF4 to provide technical support, assistance, and expertise in specific areas related to firefighting operations: the U.S. Department of the Interior, the U.S. Fire Administration, National Weather Service, U.S. Environmental Protection Agency, the U.S. Department of Defense, and the U.S. Department of State.

Hurricane Ike—This strong category 2 hurricane made landfall on September 13 near Galveston, TX. FEMA activated ESF4 nationally and regionally prior to landfall. ESF4 received a mission assignment for 5 incident management teams, 14 hand crews, and numerous overhead personnel and other resources. These resources ultimately supported the State of Texas with logistics coordination, emergency debris clearing, damage assessments, and aviation coordination.

More information about ESF4 is available through a short (20-minute) independent study overview course at <http://www.training.fema.gov/EMIWeb/IS/IS804.asp>. ■

Coping With Change

Shawna Legarza

In recent years, we have wanted and seen both organizational and systematic changes in Forest Service, Fire and Aviation Management. Although they understand that change is constant and transformation takes time, even the most experienced fire managers may become overwhelmed and be left feeling confused and uncertain within themselves and with regard to the decisions of fire management agencies. While we continue to work more diligently to keep up with changes and obtain good results, we often feel our lives spinning out of control, and, thus, the cycle continues. It seems we have less and less free time to communicate effectively with our families and take care of our inner selves. Where have our fundamental priorities gone?

As we balance our fate and ideology as an agency, we need to allow time for personal reflection and remember our fundamental priorities. I believe we need to be the leaders of organizational and systematic change; we need to continue to develop the wildland firefighting culture within our doctrine to take better care of ourselves, our families, and our employees.

The Ultimate Challenge

While enduring political, global, and ecological challenges and the structured flows of technology, we often find not only ourselves, but also our employees, overwhelmed with the stress and implications of change. Employees who become overwhelmed have difficulty managing stress and, thus, lessen the connections with their coworkers and families. So we must ask: How does one become receptive to the effects that change has upon oneself, coworkers, subordinates, and families? Is it plausible to relax and communicate in moments of uncertainty and confusion?

The San Juan Hotshots in Lake Chelan, WA, 2005. Photo: San Juan Hotshots.

> Is it plausible to relax and communicate in moments of uncertainty and confusion?

Historically, it is clear that change can raise doubts concerning personal beliefs and existing order. Statistical comparisons show that the inability to deal with change closely correlates to a negative subliminal behavior exhibited briefly during times of undue stress. With this said, understanding the process and the effects of change is a challenge for any leader.

During your career, the connection between challenges in your personal life and organizational changes in your professional career may evolve into a complex web of confusion that could become highly stressful and profoundly unhealthy. You may become addicted to the risk of change and the speed of the emergency, while not truly knowing the long-term physiological and psychological effects. With the competitively based subculture of firefighting, we often forget to take care of ourselves and others because we, too, have become obsessed with trying to understand and keep up with all the changes that make us uneasy and, sometimes, outright unmanageable.

During this negative reinforcing loop, communication and personal reflection become even more important. Personal reflection will allow you to evaluate yourself.

Shawna Legarza is a district fire management officer on the San Juan National Forest in Bayford, CO, and founder of the Wildland Firefighters Life Challenge Program.

With time, you may find a relationship between your inner self and the observed chaos in the outside world. By understanding this inner reflection, it may become easier to embrace change and differentiate between the fundamental variables defining your personal and professional life styles. Take time to slow down.

Individual Leadership Traits

I believe we all have unique leadership traits in our internal toolbox. The traits in your toolbox will allow you to manage the transformation of change on an individual basis. Some people may add various skills to their toolbox and use them to their utmost, others just a little, or not at all. It is your choice to accept and understand change, just as it is your choice to be a leader, a follower, or a leader of leaders.

Individuals have different leadership traits, supported by different types of incremental change, and with all levels of leadership come individual challenges and complexities. One must continue to lead within during times of uncertainty, to communicate honestly with oneself and with others, and to find peace within and on the outside. Knowing how to effectively lead yourself during times of change is difficult for even the most gifted individuals.

Shawna Legarza, superintendent of the San Juan Hotshots, 2006. Photo: San Juan Hotshots.

> You may become addicted to the risk of change and the speed of the emergency, while not truly knowing the long-term physiological and psychological effects.

The principal difficulty in evaluating your own success is contemplating your own experiences with trial and tribulation. During some leadership opportunities in the past, maybe you used trial and error to learn lessons for next time. If you make substantial changes within following your mistakes, you can learn to communicate more effectively about your feelings. You can express the feelings of change to yourself, your coworkers, and your family, thus reducing the stress-related effects of sensemaking—the ability to see things how they are and to be open to other frameworks during times of change, and the ability to find your passion and connect this passion with leadership. To understand and communicate effectively within yourself is self-leadership; to understand yourself is to understand life. All the while, understanding the success of your life means to understand the variables of incremental change over time.

Embracing Change

As leaders in Fire and Aviation Management, we need to continue to embrace change while educating our employees about taking effective care of themselves (self-leadership) and their employees (leadership). I believe the essence of leadership is leading your passion within through the challenges in life. To honestly believe what is true to you is the most reflective self-leadership discipline.

Dig deep to find your answers. Remember, the most consistent event in your lives will be the challenges of coping with change. With the global challenges we are now facing, we need to continuously embrace the transformation of change by being adaptive and creative in both our personal and professional lives. We will all learn from those who remember the fundamental priorities and embrace the transformation of change within themselves and their organizations. ■

After-Action Reviews—Who Conducts Them?

Anne E. Black, Kathleen Sutcliffe, and Michelle Barton

Reflecting on the links between intentions and outcomes is a key practice of a learning organization (Garvin 2000). The After-Action Review (AAR) is a formal reflection process intended to assist groups in capturing lessons learned from a task. AARs typically ask four questions regarding fire-response operations: (1) what did we set out to do, (2) what actually happened, (3) why is there a difference between the first two, and (4) what should we continue/what should we change? Since the Wildland Fire Lessons Learned Center sponsored training workshops on AARs for the fire community in 2002, the practice seems to have been widely adopted. You can hear the term almost every where you go these days, from engine bays to incident command posts. But just how widely has the practice been implemented? Are all levels and all functions in the fire organization conducting AARs? How good are AARs as currently used at getting at root causes of discrepancies, and is the practice having a positive impact on performance?

We asked 668 randomly selected survey participants from across the country about their AAR practices, as part of a larger study of high reliability behaviors among permanent fire staff in the Forest Service, the Bureau of Land Management, and the National Park Service (see: "A Multidisciplinary Approach to Fire Management Strategy Suppression Costs, Community Interaction, and Organizational Performance," in this issue). We asked each whether their groups (the units with which they worked most closely) had conducted an AAR in association with the last fire they were on and, if so, at what point the AAR was conducted. To help understand current practices, we also asked them what general type of fire this was (suppression, prescribed, or wildland fire use); the class of that event (initial attack, extended attack, home unit, or project-complex); the role they played during this incident (or the role they spent the most time in on that event); and at what point they conducted their AAR (after each shift, assignment, incident, or season).

We also asked respondents about their perception of their group's performance. We are still in the process of analyzing the full dataset but want to share answers to the first of these questions: who is conducting AARs and at what point?

AARs typically ask four questions regarding fire-response operations: what did we set out to do; what actually happened; why is there a difference between the first two; and what should we continue, and what should we change?

Data Classification

Because there were far more suppression events (373) than prescribed fires (59) or wildland fire use (54) events, we grouped the respondents' roles first by basic organizational unit: agency (e.g., agency representative, line officer, fire management officer, duty officer, resource advisor); dispatch (including dispatch function and Geographic Area Coordination Center level); or team (for anyone assigned to the incident).

Because there were significantly more team (538) than dispatch (73) or agency (57) respondents (fig. 1a), we broke team respondents down into their functional roles: aviation (helicopter managers, helitack, etc.); Incident Commander (type 5–1, area command); and others according to their Incident

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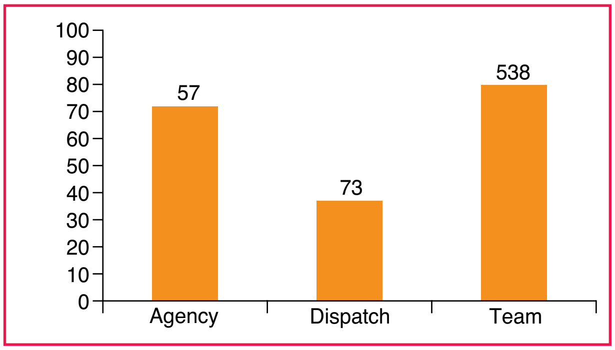
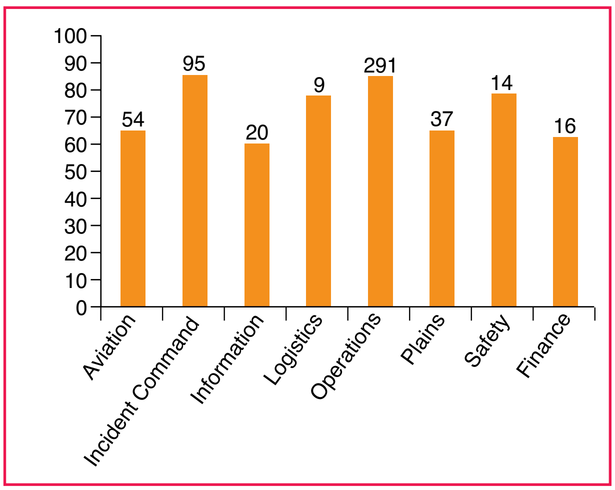
NOTE: Policy terminology and guidance have changed since this article was prepared. "Wildland fire use" is no longer considered a category of fire management but describes one potential management strategy for dealing with natural-ignition wildfires. The term has been retained here to reflect the structure of the study.

Figure 1—*Percentage of permanent Federal fire staff reporting that their group conducted an After-Action Review on their last assignment in 2007, with total number of responses per class shown at top of bar,*

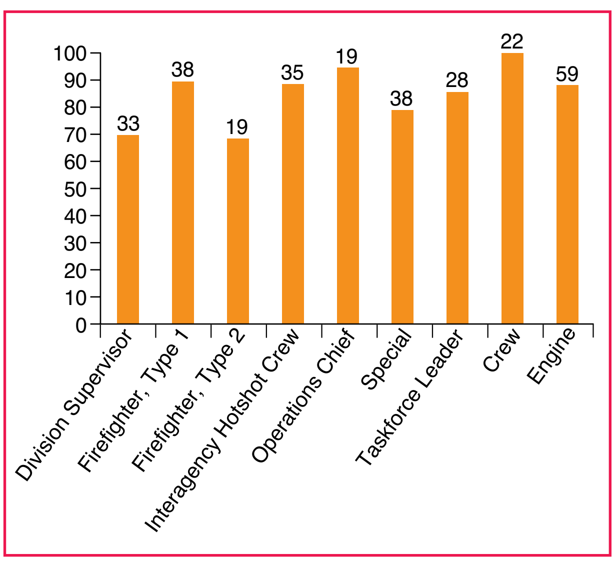
(a) Basic organizational unit



(b) Team respondents by Incident Command System function on suppression events, and



(c) Operations function by resource type.



Command System (ICS) function (information, finance, logistics, operations, planning, or safety) (fig. 1b).

Finally, because operations numbers outnumbered the responses from other ICS functions by an order of magnitude, we broke out the operations function into general resource type or level: division supervisor, firefighter 1, firefighter 2, interagency hotshot crew, operations section chief, task force/strike team leader, crew, engine, and a category that includes specialized roles (e.g., sawyers, bulldozer operators, firing bosses, and fire use module members) (fig. 1c).

While these queries and subsequent analysis cannot tell us about the quality of the AARs, they do indicate some significant differences in current practices. Subsequent analysis will help us associate learning practices with perceptions of performance.

Results

According to this study, staff on prescribed fire, fire suppression, and wildland fire use events use AARs in similar proportions: about 74 percent of the time. There are, however, significant differences in AAR use by basic organizational unit, class of fire, team function, and operational role (table 1, fig. 2). Frequency of AARs conducted by groups involved in initial attack (64 percent) is significantly different than on those on project-complex fires.

Only 37 percent of respondents in dispatch units reported their group held an AAR, whereas 86 percent of team-based respondents said their group had done so. Perhaps surprisingly, respondents working in aviation reported that their group conducted AARs less frequently than all but those in an information function. At an overall 79-percent rate, those in safety reported the group they associated with lagged significantly behind those in operations functions (85 percent). Among the operations functions, division supervisors reported their group held AARs less frequently than any other category (although not statistically so), while all of those participating in a crew reported conducting AARs.

Most of these AARs are conducted after each shift and/or after the incident—at least for prescribed fire and suppression operations (fig. 3). Respondents who last worked on a wildland fire use incident reported that their AARs were generally conducted after an assignment. This timing may reflect the different tempo of action on different

Table 1—*Statistical results for assessing differences in after-action review (AAR) practices on wildland fires.*

Categories Compared	Pearson Chi-Sq test results
Type of fire (suppression, prescription, wildland fire use)	(χ^2 (2, *N* = *653)* = 2.71, *p* = .258)
Organizational unit for all classes	(χ^2 (2, *N* = *668)* = 63.08, *p* = .000*)
Class of fire (initial assessment, extended assessment, home, or project/ complex)	(χ^2 (3, *N* = *499)* = 11.15, *p* = .011)
Team function for suppression events	(χ^2 (8, *N* = *541)* = 27.57, *p* = .001)
Operational role on suppression events	(χ^2 (8, *N* = *291)* = 16.63, *p* = .034)

* Significant results (bold) are those with p-values less than 0.05. Models indicate whether or not there are significant differences among the categories, but not which ones are significantly different.

