Exploring Use of Climate Information in Wildland Fire Management: A Decision Calendar Study

Thomas W. Corringham, Department of Economics, UCSD, La Jolla, CA
Anthony L. Westerling, Scripps Institution of Oceanography, Climate Research Division, La Jolla, CA
Barbara J. Morehouse, Institute for the Study of Planet Earth, University of Arizona, Tucson, AZ

Abstract—*Wildfire management is an institutionally complex process involving a complex budget and appropriations cycle, a variety of objectives, and a set of internal and external political constraints. Significant potential exists for enhancing the use of climate information and long-range climate forecasts in wildland fire management in the Western U.S. Written surveys and interviews of fire and fuels managers at local, regional, and national levels, provide information and insights into the decision processes, information flows, and decision nodes used in wildfire planning and management, and allow the construction of decision calendars showing how climate information needs vary seasonally, over space, and through the organizational network.*

Potential exists for fostering use of climate information, including seasonal to inter-annual climate forecasts at all organizational levels, ultimately opening possibilities for improved targeting of fuels treatments and prescribed burns, more effective positioning and movement of initial attack resources, and improved staffing and budgeting decisions. Longer-term (decadal) forecasts could be useful at the national level in setting budget and research priorities. We examine the kinds of organizational changes that could facilitate effective use of existing climate information and climate forecast capabilities.

Introduction

Devastating wildfires flaming across large expanses of the United States in recent years have galvanized politicians, fire managers, and ordinary citizens alike in an effort to understand the processes driving catastrophic fire and to develop ways to anticipate when and where severe fire is likely to occur over time and space. Scientific knowledge and information contributes to better fire prediction and management, but requires successful dissemination to and use by decision makers. An essential first step in this process involves identifying optimal points in the decision networks of agencies charged with wildland fire management where such information may be inserted into decision processes. This, in turn, requires understanding the annual cycle of decision making throughout the wildland fire management organizations. The study reported here identifies points in decision calendars where climate-fire knowledge may be productively introduced and examines the potential value of such information in strategic fire planning processes.

Background

Since the 1970s, a dramatic trend has emerged in the size of the annual area burned by wildfires in the western United States with the average annual reported area burned increasing by approximately 85 percent per decade in the eleven contiguous western states. Concomitant increases in variability in annual area burned and in fire suppression costs pose a serious challenge for Federal and State land and resource managers.

The variance in annual area burned in the last decade is nearly 22 times higher than in the 1970s. Since managers must be prepared for the worst possible scenarios in every fire season, increased uncertainty about the scale of the western fire season each year imposes high costs on public agencies to sustain appropriate levels of preparedness. Recent progress in our understanding of the links between climate and wildfire, and in our ability to forecast some aspects of both climate and wildfire season severity a season or more in advance, offers some hope that these costs might be reduced through the increased integration of climate information into strategic planning for fire and fuels management.

Western wildfires have imposed steep costs in recent years. Real average annual suppression costs for the U.S. Department of Agriculture's Forest Service alone have increased by a factor of 2.6 over the last two decades, and have exceeded $1 billion in three of the last five years. Costs for Department of Interior agencies have also increased, exceeding $300 million per year in the last four years, more than double the average of the preceding six years. While federal agencies' fire suppression budgets have increased recently, funding still reflects what would likely be spent in an "average" year. Given that average years seldom occur, actual costs tend to fluctuate between low and high extremes. Modeling area burned and suppression costs as a function of climate variability alone, Westerling and others (2004) found that the probability of the Forest Service's suppression expenses exceeding the current annual suppression budget has been over 50 percent since 1987; this is a substantial increase over the preceding 40 years, when the probability was closer to one in three.

In addition to the effects of climate variability on wildfire, long-term biomass accumulations in many western ecosystems have fueled an increased incidence of large, stand-replacing wildfires in areas where such fires were previously rare (Allen and others 2002). These severe large fires can result in erosion and changes in vegetation type, with consequences for water quality, stream flow, future biological productivity of the affected areas, and habitat loss for endangered species. Apart from deleterious ecological consequences, severe fires can also dramatically affect amenity values of public land for recreation and for homeowners living in the wildland-urban interface.