Figure 2—*Percentage of respondents on different types of suppression events reporting that their group conducted an AAR, with total number of responses from each type at top of bar.*

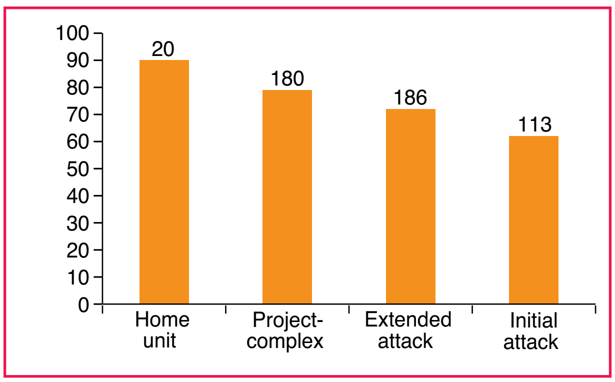
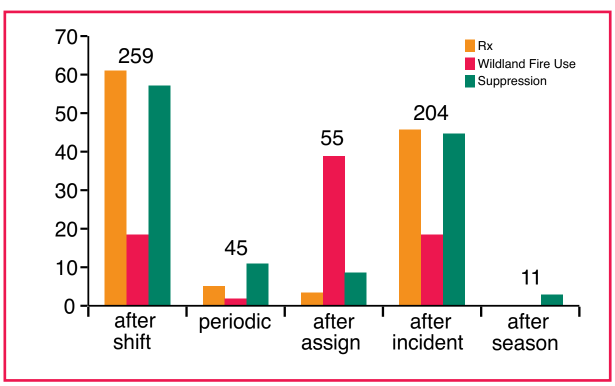


Figure 3—*Percentage of AARs conducted by strategy and timing, with total number of responses summed for each time period.*



types of incidents: "boots-in-the-black" forces conducted AARs by operational shift; prescribed fire and host units, after the incident; and wildland fire use, after an assignment or in place of a close-out. Quite a few respondents noted that they conducted several types of AARs—after shifts, after assignments, and after the fire season.

More information on AARs, including background information and training materials, as well as fire-related AARs and details on how to share your own AAR, may be found at the Wildland Fire Lessons Learned Web site: <http://www.wildfirelessons.net/AAR.aspx>. More information on this project can be found at <http://leopold.wilderness.net/research/fprojects/F017.htm>.

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Mitigation on Alabama's Gulf Coast: Bon Secour National Wildlife Refuge

Jeremy A. Keller

While southern Alabama is better known for the city of Gulf Shores and its vacation and tourism attractions, it is also home to the Bon Secour National Wildlife Refuge (NWR). In an area of intense wildland-urban interface (WUI) development pressure, it was challenging to successfully manage large areas of fire-dependent ecosystems without sacrificing our core responsibility of maintaining and restoring endangered species habitat.

> Key to maintaining the ecological integrity of the refuge is a comprehensive fire management program, including prescribed fire.

Despite the challenges, we successively implemented an aggressive fire management plan that met our primary objectives: safeguarding life and property from wildfire and caring for the natural resources of Bon Secour NWR. We put aside many traditional ways of doing business, worked hard to develop effective cooperative relationships, and are now realizing the benefits from our efforts. This article provides a case study about our efforts to carry out a successful fire management program on this challenging unit of the NWR System.

The Fort Morgan Peninsula and Bon Secour NWR

Bon Secour NWR occupies about 7,000 acres (3000 hectares) on the Fort Morgan Peninsula—a narrow, sandy strip bordered on the south by the waters of the Gulf of Mexico and to the north by Mobile Bay. The area is widely known for its stunning white "sugar sand" beaches and the vacation condos of Gulf Shores. The Fort Morgan Peninsula is undergoing explosive development, much of which is occurring in WUI areas bordering the refuge. Residents in the area view the refuge favorably, taking advantage of

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Table 1—*Historic wildfire activity on Bon Secour National Wildlife Refuge, 1988–2007.*

Year	Number of Fires	Total Acres Burned	Year	Number of Fires	Total Acres Burned
1988	2	0.2	1998	1	3.0
1989	0	0.0	1999	1	3.0
1990	1	0.3	2001	1	455.0
1991	3	885.2	2002	1	12.7
1992	1	175.0	2003	0	0.0
1993	0	0.0	2004	2	5.5
1994	4	57.6	2005	0	0.0
1995	2	21.0	2006	0	0.0
1996	1	49.0	2007	1	180.0
1997	2	728.1			

Table 2—*Significant wildfire incidents, Bon Secour National Wildlife Refuge.*

Incident	Acres	Year
Oyster Bay Fire	820	1991
Little Dauphin Fire	175	1992
Mouse Fire	722	1997
Little Point Clear Fire	455	2001
Three Rivers Fire	180	2007

the numerous recreational opportunities or simply appreciating the fact that it will remain undeveloped. However, residents and visitors are generally oblivious to the potential danger of wildfires to developments because more attention is focused on the threat of hurricanes.

Bon Secour NWR was established in 1980 to protect unique coastal ecosystems dwindling in extent because of rapid development all along the Gulf Coast. The refuge protects critical habitat for the endangered Alabama beach mouse (*Peromyscus polionotus ammobates*) and nesting sites for sea turtles and is an important stopover point for migratory birds. Key to maintaining the ecological integrity of the refuge is a comprehensive fire management program, including prescribed fire.

The Wildfire Problem on Bon Secour NWR

The Fort Morgan Peninsula has a cyclic pattern of wildfire occurrence, with several years typically passing between a year or two of intense fire activity. The intervening quiet periods permit fuel loads to re-accumulate while simultaneously allowing the impact of wildfires to fall off the "radar screen" of local communities.

On average, the Bon Secour NWR has a wildfire incident about once a year with a mean size of 112 acres (453 hectares); however, these incidents are more complex than their average size and frequency alone suggest (tables 1 and 2). Fire-dependent ecosystems, heavy fuel loads, impassable terrain, hurricane debris, and encroaching subdivisions all contribute to an environment in which almost every fire

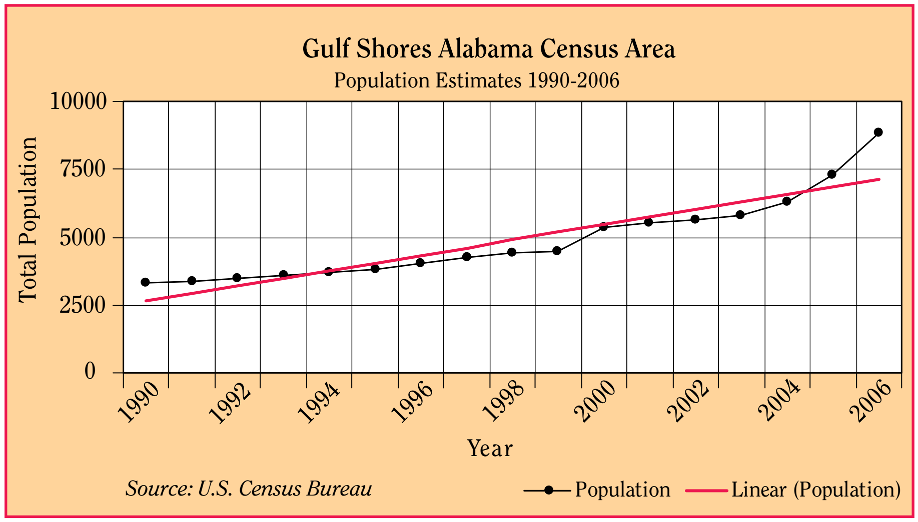

Figure 1—*Population growth around Bon Secour National Wildlife Refuge since 1990, as reflected in census data for Gulf Shores, AL. Source: U.S. Census Bureau.*

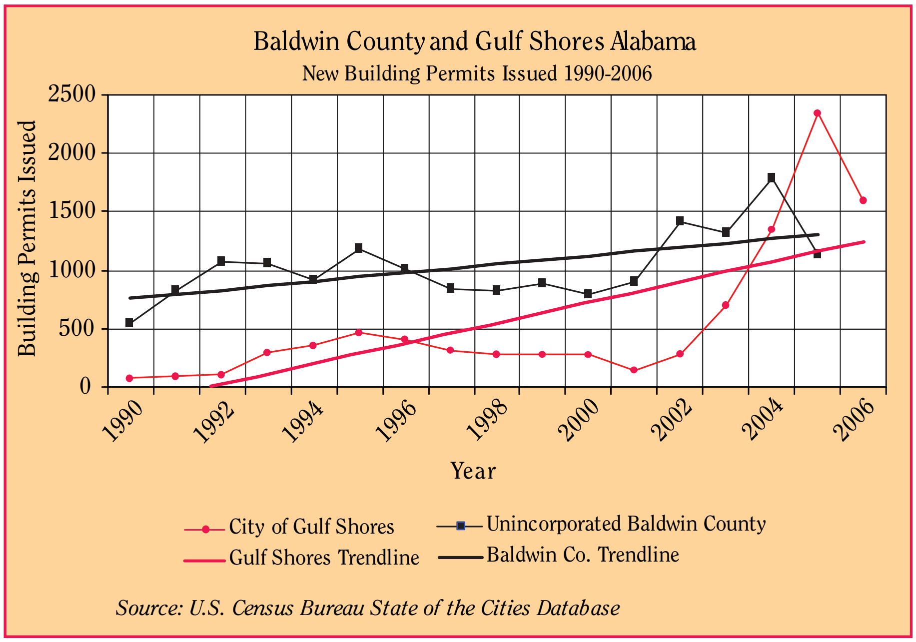

Figure 2—*Population growth around Bon Secour National Wildlife Refuge since 1990, as reflected in building permit data for unicorporated Baldwin County and Gulf Shores, AL. Source: U.S. Census Bureau.*

requires a major commitment of resources and money.

Rapid development on the Fort Morgan Peninsula has resulted in high real estate values, which means nearly every buildable square foot of private property is either developed, under development, or zoned for future development. While census data are not available for the peninsula as a whole, data for the city of Gulf Shores and for unincorporated Baldwin County reflect the rapid growth in the area. Gulf Shores has experienced a 167-percent overall increase in population since 1990, or an average annual increase of about 10.5 percent (fig. 1). Building permit data for the same period (fig. 2) tell a similar story, with the number of permits issued for Gulf Shores and Baldwin County increasing dramatically since 1990.

Table 3—*Fire resources normally available for initial attack on Bon Secour National Wildlife Refuge, with approximate response times.*

Agency	Fire Resources	Response Time to Bon Secour NWR
U.S. Fish and Wildlife Service	2 x Engine, Type 6 2 x Engine, Tracked (Type 6) 3 x Tractor-Plow, Type 4	2–3 hrs
Alabama Forestry Commission	1 x Tractor-Plow, Type 4 2 x Tractor-Plow, Type 5	30–40 min
Fort Morgan Volunteer Fire Department	2 x Engine, Type 6 3 x Engine, Type 1/2/3	10–15 min
Gulf Shores Fire-Rescue	2 x Engine, Type 6 5 x Engine, Type 1/2/3	10–15 min

Every fire on Bon Secour NWR is a WUI incident. The fires are infrequent but of high intensity and difficult to control. Vegetative cover on the Fort Morgan Peninsula is dominated by fire-dependent species. The sand pine (*Pinus clausa*), saw palmetto (*Serenoa repens*), and scrub oak (*Quercus* spp.) vegetation complex that covers most of the refuge presents a challenging fuels environment for fire managers. The density and energy content of these fuels require the use of mechanized equipment in the form of tractor-plows; no other firefighting tool can counter the intensity and rapid rates of spread produced.

Bon Secour NWR terrain is mostly dune and swale topography where ancient beach dunes generally run east and west, separated by tidally influenced sawgrass swales and cypress (*Taxodium* sp.) strands. While the sandy ridges are trafficable and offer good locations for firelines, the swales and strands are a formidable obstacle—difficult to cross on foot, and impossible to cross with tracked equipment even during extreme drought. These areas can literally be dry enough to burn intensely, yet too wet and soft to allow equipment operation.

In 2004, Hurricane Ivan complicated fire management on the refuge in two ways. First, salt water and high winds killed many overstory trees, which have since cured and created a high load of 100- and 1,000-hour fuels. Secondly, Ivan deposited large amounts of debris, most of which remains in the remote parts of the refuge. Some of this debris contributes additional heavy fuel in the form of lumber, utility poles, and other ordinary combustibles. Lurking among the debris are hazardous materials, and although much was cleaned up, undetected items still remain on the refuge as hidden dangers during fire operations.

> To successfully tackle the wildland fire issues facing the refuge and local residents, a fully engaged community is required.

Fire Resources on the Fort Morgan Peninsula

Although the Bon Secour NWR is the largest single landowner on the Fort Morgan Peninsula, there are no fire personnel stationed at the refuge. Fire management on the refuge is the responsibility of our fire staff at Gulf Coast Refuge Complex in Gautier, MS, more than 2 hours away. Initial attack for the refuge is provided by Fort Morgan Volunteer Fire Department (VFD) for refuge lands in Baldwin County, and Gulf Shores Fire-Rescue (a combination career and volunteer department) for refuge lands inside the city limits of Gulf Shores. These two fire departments are backed up by Alabama Forestry Commission tractor-plow units stationed in Loxley, 30 to 40 minutes away (table 3).

Response to wildfires on the Fort Morgan Peninsula is complicated by jurisdictional issues. The U.S. Fish and Wildlife Service has jurisdiction over all refuge lands, but has no fire resources on site. The Alabama Forestry Commission has primary jurisdiction for wildfires on all State and private property, but has few resources available. The city of Gulf Shores has annexed the entire right-of-way along State Highway 180, which runs the length of the peninsula. Owners of individual properties bordering the right-of-way may petition the city for annexation, which is rarely denied. The same owners may likewise petition for de-annexation; again, these requests are rarely denied. This has resulted in an ever-changing patchwork of jurisdictional responsibility regarding fire protection between Fort Morgan VFD and Gulf Shores Fire-Rescue.

Permanent firelines around The Rookery subdivision. Photo 1 shows area behind homes prior to treatment (Oct. 2006). Photo 2 shows area after Phase I brush-cutting treatment (Nov. 2006). Photo 3 shows area following Phase II removal of all vegetation and Phase III creation of park-like visual buffer (Sept. 2007). The red arrow points to the same house in each photo for visual reference.

Addressing the Fire Problem on the Refuge

A chief goal of our fire staff is to reintroduce prescribed fire to Bon Secour NWR. Prescribed fire is recognized as a critical tool for meeting the ecological management goals of the refuge, while simultaneously keeping fuel loads manageable. Our use of prescribed fire is especially challenging on this refuge for several reasons:

- Because Bon Secour NWR is located on a peninsula separating the Gulf of Mexico from Mobile Bay, unique coastal weather phenomena, such as sea and land breezes, complicate fire behavior. These cape-effect dynamics must be factored into all fire planning and operations; they make wind directions especially difficult to predict. They also deny the peninsula of precipitation that falls on the nearby mainland, meaning that the peninsula can have drought effects far in excess of areas just a few miles away.

- Intense development hinders the use of prescribed fire. Refuge areas that were bordered by undeveloped and unused wildlands just a few years ago are now crowded by subdivisions on all sides. This restricts burn windows because of the risk of escaped fires and smoke impacts. In the past, simple two-track roads served as adequate firebreaks between refuge lands and adjacent undeveloped properties. As development has intensified, many of these old firelines are inadequate because of their insufficient width and tendency to meander along terrain features rather than follow actual property lines.

To address these issues, a multiyear plan was initiated (table 4). Notable phases included the following:

- To use prescribed fire on a more regular basis with the least amount of risk to surrounding communities, we implemented an integrated program of new, permanent fireline construction coupled with fuel reduction buffer zones. We established 6.2 miles (10 kilometers) of 16-foot (4.9-meter) minimum width,

October 2006

September 2007

Buffer zones around The Rookery subdivision. Photo on left shows pretreatment condition with heavy shrub-layer fuels (Oct. 2006). Photo on right shows buffer area after removal of shrub layer and creation of buffer zone (Sept. 2007), preserving aesthetic values for local residents while providing a park-like fuel break between refuge and private property.

bare mineral soil firelines along refuge boundaries. These firelines are offset from current and soon to be developed residential areas by 50 to 100 feet (15 to 30 meters) onto the refuge, creating 25 acres (10 hectares) of buffer zones. Within these buffer zones, shrub-layer fuels were reduced mechanically while retaining all large overstory trees. The result is a park-like appearance that serves as both an extension of the fireline and a visual buffer for residents. (See the sidebars for images of the fireline and buffer zones.)

- To support prescribed fire and wildfire response, we initiated a series of infrastructure improvements. For many areas, heavy fire equipment previously was unloaded by stopping traffic on busy Highway 180, which presented obvious safety hazards to both fire crews and motorists. We constructed a permanent staging area that provides a 100- by 150-foot (30- by 45-meter) gravel parking and unloading apron for fire equipment and improved access to existing refuge road and fireline networks. Gravel lanes were strategically located along the new permanent firelines to allow full access for local fire department equipment around subdivisions and other vulnerable residential areas.

With all these measures in place, implementation of further prescribed burning is planned for fiscal year 2009 or fiscal year 2010. This will allow us to better manage the fuel problem on Bon Secour NWR while simultaneously achieving the ecological objectives for which the refuge was established.

Addressing the Fire Problem Through Partnerships

Fire management problems on the Fort Morgan Peninsula do not stop at the refuge boundary. While the measures described above are designed to mitigate fire management issues on the Bon Secour NWR, they address only part of the problem. To successfully tackle the wildfire issues facing the refuge and local residents, we actively engaged the community through a concerted and long-term program of cooperative relations with key partners in the area.

Prominent among these cooperative relationships are those we have fostered with local fire departments. We enjoy a particularly close partnership with the Fort Morgan VFD, an organization that has historically served as the initial attack force for the majority of wildfires on the refuge. The strength of our partnership with Fort Morgan VFD is exemplified by the location of its main fire station on refuge property.

Our cooperative relationship with Gulf Shores Fire-Rescue has strengthened in recent years as well. While this organization's main focus is oriented toward urban fire issues, there are still significant blocks of refuge land for which it provides first-line fire protection. And as annexation rapidly continues, its interest in wildland issues increases accordingly.

Because these two fire departments are key to the success of our fire management objectives on Bon Secour NWR, we have taken several measures to bolster their wildland capabilities. Between 2001 and 2008, we secured $11,000 in funds from the U.S. Department of the Interior Rural Fire Assistance (RFA) grants program for Fort Morgan VFD and $2,000 for Gulf Shores Fire-Rescue, money that primarily purchased personal protective equipment and hand tools for the departments. Where RFA funds were not adequate, we made direct equipment loans to the departments to meet specific wildfirefighting capability shortfalls. The centerpiece of these efforts was Fort Morgan VFD's purchase of a new brush truck (type 6 engine), which involved a cost-sharing arrangement with the State of Alabama; the Gulf Coast Refuge Complex provided the necessary hoses, appliances, and hand tools to bring it into service.

Figure 3—*Map exercise from the Fire Operations in the Wildland-Urban Interface (S-215) course taught at Fort Morgan Volunteer Fire Department in January 2007.*

Table 4—*Integrated fireline, fuel reduction, and fire apparatus access program for Bon Secour National Wildlife Refuge.*

Phase	Activities	Fiscal Year
0	Initial planning Endangered species, wetlands, and archaeological consultations Marking of fireline corridors	2005 and 2006
I	Initial brush cutting and tree removal to open 20-foot (6-meter) fireline corridors	2006
II	Blading of 16-foot (5-meter) fireline corridors to mineral soil on areas accessible to equipment	2007
III	Creation of 50- to 100-foot (15- to 30-meter) park-like buffer areas between firelines and vulnerable residential areas	2007
IV	Construction of gravel staging area for unloading of heavy equipment and parking of transports	2007
V	Hand clearing of 16-foot (5-meter) fireline corridors in areas unsuitable for equipment use	2009
VI	Creation of gravel access lanes for fire department apparatus on firelines around vulnerable residential areas	2010

In addition to improving our cooperator's equipment status, we have also worked to improve its human capital by offering training courses, such as Basic Wildfirefighter Training (S-130/S-190), Fire Operations in the Wildland-Urban Interface (S-215), and Advanced Firefighter Training (S-131). In 2008, funding from the Ready Reserve Program was secured for additional training in 2009 through 2012. This training will include Wildland Chainsaws (S-212), a Wildland Engine Academy, and a session of Basic Wildfirefighter Training built around the National Wildfire Coordinating Group/National Fire Protection Association Crosswalk

Agreement and geared toward the career firefighters of Gulf Shores Fire-Rescue (fig. 3). Eventually, we hope to work with our cooperators to develop a cadre of qualified engine bosses and initial attack incident commanders as a way of expanding local capabilities to safely and effectively address the local fire problem.

We have not reached out exclusively to fire departments in our efforts to stay ahead of the WUI fire threat on the Fort Morgan Peninsula. Because managing fire hazard is not a task for firefighters alone, we actively engaged the Baldwin County Emergency Management Agency (EMA) to provide emergency planning expertise and share our substantial communications capability. Based on discussions with this agency, the standard Annual Operating Plan for Bon Secour NWR was modified to more closely align with existing county emergency plans. The current version follows the Federal Emergency Management Agency planning format as much as possible. An additional benefit of our strengthened relationship with the Baldwin County EMA is that our preparation for all-hazard incidents on Bon Secour NWR has been enhanced—an important consideration in an area where hurricanes, hazardous material spills, and search-and-rescue incidents are all real possibilities.

An Early Return on Investments: The Three Rivers Fire

On August 26, 2007, Fort Morgan VFD informed us they were en route to a wildfire on a remote part of Bon Secour NWR. As relative humidity was between 80 and 90 percent on the peninsula that day, the initial expectation was the fire would not amount to much.

Figure 4—*Three Rivers Fire: (a) intense fire behavior in local fuel types; (b) tractorplow lines used to control the fire; and (c) morning briefing with representatives from local fire departments in attendance (Aug 2007).*

Because of extreme drought conditions, however, the fire was able to burn intensely in heavy fuels and posed a potential threat to a subdivision as it continued to grow through the night (fig. 4a).

Because the fire was located on a remote and roadless part of the refuge, Fort Morgan VFD's engines were unable to reach it; even their all-terrain vehicles became hopelessly bogged down. Firefighters eventually made their way in on foot, but quickly realized that hand tools were ineffective against the fire. When Gulf Coast Refuge Complex resources arrived on scene, an attempt to reach the fire with a U.S. Fish and Wildlife Service (FWS) low-ground-pressure tractor-plow unit was made, but even this machine became bogged down. Eventually, the fire was contained at 180 acres (73 hectares) using helicopters and indirect lines, along with the assistance of a thunderstorm that dropped rain almost directly on the burned area (fig. 4b).

While the Three Rivers Fire was not especially remarkable as a wildfire incident, it showcased the success of all our cooperative efforts over the years. Both Fort Morgan VFD and Gulf Shores Fire-Rescue committed resources to the fire and were fully involved in managing the incident (fig. 4c). All agencies involved worked hard to bring the incident to a successful conclusion by taking advantage of their strengths and supporting each other as appropriate. While the department's primary firefighting resources could not directly engage the fire, they were able to stand by for structural protection.

Fort Morgan VFD jumped in to provide water supply support for the FWS tracked engine and to provide facility support. Gulf Shores Fire-Rescue provided an amphibious all-terrain vehicle to re-supply FWS units and provide emergency medical support on the fireline. Baldwin County EMA stood ready to support our efforts with their radio cache and reverse 911 system, although ultimately these were not needed.

The Three Rivers fire showed how our efforts to engage local partners in managing the wildfire problem on the Fort Morgan Peninsula had begun to take place. The close relationships we developed with our cooperators were evident when these agencies quickly responded to the initial fire, seamlessly handed off to our resources, and continued to provide meaningful support through the successful conclusion of the incident.

Conclusion

Our approach to the fire problem on the Bon Secour NWR is a clear example of how an aggressive wildfire management program can be successfully pursued even without dedicated on-site fire resources in the face of extreme WUI development pressure. The key to our success has been our close and mutually beneficial partnerships with other agencies in the community. Only by accepting the reality that we cannot "go it alone," and that we need to address wildfire hazards as a team, have we been able to carry out an effective and progressive fire management program. ■

An Answer to a Burning Question: What Will the Forest Service Spend on Fire Suppression This Summer?

Karen L. Abt, Jeffrey P. Prestemon, and Krista M. Gebert

Wildfire management has become an ever-larger part of Forest Service, U.S. Department of Agriculture, and other land management agency appropriations and expenditures. In fiscal year (FY) 2008, the wildfire program budget was nearly 44 percent of initial Forest Service discretionary appropriations (U.S. Congress 2008). Total expenditures for suppression eventually exceeded the initial appropriations by more than $500 million, resulting in additional appropriations from Congress and internal transfers from Forest Service programs. Clearly, wildfire suppression has become a dominant part of Forest Service budgeting, planning, and activities.

Modeling the Past

In an effort to provide early warnings to wildfire managers and to provide additional information for the Forest Service budgeting process, we forecast Forest Service suppression costs in collaboration with Forest Service Fire and Aviation Management by using computer models that use weather trends and suppression costs as inputs. We make our forecasts in November for the current fiscal year's fire season (the current-year forecast) and, while not discussed here, we also make forecasts for the 2 fiscal years beyond that (2 and 3 years ahead). The table shows the report for our current-year forecasts, made in November 2008 for the FY 2009 fire season. All the dollar values reported for 2009 and shown in the table and accompanying figures are in estimated FY 2009 dollars to allow consistent comparisons across years.