In response to the buildup of fuels following a century of active suppression, the National Fire Plan (USDA/USDOI 1995, 2001, 2002) has charged land management agencies with reducing fuels on millions of hectares of public lands through mechanical removal, prescribed fire and wildland fire use. The project is vast in scope, and will take many years to implement. The effective application of climate information and climate forecasts to fuels management could significantly reduce the costs of both fire and fuels management, by allowing managers to strategically target areas with the highest risks on a seasonal to inter-annual basis. This is one of several uses of climate information in wildland fire management. In this paper, we identify several more, as the results of a decision calendar survey of fire and fuels managers in the Western United States.

Organization of Fire Management

Wildland fire management in the US is integrated across agencies by the National Interagency Coordinating Center (NICC) located in Boise, Idaho, and by 10 Geographic Area Coordination Centers (GACCs) (fig. 2). At the same time, wildland fire suppression and preparedness activities continue to be managed by a variety of national, state, and local agencies. Over half of the land in the Western United States is managed by federal agencies, encompassing most of the West's wildlands (fig. 3). Each agency works at different organizational levels, ranging from federal agency offices in Washington D.C. and the National Interagency Fire Center in Boise, ID, to regional agency offices, GACCs, and local administrative units managing the crews and equipment needed to actually carry out fire suppression and fuels management.

Figure 2. Geographic Areas for wildland fire management.

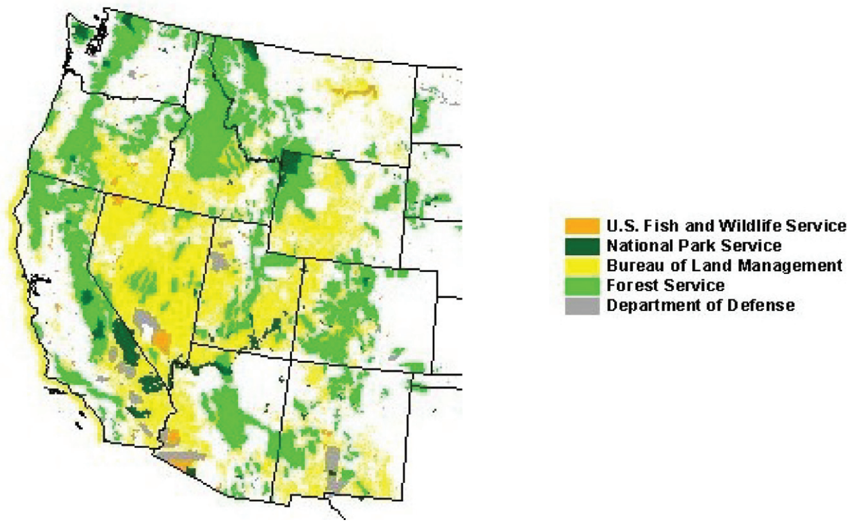

Figure 3. Federally managed land in the Western United States.

To keep the survey process manageable, we focused on two agencies, the Forest Service (USFS) and the National Park Service (NPS) and on three organizational levels of management: the local level, the regional level, and the national level. Locally, fire managers, fuels managers, and fire chiefs work within National Parks and Forests, which are overseen by regional offices of the NPS and the USFS. These positions report to national offices of the NPS and the USFS, which are located, respectively, within the Departments of the Interior and Agriculture.

National Parks and Forests also coordinate their fire suppression and fuels management activities under the auspices of regional interagency fire management organizations and administrative bodies: GACCs mentioned above and MAC groups (Multi Agency Coordination Groups), which operate during the peak fire season to coordinate all the resources available in the different agencies so as to maximize efficiency in fighting wildland fires. Outside of the fire season, most interaction between the National Parks and Forests and their regional and national offices involves budgeting and planning activities. Some planning and fuels treatment work is coordinated with the GACCs and NIFC also. A simplified flow chart shows the organizational levels and links of interest in this study (fig. 4).

Fire weather and climate information and forecasts feed into the decision processes at different levels from several sources. At the national level the Fire Weather Service, a division of NOAA's National Weather Service (NWS), provides a variety of weather and climate products for use by fire managers. At the regional level, the GACCs have Intel and Predictive Services divisions that gather and disseminate weather and climate information from the NWS, from Regional Integrated Science and Assessment programs (RISAs), and from their own fire meteorologists. The use of climate products varies from region to region, partly due to the different climatic conditions in the different regions, partly due to different levels of interest and experience among regional personnel. At the local level, climate and weather information is obtained from the GACCs and the NWS, and, at some parks and forests, from staff fire meteorologists. Local fire managers are generally highly sophisticated users of short-term weather information as it relates to suppression activities; however, the use and comprehension of longer-term climate products is highly variable.