Karen Abt is a research economist and Jeffrey Prestemon is a research forester at the Forest Service's Southern Research Station in Research Triangle Park, NC; Krista Gebert is a research economist at the Forest Service's Rocky Mountain Research Station in Missoula, MT.

Our models show that suppression costs can be statistically estimated largely from previous years' suppression costs, climate, drought conditions, and a time trend. Hazardous fuels are not directly included in our model, largely because data are not available for all regions and all years (1977 to 2008), but the effects of climate and weather on fuels and the time-trend effect of increasing fuel loads are captured in part by the other variables. Other influences on costs that are not directly included are input price trends (energy, labor, capital, etc.) and management changes (such as Appropriate Management Response and the National Fire Plan). Even with the best available data and statistical methods, a portion of suppression costs is unpredictable. As a result, our best models can only account for between 59 to 89 percent of the annual variation in costs.

Our models show that suppression costs can be statistically estimated largely from previous years' suppression costs, climate, drought conditions, and a time trend.

In the process of developing a forecast, we test several models, and we develop new models each year. The forecast in the table is based on our preferred current model, Benchmark 2, and uses the best available data and forecasting methods at our disposal. The Benchmark 2 model is slightly different from those reported in Prestemon and others (2008) and Abt and others (2009).

We model the Forest Service regions separately, regressing real (discounted) suppression costs on the independent variables noted above, and then we estimate all the regions together using statistical techniques to account for cross-region correlations. We then develop "jackknife" forecasts to test the accuracy of our forecast models. These jackknife forecasts estimate the model coefficients with all but 1 year of the data; then the coefficients and the independent variable data from the year not included are used to forecast the costs for the missing year. This process generates a time series of historical "backcasts" (fig. 1). Comparisons of the backcasts and observed costs produce estimates of the fore-

Table 1—*Wildfire suppression cost forecast results for FY 2009 (current year forecast) for Forest Service regions, in 2009 dollars.*

	Regions 1-6 (Western Regions)	Region 8 (Southern)	Region 9 (Eastern)	Region 10 (Alaska)	Rest of the Forest Service*	Total Forest Service
	Millions of 2009 dollars					
Point estimate	1,067	73	25	8	125	1,298
Mean	1,113	86	37	8	131	1,375
Median	1,113	75	26	8	131	1,368
95-percent confidence interval						
Lower bound	815	27	5	3	37	990
Upper bound	1,411	209	130	13	225	1,795
90-percent confidence interval						
Lower bound	862	32	7	4	52	1,048
Upper bound	1,364	177	101	13	209	1,720

**The "Rest of the Forest Service" includes emergency suppression related expenditures by national offices not tied to the regions and by the agency's research stations.*

cast accuracy (root mean squared error). Our forecasting methods are explained in greater detail in Prestemon and others (2008) and Abt and others (in press).

For the current-year forecast, we use the forecast models and the error distribution for all of the input data to simulate a probability density function for each forecast year (fig. 2). From the forecast model we get the point forecast, while from the simulation we get the mean, median, and the 90- and 95-percent confidence intervals, as shown in the table and figure 2.

Forecasting the Future

The current-year point forecast for FY 2009 is $1,298 million. Using the simulation analysis, the estimated mean is $1,375 million and the median forecast is $1,368 million. If forced to choose a single number for the forecast, we recommend using the median forecast, the outcome from the simulation in the middle of the probability density function. The root mean squared error associated with this forecast is $189 million (for the entire data period from FY 1982 to FY 2008).

While the Forest Service FY 2009 budget has not been finalized at the time of this writing—as of December 2008, the Forest Service was operating under a continuing resolution for October 1, 2008, to

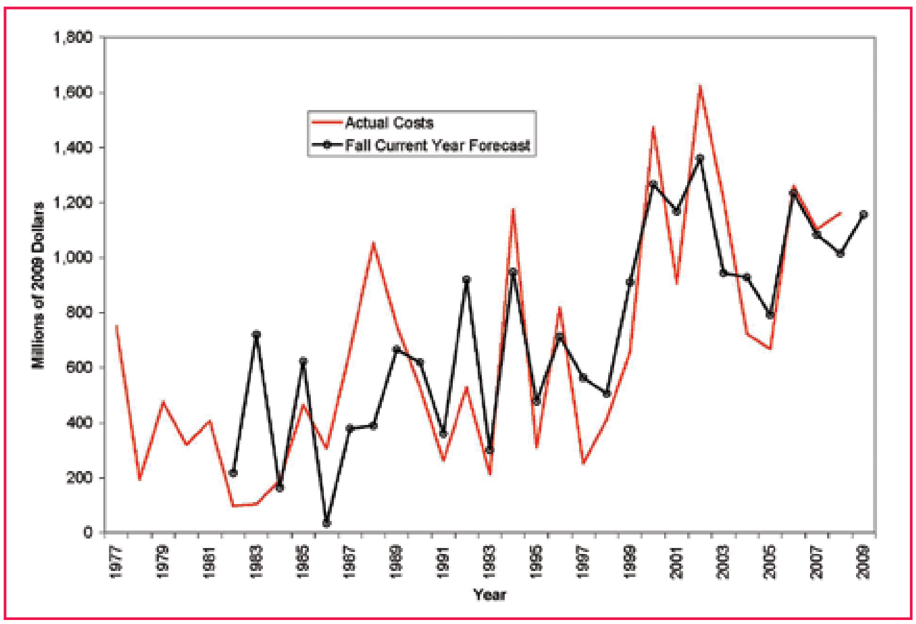

Figure 1—*Wildfire suppression cost forecasts (point estimates) and actual wildfire suppression expenditures from FY 1982 to FY 2008, and the FY 2009 forecast for the Forest Service, in 2009 dollars.*

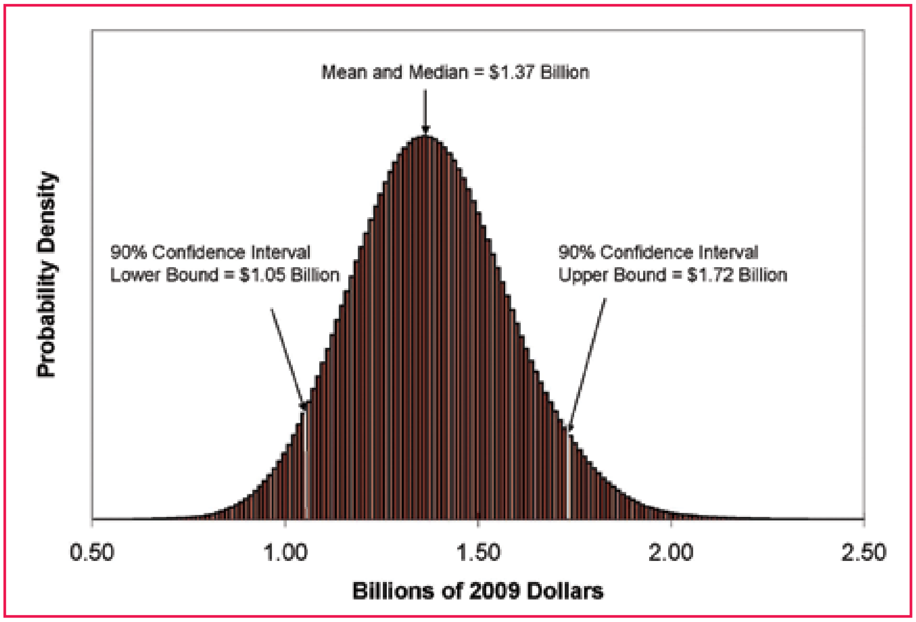

Figure 2—*Simulation results for the FY 2009 wildfire suppression cost forecast showing the mean and median forecasts as well as indicators of the 9-percent confidence interval bounds, in 2009 dollars.*

March 6, 2009—for the purpose of this analysis, we assume that the FY 2009 budget is similar to FY 2008. Using an estimated budget allocation for FY 2009 of $854 million in conjunction with the simulation results, we conclude that there is a 99-percent chance that the estimated budget will be exceeded in FY 2009. Of course, that implies a 1-percent probability that the budgeted amount will not be exceeded.

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Teaching Fire Ecology in Public Schools

Traci Weaver

When children describe a wildfire, they often reflect what they have seen and heard from the news media: fire is scary and it destroys everything. Fire education specialists from the U.S. Department of the Interior, National Park Service, and U.S. Department of Agriculture, Forest Service, in the Greater Yellowstone area (GYA) are working to revise those perceptions and explore the positive effects of fire with elementary and middle-school students through hands-on fire ecology research.

After a successful pilot program in Yellowstone and Grand Teton National Parks in 2008, the Greater Yellowstone Coordinating Committee (GYCC) granted $12,000 to support the fire ecology education field trips throughout the GYA, which includes six national forests and two national parks. Fire education specialists are joining with university graduate students and education majors to present a 3-day fire ecology and management program that involves both field and classroom exercises to fourth- through eighth-grade students.

Fire Ecology in Schools

Part of the grant provides support to Teton Science Schools, a program for university graduate students in science and environmental education, in working with Wyoming and Idaho schools near the GYA. The remaining grant money will support education majors from the Environmental Interpretation and Education Department of the University of Montana Western working with Montana schools. National Park Service and Forest Service fire education specialists provide training to the university students, coordinate visits to the national forests and national parks, and provide specific information for research locations in burned areas.

> Fire education specialists are joining with college graduate students and education majors to present a 3-day fire ecology and management program that involves both field and classroom exercises to fourth- through eighth-grade students.

In fall 2008, more than 300 students from three school districts explored burned areas while learning about fire's role in the GYA ecosystem. In September, 200 fifth-grade students in Teton County, WY, visited the Teton Science Schools campus in Grand Teton National Park for a 3-day program. The students learned basic fire ecology and then conducted field research. The research plots were on the site of a prescribed burn conducted by interagency fire crews in 2001 to reduce potential fire fuels around the Teton Science Schools campus. The fifth-graders collected data for the park's fire effects program.

Each group measured sagebrush and bitterbrush in burned and unburned areas and then had its own research focus, such as comparing soil moisture and temperature in each site or counting the scat of different wildlife species. Each group drew comparison graphs and presented its findings to the other students.

"The students' research was authentic and useful for Grand Teton National Park," said Josh Kleyman, a lead graduate faculty member at Teton Science Schools. "Students were inspired to know that their data collection and academic work had real-world implications. Moreover, the teachers were excited about this new opportunity."

According to Diane Abendroth, the Grand Teton's fire ecologist, "Teton Science students are contributing field data that is valuable to the park's fire management program. This partnership gives us an opportunity to explore new and important questions about local fire ecology."

Research Goes Back to the Classroom...

Teton Science Schools returned to the fifth graders' classrooms in

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Counting trees—*Montana sixth-grade students identify and count trees that have regenerated after the 1988 North Fork Fire in Yellowstone. Photo: Traci Weaver, National Park Service.*

the spring for follow-up with the students, who created more graphs and analyzed the information they had gathered in the previous fall, incorporating math and science standards emphasized by the Teton County School District.

"With an outreach group of instructors visiting gateway communities to explore fire ecology and the follow-up work in the Teton County fifth-grade classrooms, the nature of the collaboration has truly been profound," Kleyman said. "We look forward to more opportunities for authentic research within our parks and forests."

...And the Classroom Goes to the Field

In October 2008, students from two Montana schools visited burn sites 20 years after the famous 1988 Yellowstone fires. They discovered that, while the fires' scars are still there, so is an amazing display of natural regeneration.

A standing carpet of 3- to 12-foot (1- to 4-meter) tall lodgepole pines, Douglas-fir, and spruce now covers much of the burned acreage.

The students visited Yellowstone through a partnership between the National Park Service and Teton Science Schools. After receiving training about Yellowstone's fire management program, Teton Science graduate students conducted a 3-day fire ecology and fire management session for Chief

Holes—*Students study holes left behind by insect-seeking birds. Photo: Traci Weaver, National Park Service.*

Joseph Middle School sixth graders in Bozeman, MT. Because those children have "Fire Fridays" with education specialists from the Gallatin National Forest, they already had a basic understanding of wildfire fuels, fire behavior, fire prevention, and the dynamics of the wildland-urban interface.

The graduate students spent the first classroom day teaching the students about fire's role in the Greater Yellowstone area and explaining how to conduct field

> Three hundred students learned basic fire ecology and then conducted field research, monitoring vegetation in burned and unburned plots of sagebrush in the park.

research. In the park, the students broke into groups and collected data near Undine Falls, one site within the more than 500,000-acre (202,190-hectare) North Fork Fire area, the largest of Yellowstone's 1988 blazes. The research site contained areas that were severely burned, moderately burned, and unburned, allowing the students to make comparisons. They learned how to identify lodgepole pine, Douglas-fir, and spruce and how to record the number of each species in a 10-meter (33-foot)-diameter plot.

Measuring—*Teton Science Schools graduate student Sarah Fuller (right) helps Teton County, WY, fifth-grade students measure sage and bitterbrush regrowth, 7 years post-prescribed fire. Photo: Traci Weaver, National Park Service.*

"For many students this was either their first time to the park or, at least, their first time off the road and boardwalks," said sixth-grade teacher Wendy Pierce. "I have always been unsure how to collect data with a large group of kids, so it was really interesting to watch the grad students' teaching techniques."

Real-World Scenarios and Decisionmaking

The lessons concluded back in the classroom with role-playing according to different groups affected by wildfire: biologists, ranchers, town council members, tourists, and fire managers. Each group had to decide what measures to recommend for a hypothetical fire: full suppression, partial suppression, or allowing the fire to fulfill its natural role.

"The role-playing exercise has kids making the tough decisions that land managers must make when they face a wildfire," said Marianne Baumberger, fire prevention and education technician for the Gallatin National Forest. "They definitely understood that fire plays an important role in the Greater Yellowstone Ecosystem, but it is a delicate balance when you consider safety, esthetics, habitat, impacts to people, and cost."

Outdoor classroom—*Teton Science Schools graduate student Josh Gold explains research procedures to a group of sixth-grade students in an area that burned in the 1988 North Fork Fire in Yellowstone. Photo: Traci Weaver, National Park Service.*

Posting results—*Students talk about a graph showing which type of tree shows the most regeneration since the 1988 Yellowstone fires. Photo: Traci Weaver, National Park Service.*

Expanding on the Experience

Fourth graders from Gardiner Elementary School near Yellowstone's north entrance completed similar field activities and followed up with more classroom time afterward. They concluded their field lessons by taking pictures and then, in the classroom, the group produced a podcast that captured one important aspect of what they'd learned. Their podcast can be viewed at <http://gsblog.tetonscience.org/archives/387>. With the Greater Yellowstone Coordinating Committee grant money, the fire ecology education program is expanding, allowing more children the opportunity to witness first-hand the effects fire has on the ecosystem as well as learn about fire management. Perhaps most importantly, it's getting more kids out in the parks and forests, experiencing nature and understanding natural processes. ■

Plow-Line Disturbance From Wildfire Suppression in Two Florida State Parks

Jeffrey T. Hutchinson and Richard E. Roberts

Historically, lightning-ignited fires in Florida spread frequently across large areas of the landscape, creating habitats for plants and animals, and naturally reducing fuel loads (Abrahamson and Hartnett 1990). Today, large, contiguous landscapes are rare because of the development of residential areas and roadways, and because fires that burn across Florida landscapes are rare. However, remnant natural areas within the landscape remain susceptible to lightning-ignited fires, arson, or accidental fires. In these areas, wildfires (defined in this paper as any fire not meeting management objectives, including lightning-ignited fires, human-caused fires, and fire that escapes the boundary of a prescribed burn) often require quick suppression techniques to prevent loss of property and potential loss of human life.

The primary method for controlling wildfires in Florida is the use of a tractor and attached fire plow to create bare mineral soil fire breaks. Although highly effective in controlling wildfires, plow lines create trenches that result in major soil disturbances, continuous berms, alterations of hydrological patterns, and sites for potential invasion by exotic plants. Suppression of wildfires creates enduring environmental impacts that are perhaps more significant than the effects of wildfire (Taylor and Gibbons 1985; Ingalsbee 2004). With the exception of a few studies (Taylor and Gibbons 1985, Caling and Adams 1999, Ingalsbee 2004), little is known about the disturbance or ecological impacts created by wildfire suppression techniques. The long-term impacts of logging roads on water quality and fish habitat are well known, but the impacts of plow lines on plant and animal communities are mostly unknown (Ingalsbee 2004). The objective of this study was to assess the relative amount of disturbance caused by fire suppression techniques in small natural areas of southeast Florida.

> Although the total number of plow lines constructed and area of plow-line disturbance from wildfire suppression techniques during a wildfire may appear to be insignificant, site-specific impacts may be substantial. Generally, the damage to natural resources caused by fire plows is greater and longer lasting than the effects of a wildfire.

Florida's Changing Landscape

Coastal southeast Florida contains one of the highest human population densities in the United States. Based on models, the population is expected to increase at a rate greater than 28 of the 50 States by the year 2020 (Burchell and others 1999). The increased urbanization of southeast Florida has resulted in rapid suppression of wildfires to save structures. At the same time, there has been a decrease in prescribed burning due to complaints of smoke, pressure on public officials, and a general lack of knowledge pertaining to fire ecology by people moving to Florida from other regions. As prescribed burning decreases and fuel loads increase, it is inevitable that wildfires will be more severe in southeast Florida, threatening and possibly destroying homes and other structures.

The State of Florida continues to purchase preservation lands amid the rapid urbanization. Remnant natural communities in Florida are often purchased because they represent unique and rare habitats, many of which are fire-dependent and contain multiple rare species of plants and animals. Management of

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these urban natural areas becomes more difficult as residential developments are built directly adjacent to conservation lands. Many smaller natural areas less than 12,000 acres (4,800 hectares) with fire-dependent natural communities are partially surrounded by residential communities, major highways, and other smoke-sensitive sites (i.e., schools, hospitals, and nursing homes). Because of the alteration of habitat, decrease in surface hydrology, increased fuel loads, and intensification of urbanization, it is now nearly impossible to achieve the historical natural fire regime in many of Florida's natural communities through the use of prescribed burning, even with the most strict burn prescriptions and smoke management. The lack of naturally occurring landscape fires, the subsequent buildup of fuels, and the limitations of using prescribed fire in the close vicinity of residential homes make many natural areas in Florida susceptible to lightning-ignitedd, arson, or accidental fires.

Study Areas

Data were collected from seven wildfires that occurred in Savannas Preserve State Park (4,997 acres [2,023 hectares]) in St. Lucie County and Jonathan Dickinson State Park (11,466 acres [4,642 hectares]) in Martin and Palm Beach Counties, FL, from February 1999 to February 2001. Both parks are located near urban areas in coastal southeast Florida, one of the most highly populated areas in the State, and are partially surrounded by residential development and major roadways that include Interstate 95 and U.S. Highway 1.

The dominant fire-dependent community at the Savannas Preserve State Park (SPSP) is mesic pine flatwoods. This community has a fire-return interval of approximately 1 to 8 years (FNAI 1990), indicating that fire could potentially burn through this habitat every 1 to 8 years. The flatwoods plant community of this park is highly diverse. Dominant plants are saw palmetto (*Serenoa repens*), gallberry (*Ilex glabra*), and slash pine (*Pinus elliottii*), with an understory of wire grass (*Aristida* spp.), chalky bluestem (Andropogon virginicus var. glaucus), milkworts (*Polygala* spp.), rose gentian (*Sabatia* spp.), meadow beauty (*Rhexia* spp.), and yellow-eyed grass (*Xyris* spp.).

Quantitative effects of plow-line disturbance during seven wildfires at Savannas Preserve State Park (SPSP) and Jonathan Dickinson State Park (JDSP) in southeast Florida from February 1999 to February 2001.

Park	Type of Fire	Area Burned, Acres (ha)	Number of Plow Lines	Plow-Line Length, Miles (km)	Plow-Line Area, Acres (ha)	Plow-Line Volume, Cubic Yards (m^3)	Ratio Burnt Area, Acres (ha) to Plow-Line, Miles (km)
SPSP[1]	Escape	135.1 (64.7)	48	2.1 (3.4)	1.2 (0.5)	4,019 (3,675)	64:1 (16:1)
SPSP	Arson	6.2 (2.5)	8	0.4 (0.6)	0.3 (0.1)	921 (842)	14:1 (3.5:1)
SPSP	Arson	41.3 (16.7)	30	1.6 (2.6)	1.0 (0.4)	2,751 (2,515)	26:1 (6.5:1)
SPSP	Arson	5.9 (2.4)	10	0.4 (0.6)	0.5 (0.2)	1,044 (955)	16:1 (4:1)
SPSP	Arson	55.6 (22.5)	41	0.8 (1.3)	0.5 (0.2)	1,804 (1,650)	75:1 (19:1)
SPSP	Lightning	8.4 (3.4)	15	0.8 (1.3)	0.5 (0.2)	2,140 (1,957)	11:1 (2.8:1)
JDSP[2]	Lightning	189.9 (76.8)	50	3.8 (6.1)	3.2 (1.3)	7,714 (7,054)	50:1 (12.6:1)
TOTALS		442.5 (179.1)	202	9.8 (15.8)	7.2 (2.9)	20,454 (1,870)	mean=37:1 (9.3:1)

[1]SPSP=Savannas Preserve State Park.
[2]JDSP=Jonathan Dickinson State Park.

Jonathan Dickinson State Park (JDSP) covers approximately 9,200 acres (3,723 hectares) in southeast Florida, with pine flatwoods and sand pine scrub as the dominant fire-dependent communities. The sandhill community is also important at JDSP because it is at the limit of its southern range. The wildfire at JDSP burned largely in the sand pine scrub and sandhill communities. The sand pine scrub fire return interval is 20 to 60 years (Roberts and Cox 2000) and the sandhill community fire return interval is 2 to 5 years (FNAI 1990). The scrub is characterized by a closed-canopy forest of sand pines (*Pinus clausa*) with a dense understory of oaks (*Quercus spp.*), and the sandhills have widely spaced slash pines and turkey oaks (*Quercus laevis*) with a sparse understory of scrub oaks (Roberts and others 2006).

Disturbance Estimates

Data were collected from wildfires over a 24-month period. The area of each wildfire was determined by walking the perimeter of the burn area with a global positioning system (GPS); plow lines created to suppress wildfires were mapped similarly by walking each line with a GPS (fig. 1). Plow-line depth (estimated from the top of the soil mound to the lowest point in the bottom of the trench) and width were estimated in the field with a yard stick and measuring tape (fig. 2), then transformed using PathFinder Office software and downloaded into ArcView 3.1 geographical information system (GIS). Length of each plow line was obtained from ArcView GIS shapefiles.

Area of plow-line disturbance was calculated by multiplying length by width of each plow line. Volume of soil displaced was calculated by multiplying length by width by depth. Depth was defined as the height from the top of the soil mound to the bottom of the trench. Ratio of area burned to plow line length was calculated as an index of disturbance.

Results

Seven wildfires were documented in the two parks over a 24-month period from 1999 to 2001, burning a total of 442 acres (179 hectares), or approximately 2.7 percent of the total area of both parks (see table). Of the seven wildfires, four were caused by arson, two were ignited by lightning, and one escaped during a prescribed burn. The wildfires occurred primarily in mesic pine flatwoods habitat (in the SPSP) and sand pine scrub and sandhill habitat (in the JDSP). All seven wildfires required immediate suppression because of the close proximity of homes and major and secondary roadways. The mean area burned per wildfire was 63 acres (26 hectares). Wildfire suppression activities resulted in a total of 202 plow lines for all seven fires with an average of 29 plow lines constructed per wildfire. For all seven wildfires, the estimated total area disturbed from wildfire suppression was 7.2 acres (2.9 hectares).

Plow-line length for all wildfires totaled 9.8 miles (16 kilometers). Plow-line lengths varied from 18 to 3,459 feet (5 to 1,057 meters), with a mean of 254 feet (78 meters). Forty-eight percent of the plow lines were attributed to the two largest fires, one ignited by lightning and one escaped during a prescribed burn. The average area disturbance for each wildfire was 1 acre (0.4 hectares) and ranged from 0.3 to 3.2 acres (0.1 to 1.3 hectares). Plow-line depths ranged from 0.5 to 3.5 feet (0.2 to 1.1 meters), with a mean of 0.6 feet (0.2 meters). Width of plow lines varied from 1.5 to 12 feet (0.5 to

Figure 1—*Mapping plow-line disturbance with GPS in a pine flatwoods community at Savannas Preserve State Park. Photo: Jeffrey T. Hutchinson.*

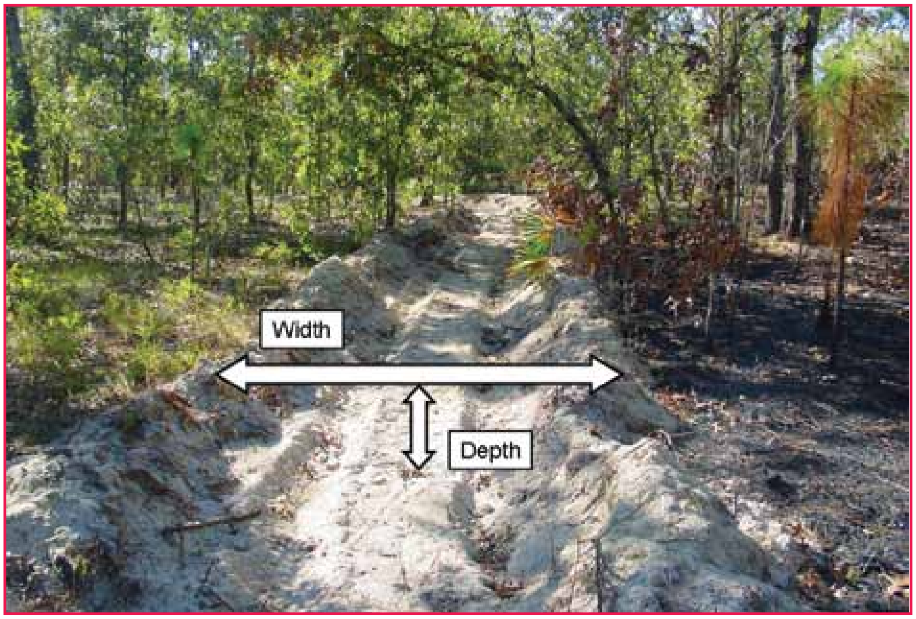

Figure 2—*Plow lines created during wildfire suppression in xeric communities of south Florida create long-lasting disturbances that persist for decades. Photo: Jeffrey T. Hutchinson.*

3.7 meters), with a mean of 1.7 feet (0.5 meters). In many instances, multiple plow lines were constructed adjacent to other lines, increasing the total width.