Traditionally short-term weather information has been used to great effect operationally in wildland fire suppression during the fire season. With increasingly long and severe fire seasons, and with an increased emphasis among federal agencies to restore natural fire regimes to ecosystems through use of fuels treatments such as mechanical thinning, prescribed fires and wildland fire use, longer-term climate information products are finding use to support longer term planning decisions.

Climate Science and Climate Forecasts

Over the past several decades, there has been increasing interest in developing a better understanding of the use of scientific and forecasting information by decision makers (Sarewitz and others 2000, Stern and Easterling 1999). The Regional Integrated Science and Assessment Program funded by the US National Oceanic and Atmospheric Administration's Office of Global Programs (NOAA-OGP) funds research specifically designed to identify climate information and forecast needs and foster utilization of climate information in the regional scale in the United States. The Climate Impacts Group (CIG) in the US Pacific Northwest, for example has been working with water managers to integrate long-term climate change information into their decision processes (Miles and others 2000). Likewise the California Applications Project (CAP) works closely with water managers and administrators to incorporate climate change information into planning at state and sub-state scales. In the US Southwest, water and rural livelihoods are among the research foci of the Climate Assessment for the Southwest (CLIMAS) project (Morehouse and others 2000).

Scientific information and forecasts can provide important guidance to decision makers who are concerned about reducing risks to vulnerable populations, ecosystems, and the built environment, reducing their

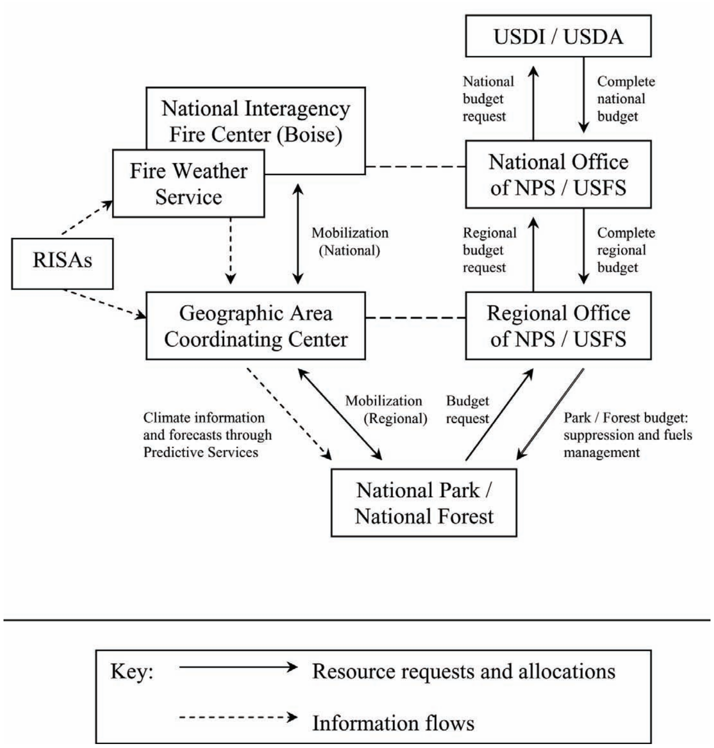

Figure 4. Wildland Fire Management Organizational Flowchart.

operational costs, diminishing the potential for lawsuits or other challenges to their decisions and activities, and managing in a more rational manner the resources for which they are responsible. For example, information about past climatic conditions can prompt decision makers to change their assumptions about what constitutes "normal" climatic conditions; this in turn can influence the degree and nature of extreme conditions they include in their infrastructure planning and construction activities. Historical climate information is also useful for anticipating the potential intensity of threats to life and property in planning for emergency preparedness. The recent drought conditions in Arizona and New Mexico, for example, have been outside the norms assumed by water managers, fire managers, and forest managers. In providing information about the swings in climatic conditions over time scales of more than 100 years (the length of the historical record in this region), scientists provide information that is useful for developing new and better plans for responding to severe drought stress, and for refining models used to anticipate biophysical drought responses such as likely streamflow and reservoir levels, and fuel moisture conditions.