The range of area disturbed per plow line was between 7.4 and 3,469 square feet (6.2 to 2900 square meters), with a mean of 147 square feet (13.6 square meters). Total soil displacement per plow line ranged from 1.2 to 1,734 cubic yards (0.9 to 1,326 cubic meters), with a mean of 77 cubic yards (59 cubic meters). During the 7 wildfires, an estimated total of 20,393 cubic yards (15,591 cubic meters) of soil was displaced, a volume that is approximately equivalent to 7,800 full-size pickup truckloads of soil. In many areas, disturbance from the tractor (e.g., maneuvering and turning) and staging of equipment also resulted in severe soil and vegetation disturbance; however, this disturbance was not included in the analysis. Ratio of area burned to plow-line length ranged from 11:1 to 64:1 acres per mile (3:1 to 16:1 hectares per kilometer), with a mean of 37:1 acres per mile (9:1 hectares per kilometer), indicating that on average, for every 37 acres (15 hectares) burned, 1 mile (1.6 kilometers) of plow line was put in to control the wildfire. The highest ratios were recorded on the three smallest wildfires, while the lowest ratios were recorded for the two largest wildfires.

Discussion

Although the total number of plow lines constructed and area of plow-line disturbance from wildfire suppression techniques during a wildfire may appear to be insignificant, site-specific impacts may be substantial (Ingalsbee 2004). The plow used to create fire breaks repositions the first 1 to 3 feet (0.3 to 0.9 meters) of the soil, rhizomes, roots, and other vegetative debris to one side of the plow line, creating a berm and channel. In hydric habitat, creating plow lines is analogous to ditching and draining wetlands. Trenches created by plow lines, regardless of depth, act as channels and can alter the hydrology of natural communities by pooling water or directing water along the furrowed path. They prevent the sheet and ground water flow that naturally occur in the low-relief wetland and upland communities of south Florida and that are particularly important in southern Florida where elevation changes of less than 3 feet result in different vegetation types and habitat. These alterations may also reduce hydroperiods and prolong dry season droughts (Taylor and Gibbons 1985).

Increases in water levels and raised soil levels along plow lines create habitat for invasive plants that can alter the structure and composition of natural communities, including pine flatwoods, dry prairies, wet prairies, and seasonal ponds. Southeast Florida is highly susceptible to invasive plants (Gordon 1998, Langeland and Craddock-Burks 1998). Old World climbing fern (*Lygodium microphyllum*), melaleuca (*Melaleuca quinquenervia*), Brazilian pepper (*Schinus terebinthifolius*), torpedograss (*Panicum repens*), and cogon grass (*Imperata cylindrica*) are often the first plants to invade recently disturbed areas, and they may eventually spread into nearby undisturbed habitat (Langeland and Craddock-Burks 1998). Some may be spread by the tractor and plow by its dragging rhizomes, seeds, spores and other fragments along the plow line. In south-central Florida, for example, invasive plants were documented along plow lines created during wildfire suppression in an area where none were previously known (Hutchinson and Menges 2006). Additionally, during wildfires, personnel and equipment staging areas typically occur in open, disturbed areas that contain a high percentage of invasive plants

(Ingalsbee 2004) that can easily be spread into the interior portion of natural areas on the clothing of firefighters or equipment.

In SPSP, numerous plow lines from past wildfire suppression were observed following prescribed burns conducted between 1999 and 2001 (J.T. Hutchinson, personal observation). At one site in SPSP, the number of plow lines and berms from past wildfire suppression efforts resembled bedding preparation for row crops. Wildfire suppression creates trenches that remain an unsightly scar for many years (FDEP 1999). The bulldozer lines and fire plow impacts from suppression of a 1971 wildfire at JDSP are still visible 36 years later, particularly in xeric communities (R.E. Roberts, personal observation). The Florida Department of Environmental Protection has guidelines in place for re-contouring plow lines that result from wildfire (FDEP 1999); however, it is unknown how strictly these guidelines are followed.

During the wildfire reported here in JDSP, we observed a plow line constructed along the ecotone of a flatwoods/cypress strand. The cypress strand was inundated with several inches of water, which would have acted as a natural fire break; however, the operator of the tractor and attached plow was unfamiliar with the habitat and trenched a plow line where none was necessary. A potential solution to excessive plow-line disturbance during wildfire suppression is for land managers and fire suppression officials to meet at least annually and discuss the logistics and operation procedures for wildfire suppression in each specific parcel of land. During a wildfire, a representative of the fire suppression agency and a representative of the natural area, such as the land manager or park biologist, should coordinate fire suppression activities. Environmental impacts can be minimized by utilizing natural barriers such as wetlands (Backer and others 2004), but this requires the guidance of someone familiar with the site.

It is important that fire management objectives based on protection of human life and property and those based on maintaining remnant natural communities and biodiversity both be obtained with minimal conflict (Caling and Adams 1999). However, the results of this study indicate that wildfire suppression activities cause disturbances to natural communities, especially in small remnant sites. The ecological considerations of small remnant natural areas in southeast Florida are often disregarded (Caling and Adams 1999), although continual plow-line disturbances during wildfire suppression over decades will eventually lead to major structural, compositional, and hydrological changes to remnant natural communities, in particular the pine flatwoods that are dependent on frequent fire.

Generally, the damage to natural resources caused by fire plows is greater and longer lasting than the effects of a wildfire. Because of the high maintenance costs and environmental damage, it is possible that the effects of wildfire suppression may be more costly over time than the actual fire (Taylor and Gibbons 1985). This is especially true when invasive plants invade the plow lines and spread out into undisturbed areas. From 1997 to 2005, the Florida Department of Environmental Protection (FDEP), Bureau of Invasive Plants, spent approximately $31 million to treat 277,998 acres (112,550 hectares) of public conservation lands infested with exotic plants (Drew Leslie, FDEP, personal communication). The combined deleterious effects of plow lines, invasive plants, reduction in prescribed fire, increases in wildfires, negative recreational activities, feral hogs, and residential development on remnant natural communities in south Florida result in greater increases in edge effects and an increase in fragmentation on sites that are already insular. Limited data exist on the effects of plow-line disturbance from wildfire suppression, and more detailed research is needed, not only in Florida, but throughout fire-dependent communities.

Acknowledgments

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Lessons From the Hayman Fire: Forest Understory Responses to the Scarify-and-Seed Postfire Rehabilitation Treatment

Paula J. Fornwalt

In unburned forests, organic plant litter and live vegetation help stabilize the soil and promote water infiltration. Much of this plant material is consumed during severe wildfires, leaving the bare ground susceptible to elevated postfire water runoff and soil erosion (Shakesby and Doerr 2006). Severe wildfires can also produce a water-repellant layer in the soil that further decreases water infiltration (DeBano 2000). Even after moderate rain events, runoff and erosion in severely burned areas can cause extensive and costly damage to roads, buildings, reservoirs, and ecosystems (Beyers and others 1998).

Land managers often prescribe seeding treatments immediately after wildfire in an attempt to minimize this potential damage. This relatively inexpensive rehabilitation treatment aims to stabilize the soil and decrease water runoff by rapidly increasing vegetative ground cover. Exotic grasses, including orchardgrass (*Dactylis glomerata*), timothy (*Phleum pratense*), and wheat (*Triticum aestivum*), are frequently used because seeds of these quick-growing species are readily available (Robichaud and others 2000). However, scientists and managers are beginning to realize that seeded species often do not establish densely enough to be effective at controlling runoff and erosion (Robichaud and others 2006, Wagenbrenner and others 2006).

Consequently, managers are increasingly using other treatments, either alone or in conjunction with seeding; for example, seeding was combined with soil scarification on several large burns in the Colorado Front Range. Scarification is a mechanical soil treatment that aims to increase water infiltration by roughening up the soil surface and disturbing the water-repellant soil layer (Robichaud and others 2003). When combined with seeding, scarification may also help keep seeds on site until germination occurs. Unfortunately, the effects of the scarify-and-seed treatment on postfire runoff and erosion and on regenerating understory plant communities have not been closely analyzed. I seized an opportunity created by the 2002 Hayman Fire to assess the ecological impacts of the scarify-and-seed treatment by comparing understory establishment at two neighboring sites, one which burned but had no postfire rehabilitation treatment and the other which burned and was subsequently scarified and seeded.

> Land managers often prescribe seeding treatments immediately after wildfire in an attempt to minimize potential damage. This rehabilitation treatment aims to stabilize the soil and decrease water runoff by rapidly increasing vegetative ground cover.

The 2002 Hayman Fire: A Research Opportunity

The Colorado Front Range has experienced several large and severe wildfires since the mid-1990s. These fires likely represent a shift in fire regimes—from one of mixed severity to one of high severity—that is partly a result of fire suppression and grazing activities since the late 19th century (Brown and others 1999, Kaufmann and others 2001). All these fires occurred partly in the wildland-urban interface, where human values were at risk from both fires and subsequent flooding and erosion. To date, the largest and most severe fire known to burn in the Front Range was the June

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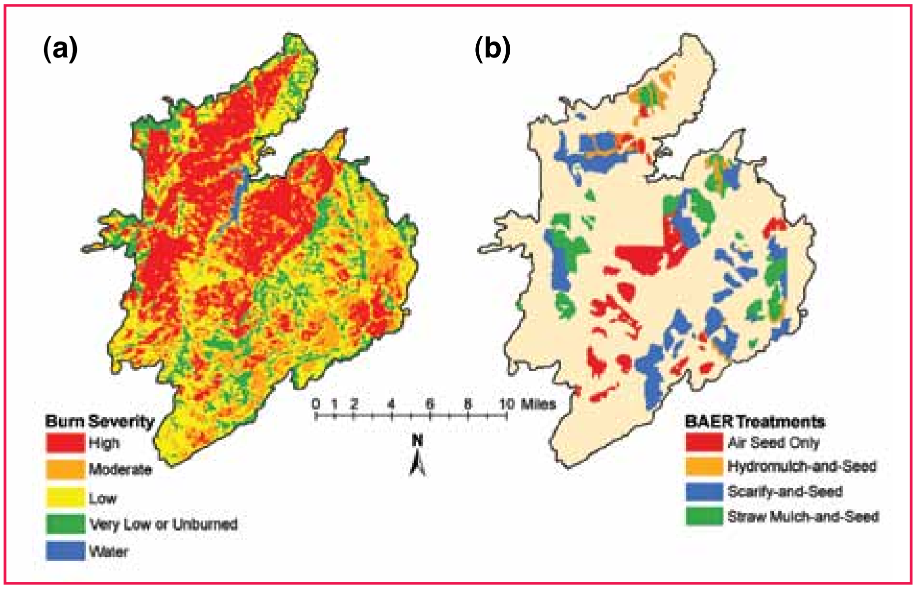

Figure 1—*Burn severity map of the Hayman Fire (a) and locations of Forest Service postfire rehabilitation treatments (b). The burn severity map was derived by the Forest Service from a SPOT4 satellite image and is largely based on overstory tree mortality (Robichaud and others 2003).*

2002 Hayman Fire, which burned 137,600 acres (55,800 hectares) of land dominated by ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*). Over 50 percent of the Hayman burned as a moderate-severity to high-severity fire (fig. 1a), with complete or nearly complete overstory mortality and extensive crown, litter, and duff consumption (Robichaud and others 2003). Most of the Hayman Fire occurred on National Forest System land.

The steep, dissected topography and the highly erodible granitic soils common throughout the Hayman Fire area made moderately and severely burned areas extremely susceptible to elevated postfire runoff and erosion. Therefore, the Forest Service rehabilitated approximately 32,000 acres (12,800 hectares) of moderately and severely burned forest in the months following the fire (fig. 1b), at a cost of more than $16.5 million (Robichaud and others 2003). The scarify-and-seed treatment was implemented on 13,200 acres (5,300 hectares) and cost over $1.5 million to apply. Soil scarification was done along terrain contours, either by all-terrain vehicles pulling harrows (fig. 2) or by hand with McLeods. After scarification, a certified weed-free mixture of 70 percent barley (*Hordeum vulgare*) and 30 percent triticale (×*Triticosecale rimpaui*, a wheat-rye hybrid) was applied to the scarified area at a target density of 26 seeds per square foot (280 seeds per square meter). Both species are exotic annual cereal grasses that typically germinate quickly but persist on the landscape for only a few years.

In 2004, understory plant data were collected in unrehabilitated and rehabilitated study sites within the Hayman Fire area (fig. 1b). The unrehabilitated site and the twenty 0.25-acre (0.1-hectare) upland plots within it were originally established in 1996 as part of other research activities (Fornwalt and others 2003, 2009; Kaufmann and others 2000). Three of these plots were moderately or severely burned and were incorporated into this study. I also established a rehabilitated study site 2 miles (1.2 kilometers) to the east of the unrehabilitated site. The rehabilitated site is in an area that was moderately to severely burned by the Hayman Fire and was subsequently scarified and seeded (fig. 3); the site contains 14

Figure 2—*The scarify-and-seed treatment was implemented on 13,200 acres (4,340 hectares) of moderately to severely burned Forest Service land in the months following the Hayman Fire. Scarification was done in rows either by all-terrain vehicles pulling harrows (as shown in the photo) or by hand with McLeods. Barley and triticale seeds were spread on the scarified areas. Photo: Pete Robichaud.*

upland plots. The two sites are similar in elevation, topography, and pre-fire overstory structure. In each plot, the presence of all vascular plant species was recorded, and percentage vegetative cover by species was estimated in ten 11-square-foot (1-square-meter) subplots located within the plot. Only live plants were included in the surveys, with the exception of the seeded grasses; dead seeded grasses were also measured because of their potential to affect understory establishment. We tested for differences in understory response variables between sites using multiresponse permutation procedures, a nonparametric alternative to analysis of variance.

Figure 3—*Seeded grass establishment was generally imperceptible in scarified and seeded areas of the Hayman Fire, although in this area, establishment was uncharacteristically successful. The photo was taken in the summer of 2004, a year and a half after the treatment was applied. Photo: Paula Fornwalt.*

Impacts of the Scarify-and-Seed Rehabilitation Treatment on the Forest Understory

The Rehabilitation Treatment

Of the two grasses seeded, only triticale was found growing in the plots; barley was never encountered. Triticale was present at both sites. At the unrehabilitated site, live and dead triticale were found in 33 percent of the plots, while at the rehabilitated site, live triticale was found in 64 percent of the plots and dead triticale was found in 71 percent. It is unknown how triticale arrived at the unrehabilitated site; seeds may have been inadvertently dropped from aircraft while seeding other portions of the burn, or they may have dispersed in from upslope rehabilitated areas. The cover of both live and dead triticale was similar between the two sites ($p = 0.599$ and 0.484, respectively). Live and dead triticale, combined, averaged less than 0.5 percent and never exceeded 3.0 percent in any single plot. No visible evidence of the postfire scarification treatment (for example, recently disturbed mineral soil) was visible at survey time.

Scarification is a mechanical soil treatment that aims to increase water infiltration by roughening up the soil surface and disturbing the water-repellant soil layer. When combined with seeding, scarification may also help keep seeds on site until germination occurs.

I suspect that unfavorable weather conditions during 2002 and 2003 were at least partially responsible for the poor establishment of seeded grasses on upland slopes. These summers were among the warmest and driest on record in the Colorado Front Range; high temperatures and lack of moisture may have killed many seeds and germinated seedlings. The summer of 2004 then brought several high-intensity rainfall events that likely washed away much of the remaining viable seed.

Other researchers monitoring the effectiveness of the scarify-and-seed treatment in the Hayman Fire area also found that seeding did not increase vegetative cover (Rough 2007). In addition, they found that the average depth of scarification after the Hayman Fire was less than 1 inch (2.5 centimeters), and, therefore, scarification alone was not sufficient to break through the hydrophobic layer that extended nearly 4 inches (10 centimeters) into the soil profile. As a result, the treatment was not effective in reducing sediment yields immediately after the fire; indeed, the mechanical disturbance caused by scarification may have even increased sediment movement immediately after the treatment was implemented.

Impacts on Native Species

A total of 128 native plant species were found within the two sites. Native plant richness and cover were similar at the rehabilitated and unrehabilitated sites ($p = 0.256$ and 0.381, respectively), with native richness averaging 42 species per plot and native cover averaging 19 percent.

Many of the native species found in the rehabilitated and unrehabilitated sites are perennial species that are abundant throughout unburned Front Range forests, including the graminoids Ross' sedge (*Carex rossii*), prairie Junegrass (*Koeleria macrantha*), and mountain muhly (*Muhlenbergia montana*); and the shrub kinnikinnick (*Arctostaphylos uva-ursi*). The perennial forbs hairy false goldenaster (*Heterotheca villosa*), prairie bluebells (*Mertensia lanceolata*), and eastern pasqueflower (*Pulsatilla patens*) are also abundant in the Front Range (fig. 4). Each of these species occurred in more than 75 percent of plots studied here, and together, they constituted nearly 30 percent of the native plant cover. The cover of each species appears to have been unaffected by the scarify-and-seed treatment ($p > 0.250$ in all cases).

These findings suggest that the scarify-and-seed treatment had little to no impact on native plant establishment after the Hayman Fire. This is not surprising, given that there was likely little competition from the seeded grasses. Furthermore, many of the native understory species are adapted to regenerate quickly after disturbance, either by sprouting from surviving underground parts or by geminating from seeds in the soil seedbank (USDA Forest Service 2009). Indeed, native plant richness and cover at both sites were similar to that observed in the unrehabilitated site before the fire, suggesting that understory recovery in this system can naturally occur in as little as 2 years (Fornwalt and others 2003, 2009). Others also have found that low levels of seeded grass cover did not affect native species in fire-adapted ecosystems (Keeley and others 1981), but high levels of seeded grass cover decreased native plant establishment and growth in many cases (Keeley and others 1981, Keeley 2004, Schoennagel and Waller 1999).

Impacts on Exotic Invaders

Fourteen exotic species were found in the plots (excluding triticale). In general, the number and cover of exotic species per plot were low, with an average exotic richness of four species per plot and an average exotic cover of only 0.6 percent. Neither exotic plant richness nor cover differed significantly between sites ($p = 0.835$ and 1.000, respectively).

Six of the exotic species, cheatgrass (*Bromus tectorum*), musk thistle

Figure 4—*The native species prairie bluebells (top left), kinnikinnick (top center), and eastern pasqueflower (top right) are abundant throughout the Colorado Front Range and appear to have been unimpacted by the scarify-and-seed rehabilitation treatment. Canadian thistle (bottom left), mullein (bottom center), and musk thistle (bottom right) were three of the six noxious weed species found in the unrehabilitated and rehabilitated sites, though they were uncommon and do not appear to have been stimulated by the postfire rehabilitation activities. Kinnikinnick photo by Laurie Huckaby; all other photos by Paula Fornwalt.*

(*Carduus nutans*), Canadian thistle (*Cirsium arvense*), Saint Johnswort (*Hypericum perforatum*), butter-and-eggs (*Linaria vulgaris*), and mullein (*Verbascum thapsus*), are noxious weeds in Colorado (see fig. 4). All these species had negligible cover: butter-and-eggs cover was less than 0.5 percent, while all other species had less than 0.1 percent cover each. None of the species appear to have been affected by the scarify-and-seed treatment ($p > 0.500$ in all cases).

Exotic species often increase following disturbances by taking advantage of reduced competition for resources, and management activities such as firefighting and rehabilitation may also introduce exotic species to locations where they did not previously occur (Keeley and others 2006). Although these results suggest that the scarify-and-seed treatment per se had little or no effect on exotics, the fire as a whole did increase exotic richness and cover relative to prefire levels, especially in the most severely burned areas (Fornwalt and others, in review). While exotic richness and cover in the Hayman Fire area remain low at this point in time and exotic species do not yet appear to be affecting native plant recovery, they should nonetheless continue to be monitored in both rehabilitated and unrehabilitated areas.

Management Implications

Managers have implemented the scarify-and-seed treatment after several recent Colorado Front Range fires, but the effects of the treatment on the forest understory had never before been documented. While the interpretation of these findings is somewhat constrained by the small number of plots and lack of study site replication, they nonetheless suggest that the scarify-and-seed treatment had little to no effect on understory recovery after the Hayman Fire. This is likely because the scarify-and-seed treatment effects were nearly imperceptible: seeded grass establishment was negligible, and signs of soil scarification were not visible a year and a half after treatment was applied. Furthermore, other researchers working in the Hayman Fire found that the scarify-and-seed treatment had no impact on postfire erosion. In light of the considerable cost and increasingly widespread use of this rehabilitation treatment, it is imperative that researchers and managers continue to learn more about both the effectiveness and the ecological impacts of scarification and seeding after fire.

For more information about this study or for copies of related publications, contact Paula Fornwalt, Forest Service, Rocky Mountain Research Station, 240 West Prospect Road, Fort Collins, CO 80526, email pfornwalt@fs.fed.us, phone 970-498-2581.

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Wildland Fire Behavior and "The Course of Science" Flowchart: Is There a Connection?

Martin E. Alexander

I've been involved in wildland fire since 1972. Except for a couple of seasons as a hotshot crew member followed by another season with the Forest Service in wilderness fuel inventory capped off by some slash burning, all that time has been spent in fire research. Even as a wildland fire researcher, I've kept actively involved in observing and analyzing free-burning wildfires over the years, and I've occasionally served as an operational fire behavior specialist on major fires and multifire incidents in northern Alberta and the Northwest Territories. This focused fire background has helped me understand that wildland fires are not always easily observed, monitored, explained, or documented.

I came across "The Course of Science" flowchart on a coffee room bulletin board in 1990 during a 3-year (1989–92) sojourn in Australia. Over the years, I've come to appreciate the humor and cynical nature embedded in the "Course of Science" flowchart more and more. But perhaps of greater value is this flowchart's ability to remind us of the traps to which we, in the research and development community, and in turn the users of the

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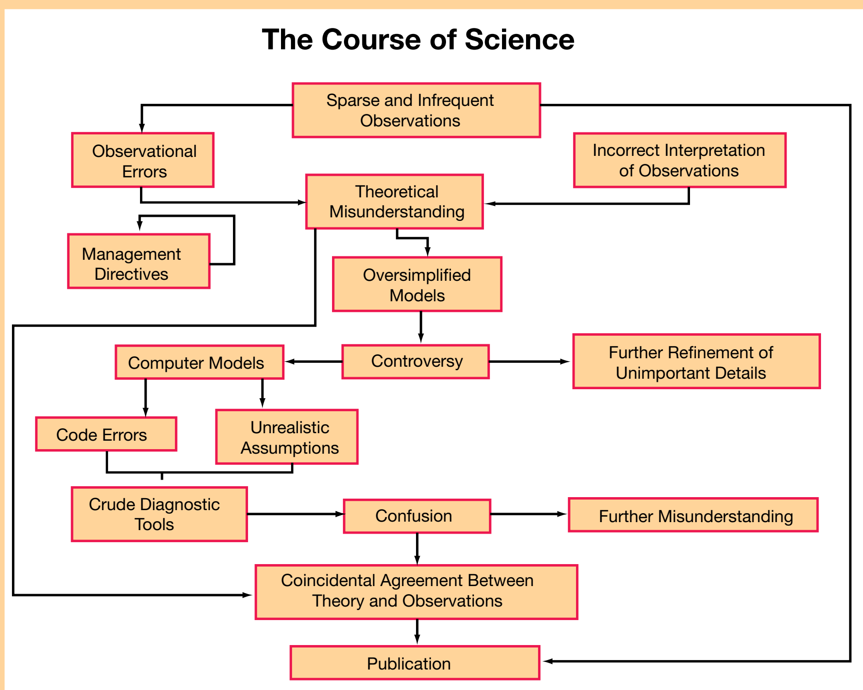
Wildland fires are highly volatile, multidimensional phenomena, not always easily observed, monitored, explained, and documented. Photo: Martin E. Alexander, Canadian Forest Service, Northern Forestry Centre, Edmonton, AB, 1981.



In this author's opinion, the relevancy of the "Course of Science" flowchart to wildland fire science, and more specifically to fire behavior, is probably a far better fit to the general course of research, development, and application in this field than most of us would care to admit.

knowledge and products generated by fire researchers, can so easily fall victim. As Dr. Mary Omodei (2009), a wildland fire psychologist, has pointed out, this flowchart "characterizes not only everyday intuitive thinking but also science as well in our zeal to understand and our zeal to publish interesting findings."

Usage

I've frequently presented the "Course of Science" flowchart in regional, national, and international fire behavior training courses and in other invited presentations (e.g., Alexander 2000, 2006). My most recent use was in a keynote address that I presented as a member of the international advisory committee member of the Fire Paradox project (<http://www.fireparadox.org/>) on the island of Crete, Greece, in June 2008 (Alexander 2008).

The chart always draws a good laugh and it has been my experience that folks can relate to some of the common flaws to which we, as humans, are prone when it comes to our attempts at trying to understand the complexities associated with wildland fire behavior. This certainly appears to be the case, not surprisingly, when it comes to situations involving extreme fire behavior.

But Where Did It Come From?

Despite its growing world-wide popularity, the origin of the "Course of Science" flowchart remains a mystery. My own search for the original led me to Wergen (2000). When contacted about the "Course of Science" flowchart, Dr. Wergen (2009) stated, "I first spotted the diagram on a notice board at ECMWF [European Centre for Medium-Range Weather Forecasts]. The people there referred me to Science as the source. However, a search in Science was not successful. I have had it translated into German."
Another published user, Bormel (2008), states that he originally found this flowchart "taped to the door of the biostats/computer lab at Harvard's School of Public Health, many years back."

These authors, others from various fields (including meteorology, health care, astronomy, and wildland fire behavior), and I have all found it useful to identify our own linkages and flaws that come up during the course of science.