With the phenomenal growth in the provision of information via the internet over the past decade, access to all sorts of scientific information has become virtually ubiquitous. Indeed, complaints are frequently heard that there is so much information that people have difficulty not only knowing what information to use, but also in assimilating the vast amount of information available into useful syntheses. Climate forecasts, for example, are readily accessible via the NOAA web site and from other entities such as the International Research Institute (IRI). Knowing which forecasts are useful for what purposes, as well as the temporal and spatial distribution of forecast accuracy and skill is daunting. Workshops such as those conducted by CLIMAS for fire and fuel managers and decision makers (Morehouse 2000, Garfin and Morehouse 2001, Garfin and others 2003), provide opportunities to learn about the information that is available, how forecasts are made, and how much confidence forecasters place in their products over time and geographical space. Through interactions with climatologists, participants are also able to determine which types of information are most useful for what purposes, over what time periods, and in what areas.

Similarly, recent advances in assessing the skill and accuracy of climate forecasts promises to reduce some of the perplexity in using forecasts (Hartmann et al 2002). Such information provides decision makers with insight into how much weight they should place on certain forecasts, given the set of variables they must evaluate. Because climate forecasts are probabilistic in nature, it is never possible to have a 100-percent dependable prediction. However, scientific information about forecast skill and accuracy provides a means to understand how much reliance to place on any given forecast. This type of information has been identified repeatedly as among the most-needed types of knowledge, for scientific information to be integrated into decision processes.

Examples of Climate Information Uses in Wildland Fire Management: Budgeting, Staffing, Suppression, and Fuels Treatment

Several examples may be identified where scientific information and forecasts can play an important role in fire management. First, the National Fire Plan requires planning out 10 years (Departments of Agriculture and Interior 2001). In contrast, forecasts of wildfire season area burned can be made with reliable confidence for up to two years in advance in the Southwest, up to a year in advance in some interior basins, and up to a season in advance in many other parts of the western United States. For longer time horizons, instrumental and paleo records can provide analogous scenarios that can be used to explore the possible extent in space, time, and impact of extreme conditions that might affect fire regimes in wildlands. Such information can be incorporated into long-range forest and fuels planning.

Second, at more immediate time scales, forecasts and other information provide support for annual budget requests for fire management, and at the seasonal level, for emergency funding requests. In the West, such requests are formulated in February when enough of the winter has passed for managers to have an early insight into the likely severity of the upcoming fire season. These funding requests are predicated on an assessment of the resources needed to suppress fires. As the fire season approaches, shorter-term climate information can provide decision makers with information that is useful for refining plans for suppression activities, for possibilities related to fire use (for example, allowing already-ignited fires to burn in areas where such burns would be beneficial to the landscape), and for allocating resources. Fiscal-year suppression-expenditure estimates, which are based on observed and forecast climate, and are updated on a regular basis throughout the fire season, are also used to keep the USDA, USDI and Congress apprised of funding needs.

Prescribed burning is another area where scientific information is essential. Climate information for the past several years and for the upcoming season or year allows managers to determine the relative risk of carrying out prescribed burns, based on current and predicted conditions. For example, managers can compare existing conditions to those of analogous years in the past, based on scientific analysis of the instrumental and paleo records of fire occurrence and climate conditions in the region. Forecasts provide insights into the likelihood of anomalous wet or dry conditions, as well as of "normal" conditions (for example, those that were statistically prevalent over the thirty-year record; currently the base data are for 1970-2000). Prescribed burning plans can also be informed by scientific information such as that produced by remote sensing; for example, NDVI "greenness maps," which provide geo-referenced information about vegetation moisture conditions.

All of the above decision activities at some point require plans and action with regard to assembling and allocating resources. The number of fire fighters and support personnel needed must be identified, vendors to provide support services must be contracted, and aircraft and other equipment needs must be detailed. The decision calendar that we have employed in this study highlights these types of decision nodes, and the entry points where climate and related scientific information may be most readily and effectively introduced. It is at these points that use of scientific information and forecasts is most likely to improve district and forest-level fire management planning, budgeting, and decision-making.

Survey Methods

To construct fire management decision calendars showing the use of climate information, a survey was conducted in 2002-2003 of nine fire management officers and decision makers based in the Southwest and California, and of several dozen members of wildland fire management groups assembled for other purposes. Conversations with several key decision makers responsible for interagency coordination provided supplemental background information. We selected a structured, key-informant survey approach for our study as this was the most efficient way to obtain the required information, and it provided a means of gathering information from informants in a consistent format.

The survey was designed to gather a range of information. First, we asked respondents to complete a decision calendar, specifying when during the fire year key prevention and suppression decisions are made, and indicating the extent to which climate information and climate forecasts are used to support these decision-making processes. We asked informants to specify what climate information and climate forecasts are used, where these products are obtained, and what additional climate products managers would find useful. We asked respondents about their perceptions of the limitations of these products, in terms of the accuracy of forecasts and in terms of other constraints in the decision processes. We asked if agencies kept records of yearly management goals and of post-season evaluations, and if respondents could provide examples of climate information successes and failures. Finally, we asked respondents to rank a set of wildland fire management objectives in terms of importance.

The inclusion of a decision calendar format was a key feature of our survey design. Decision calendars, as we define them here, are temporally organized structures that reflect the timing of planning and decision making in the course of a regular fire year. Decision calendars have been used previously in integrated climate assessments. We based our calendar format on that used by Weiner (2004). Using this approach allowed us to determine what sorts of plans and decisions were important at which times of the year. This in turn allowed us to associate the timing of decisions, historical climate conditions during those periods, and forecasts for those time periods.

The survey selection process itself was structured, rather than random. We chose to focus geographically on the Southwest and the Pacific Southwest Regions. Second, within these regions, we targeted fire managers in national parks and forests where we had an existing connection or that were relatively accessible. Third, we took advantage of meetings we were attending for other purposes to conduct interviews with selected attendees. The small number of Parks and Forests we survey happen to have high levels of prescribed fire activity, which may bias our results. In spite of these limitations, we collected a comprehensive and varied sample of respondents in the targeted regions. The framework we employ could readily be extended to generate a more complete picture of climate information use for fire and fuels management throughout the United States.

Survey Results

While the number of respondents was too low to conduct a statistical evaluation of responses, valuable insights emerged from the project's focus on key informants who provided information that could be generalized across all fire management groups in the Forest Service and Park Service.

The decision calendars obtained (fig. 5) from our respondents show several interesting patterns. The types of decisions that are made throughout the year can be broken into several groups: pre-season planning, staffing decisions, monitoring of conditions, prescribed fire activities and other fuels management activities such as thinning and pile burning, peak season suppression activities, regular season budget requests and allocation decisions, and emergency severity funding requests.

The timing of these activities varies over the geographical extent of our study areas. In particular, the peak suppression season differs in length and actual time of year from region to region. Southern California has a long season with a special concern in the late fall/early winter season when strong Santa Ana winds are dominant. The Sierra Nevada in central and northern California has a relatively short season in comparison, while New Mexico and Arizona fire seasons depend heavily on the onset and wetness of the June-August monsoon season. Of particular concern is the probability of dry lighting igniting fires in the pre-monsoon period. Monsoon rains typically end the spring/summer fire season, although a second fire season may occur in the fall after the end of the monsoon season. Similarly, optimal windows for prescribed fire and fuels management activities also vary greatly across the study areas.

The decision calendars also differ across organizational levels. Local staffing decisions involve seasonal staffing, training, and determination of hiring and lay-off dates. Local budgeting involves the internal allocation of funds, annual funding requests, and peak season severity funding requests. Local pre-suppression activities include fuels treatments, prescribed fire, broadcast burns, pile burning, and mechanical thinning projects. Local suppression activities include the pre-positioning of local resources, movement of resources, mutual aid decisions, severity requests, large fire management (planning and implementation), fire use (planning and implementation), fire prevention, restrictions, and area closures. Other local activities reported by survey respondents include outreach, public education, special staffing, training, 5-year planning and analysis, and Geographic Information System (GIS) analysis.

Regional and national level activities include suppression support for large fires or multiple fire events, or widespread high fire danger or preparedness levels, strategic pre-positioning and movement of resources, again, generally when high danger conditions are present, planning and budgeting work, and the dissemination of information. Research and changes in overall organizational structure are managed at the national level.

Potential for Improved Use of Climate Information

Based on survey responses, we have identified the following decision processes that would benefit from enhanced use of climate information.

At the national level (NIFC and Washington DC offices of the NPS and USFS), national annual and inter-annual budget requests and allocations are conducted in the late winter and early spring. Budgeting procedures could be improved by explicitly taking seasonal to inter-annual climate forecasts into consideration, as could communications with Congress throughout the fiscal year. National suppression activities and mobilization decisions during the peak fire season, and preparedness and presuppression planning and budgeting in the off-season could be made more cost-effective through greater reliance on climate products. Finally, inter-annual and decadal forecasts could be considered in the formulation of the research agenda of the Joint Fire Science Program (JFSP) Board.