Developing the Science of Wildland Fire Behavior

Perhaps the mystery of the origin of the "Course of Science" flowchart will be solved one day. In the meantime, I keep a copy of this flowchart prominently displayed in my office as a constant reminder to myself of the pitfalls or general tendency within the wildland fire behavior science community to follow these various paths. I had a copy of the "Course of Science" flowchart handy, for example, as I endeavored to put forth the case that the blowup associated with the 1988 Brewer Fire in Montana was likely caused by a "heat burst," a seemingly rare meteorological phenomenon (Alexander 2002, 2004). Use of the "Course of Science" flowchart is not restricted to members of the wildland fire behavior science community. Operational fire management personnel may find it equally as valuable. I think it provides a useful aid to critical thinking—whether for the fire researcher, the firefighter, or the fire manager—when it comes to reaching conclusions perhaps too

An Example Related to Extreme Wildland Fire Behavior

Williams (2007) reported on an interesting hypothesis regarding extreme fire behavior associated with the wildland conflagrations that descended on Canberra, Australia, on 18 January 2003 (<http://en.wikipedia.org/wiki/2003_Canberra_bushfires>). She suggested that the accumulation of flammable gases ahead of a high-intensity fire might explain why such fires unexpectedly and very rapidly increase their forward movement with explosive speed.

Sullivan and others (2007), however, point out that this "conflicts with the fact that because of the buoyancy of heated gas, the one place that these flammable pyrolysis products cannot be found is downwind of the fire front." They also note that the turbulent flows associated with wildland fires "quickly disperse these gases," so there is no opportunity for them to accumulate.

Arnold and Buck (1954), however, pointed out that "Most fires burn so inefficiently that large quantities of volatile flammable gasses are driven off without being burned. Under certain air conditions these gasses may be trapped near the ground in low inversions or in poorly ventilated basis or canyons."

Additions to the "Course of Science" Flowchart Over Time

In the version of the "Course of Science" flowchart that I came across 29 years ago as presented here, someone had obviously added in by hand to the otherwise unaltered graphic a flowline from the "Theoretical Understanding" box to the "Coincidental Agreement between Theory and Observations" box. I myself have since added a flowline from the "Sparse and Infrequent Observations" box to the "Publication" box. In the version presented by Wergen (2000), Bormel (2008), and Williams (2008), I note that they have included an additional box titled "Cover-up Subsequent Results" flowing out of the "Publication" box. I have elected not to include that addition in the version presented here. Other variants of the "Course of Science" flowchart are now beginning to appear (e.g., Sage 2008).

quickly with regard to wildland fire behavior.

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Fuels Treatments and Fire Models: Errors and Corrections

J. Morgan Varner and Christopher R. Keyes

Fire behavior and fire effects models are arguably among the most important tools in fire and fuels management. Given the power, accessibility, and utility of these models, fuels planners and scientists commonly use them to compare potential fire intensity and severity on planned and unplanned wildland fires.

How well the models are run is another matter. Modeling errors in fuels treatment proposals and scientific papers can exaggerate or mischaracterize the effectiveness of potential fuels treatments designed to abate hazardous fire behavior. Unrealistic outputs can typically be traced to unrealistic inputs, so close analysis of common input errors can suggest best practices to minimize modeling problems and maximize treatment effectiveness. Beyond this, the revision of old models and the design of new models can promote ease of use and more realistic outputs in complex and extreme input conditions.

Modeling Fuels Treatments

Fire and fuels managers and planners use modeling software to predict changes in fire behavior resulting from surface and canopy fuels treatments according to the "activity fuels" that these treatments leave behind. In the Western United States, fuels treatments are typically designed to reduce surface fireline intensity, prevent crown ignition, and interrupt canopy fire spread; several models have the ability to predict changes in these behaviors, many based on equations developed by Rothermel (1972) and Van Wagner (1977) for surface and crown initiation and spread. Fire effects models, on the other hand, predict the consequences of fires, generating estimates of tree mortality, soil heating, erosion, fuels consumption, and emissions.

> Errors in modeling fuels treatment, fire behavior, and fire effects can often be tied to unsupported assumptions about actual conditions and over-reliance on default values.

In a recent survey of fire and fuels managers by Miller and Landres (2004), among the most used fire behavior models were BehavePlus, FARSITE, and NEXUS. Among fire effects models, several of the most used were First Order Fire Effects Model (FOFEM), Consume, the Fire Emission Production Simulator (FEPS), Fuels Management Analyst Plus, and the Forest Vegetation Simulator (FVS)-Fire and Fuels Extension (FFE) (Reinhardt and Crookston 2003). Development of both fire behavior and effects models (e.g., Crown Fire Initiation and Spread [CFIS]; Alexander 2007) continues.

McHugh (2006) reviewed the use of fire behavior and effects models by resource managers and fire scientists. Fuels managers use these behavior and effects models in fuels treatment planning to compare the results of proposed treatments. Fire and fuels scientists also use these models to compare outcomes on modeled fire behavior and to understand long-term changes in living and dead fuels. Between 1996 and 2009 alone, at least 19 papers were published in fire science and forestry journals and conference proceedings that used these models to predict fire behavior and/or effects following fuels treatment.

Many proposed fuels treatments and some of the recent scientific literature contain examples of the inexact application of these decision support tools—or more simply stated: "user errors." For example, a recent study by Jolly (2007) analyzed the sensitivity of BehavePlus to changes in live fuel moisture content, finding that users may commit errors if faulty assumptions are made. Other errors that may occur can be attributed to faulty assumptions regarding fuel moisture, wind adjustment, fuel model selection, fuel decomposition rates, fuel load estimates, foliar moisture content, and the patchiness of fuels. By examining these factors, future errors by fire and fuels managers and scientists may be avoided.

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Best Practices for Modeling Fuels Treatment Effects

1. **Fully disclose all inputs and assumptions.** Users should list all value assignments that were used in modeling (fuel moisture, loading, depths, and data sources). The greater the disclosure, the greater the result's repeatability and level of trust.
2. **Use field data as much as possible; use published estimates when necessary.** Field-derived values for fuel loading, depth, and moisture are always preferred. When these are not available and data collection is not possible, published values can be used but must be identified.
3. **Project results over time.** Treatment comparisons made immediately following fuels treatments may poorly characterize mid- or long-term fire behaviors. Comparing fire responses over longer timespans will help characterize treatment effects and guide the timing of retreatment or maintenance return intervals.
4. **Press the science community for decision support.** Activity fuels dynamics, for instance, are poorly understood; model users should support research that helps guide the management of these increasingly common fuels. Development of decision support tools that incorporate the dynamics of activity fuels and the effects of canopy and surface fuel patchiness should be encouraged.

Common Errors in Modeling

By being conscious of input factor complexity, managers may recognize and avoid modeling errors and increase the credibility of fuels treatment model output, while model developers can improve decision support tools to assist fuels planners and scientists. The following are common errors in assigning parameter values, their consequences in modeled outcomes, and best practices to avoid such errors in developing realistic and effective fuels treatments.

Fuel Moisture Estimation

Fuel moisture is a fundamental factor in the ignition and spread of wildland fires, and errors in moisture estimation are common in fire behavior modeling. These errors occur when investigators assign identical fuel moistures to different fuels treatment scenarios despite the differences in live and dead fuel moistures among stands with differing amounts of canopy closure.

Treatments designed to reduce stand density, canopy bulk density, or crown base height result in decreased woody fuel moisture content due to greater incoming solar radiation, greater wind penetration, and reduced relative humidity—factors requiring adjustment of input moisture levels. Assigned fuel moisture values should be derived from on-site measurements, and future research should examine fuel moisture variation in beneath-canopy fuels.

> Many proposed fuels treatments and recent scientific literature contain examples of the inexact application of these decision support tools—or more simply stated: "user errors."

Wind Adjustment Factor

Windspeed is another fundamental factor in fire spread and intensity, and the effects of fuels treatment on those winds is not generally appreciated: as stand density and vertical structure are reduced, so is the impediment to wind (Albini and Baughman 1979). A common goal of silvicultural fuels treatments is to increase the spacing between crowns and increase canopy base height (Agee and Skinner 2005), both of which increase in-stand windspeeds, a factor not always taken into account in fuels treatment comparisons.

Future research efforts should clarify the effects of different fuels treatments on the wind adjustment factor. In the meantime, most modeling software allows users to project wind speeds with the aid of look-up tables based on published approximations (e.g., Albini and Baughman 1979) or personal experience.

Fuelbed Characterization

Fuel Loading Estimates

Fuel mass is a major driver of fire behavior and severity, and errors in estimating fuel loading are common in published fuels treatment studies. Specific errors include use of unexamined default values and crude estimates of activity fuels.

Both underestimating and overestimating fuel loads result in poor prediction of fire intensity and severity, particularly where large amounts of woody activity fuels remain following a treatment. Rather than basing their estimates of loading on small sample sizes or on unsupported default values, researchers and managers should refer to photo series data (e.g., Ottmar and Vihnanek 2000), conduct on-site sampling using line intersect sampling (e.g., Brown 1974) or biomass equations (Means et al. 1996), or estimate fuel loading values with much deliberation.

Fuel Model Assignment

Fuel models are based on values of fuelbed loading, bulk density, surface area-to-volume ratio, moisture of extinction, depth, and heat content (Anderson 1982). Every fuel model carries its own assumptions about the interactions of these parameters, making fuel model selection (or "assignment") an integral part of meaningful analysis. Managers and scientists make fuel model assignment errors when they violate model assumptions. These fuel model assignment errors are most apparent when modeled fuelbeds contain activity fuel loadings that exceed the loads used to build the models; a recent example of this is the difficulty many managers and scientists have faced in modeling masticated fuelbeds. Users also commit assignment errors in applying the same models to both untreated and treated stands.

Fuel model selection is an important disclosure in any fuels analysis report. The Scott and Burgan (2005) models and models created in Fuels Management Analysts Plus (Carlton 2006) offer more input options for fuelbeds with substantial activity fuels. Users should also examine the methods of investigators that base their fuel modeling on collected field values.

Foliar Moisture Content

Many investigators fail to disclose modeled values of foliar moisture or use default values that may be poor estimates of actual field conditions. Some reports include assigned foliar moisture content values without justification or use values that lie on the extremes of published data.

In addition to surface fireline intensity and canopy base height, foliar moisture content is a determinant of torching and crown fire initiation. Its importance is minor at lower surface fire intensities, but its proportional importance increases and becomes operationally significant as predicted surface fire intensities increase (Keyes 2006) or when dead, dry foliage is attached to standing trees. In a review of published foliar moisture content values of western conifers, Keyes (2006) found that foliar moisture content in conifers of North America varied between 73 and 480 percent, depending upon species, foliage age, and season. The range and importance of such values require careful consideration when modeling fire behavior after fuels treatment.

Time Since Treatment

Model users often maintain constant fuel values when projecting fuel conditions into the future. Yet fuel load and the availability of activity fuels changes tremendously following treatment: both values are affected by the amount and arrangement of residual overstory (Carlton and Pickford 1982). In addition, the time elapsed since treatment is critical to fuelbed decay, recruitment, and recovery. This error is most obvious when a treated area is subjected to modeled wildfire soon after treatment and before fuelbed recovery.

As time elapses, downed fuels cure, decompose, and flatten. Particularly after fire and herbicide use—but also with mechanical treatments—tree and shrub mortality leads to substantial increases in post-treatment surface fuels. Depending on the time elapsed, fuel levels may be higher, lower, or the same as pretreatment fuels. Brose and Wade (2002) examined contrasting treatments across time, illustrating how treatment effects may be short-lived and long-term effects may be unexpected. Furthermore, post-treatment changes in vertical and horizontal canopy closure may change future windspeeds, affecting surface woody fuel moisture.

With time, fuels generated by treatment begin to decay, affecting subsequent potential fire behavior. Comparison of fuels treatment effects should thus address an extended period of time following the initial treatment—a factor typically modeled within the FVS-FFE.

Fuelbed Patchiness

Fire behavior and effects models suffer from a fundamental weakness that hinders their ability to match field observations: models assume fuelbed uniformity, while canopy and surface fuels are typically distributed in patches. While model developers are the first to point out this limitation, users may fail to recognize it.

Canopy fuel is a collection of individual crowns that may be patchy, regularly spaced, or distributed at random, and this distribution influences the spread of canopy fire whether or not the canopy bulk density among patches or stands are equal. Surface and ground fuels, too, are rarely arranged uniformly, even in fuelbeds without activity fuels. In stands with recent fuels treatments, activity fuels are typically patchy, whether aggregated in piles, on skid trails, or on bare soil generated by mechanical equipment.

In activity fuelbeds, available fuel loading and packing may be poor predictors of surface fire spread and intensity across these patchy fuels. In lieu of models that incorporate patchiness typical of managed fuelbeds, managers and scientists should acknowledge the irregularity inherent in activity fuelbeds and the resulting unpredictability in fire spread and intensity.

Conclusions

Errors in modeling fuels treatment, fire behavior, and fire effects can often be tied to unsupported assumptions about actual conditions and over-reliance on default values. In some cases, the basis for assigning fire modeling values are available but have not been adequately implemented. In other cases, model limitations are known but no compensation is made in assigning values or interpreting results.

Ultimately, the complex relationships between wildland fire and stand structure must be captured in useful rules and readily accessible forms so that the individuals responsible for prescribing fuels management operations can base their plans on a foundation of best available scientific knowledge. In general, guidance to assist fuels managers in model assumptions and parameter assignments needs revision to better support fuels treatment decisionmaking.

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