At the regional level (regional offices of the NPS, USFS, and the GACCs), regional budgeting and resource allocation activities occur before and during the fire season. Annual hiring, training, and staffing decisions are made leading up to the fire season, as are decisions concerning the pre-positioning of initial attack resources. These decision processes could benefit from increased use of seasonal and annual climate forecasts. The allocation of resources to fire suppression and prescribed fire activities occurs throughout the year, and regional mobilization decisions and mutual aid decisions are made during the peak fire season. These decisions could be improved through greater reliance on seasonal and

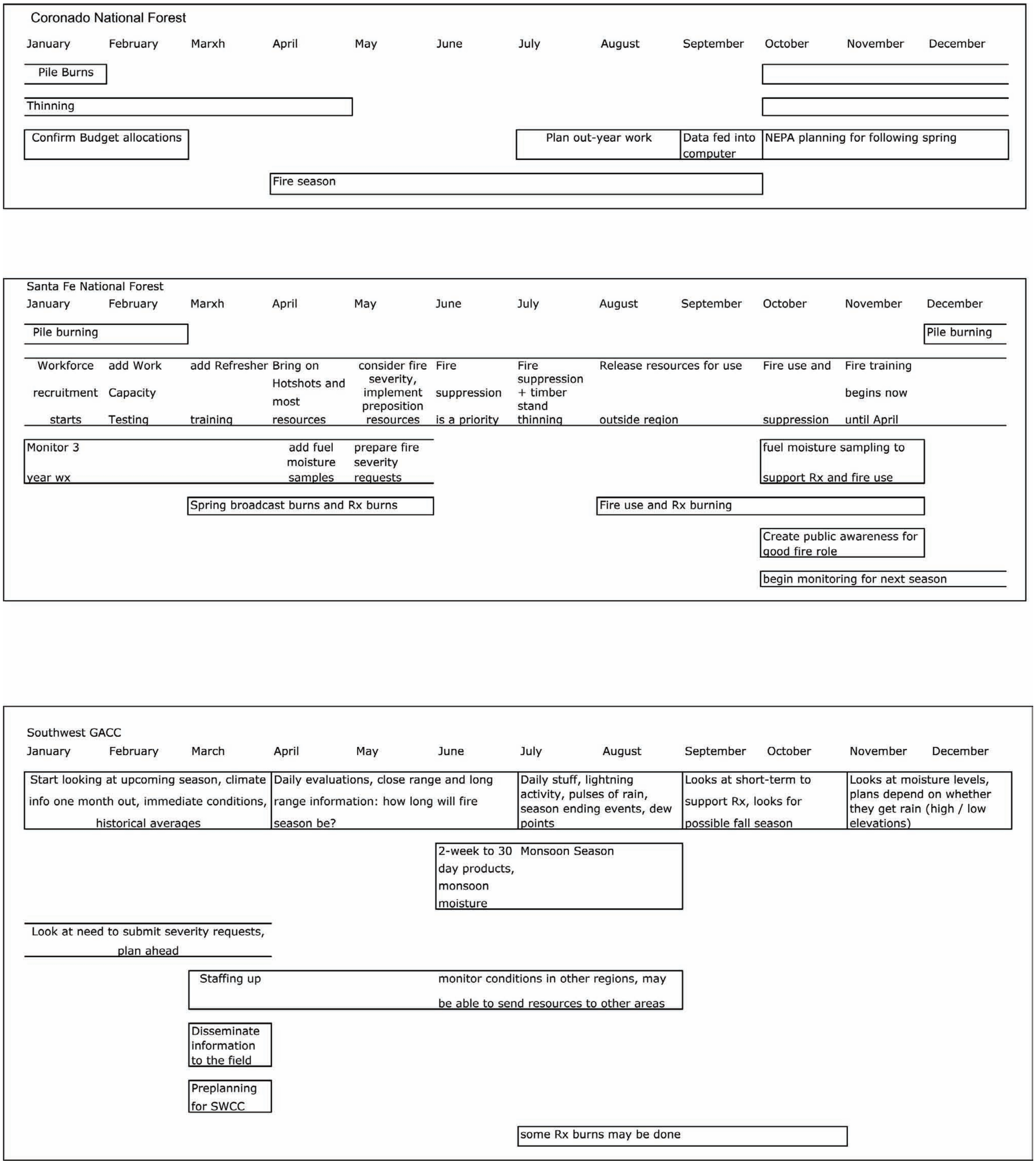

Figure 5a. Decision Calendars.

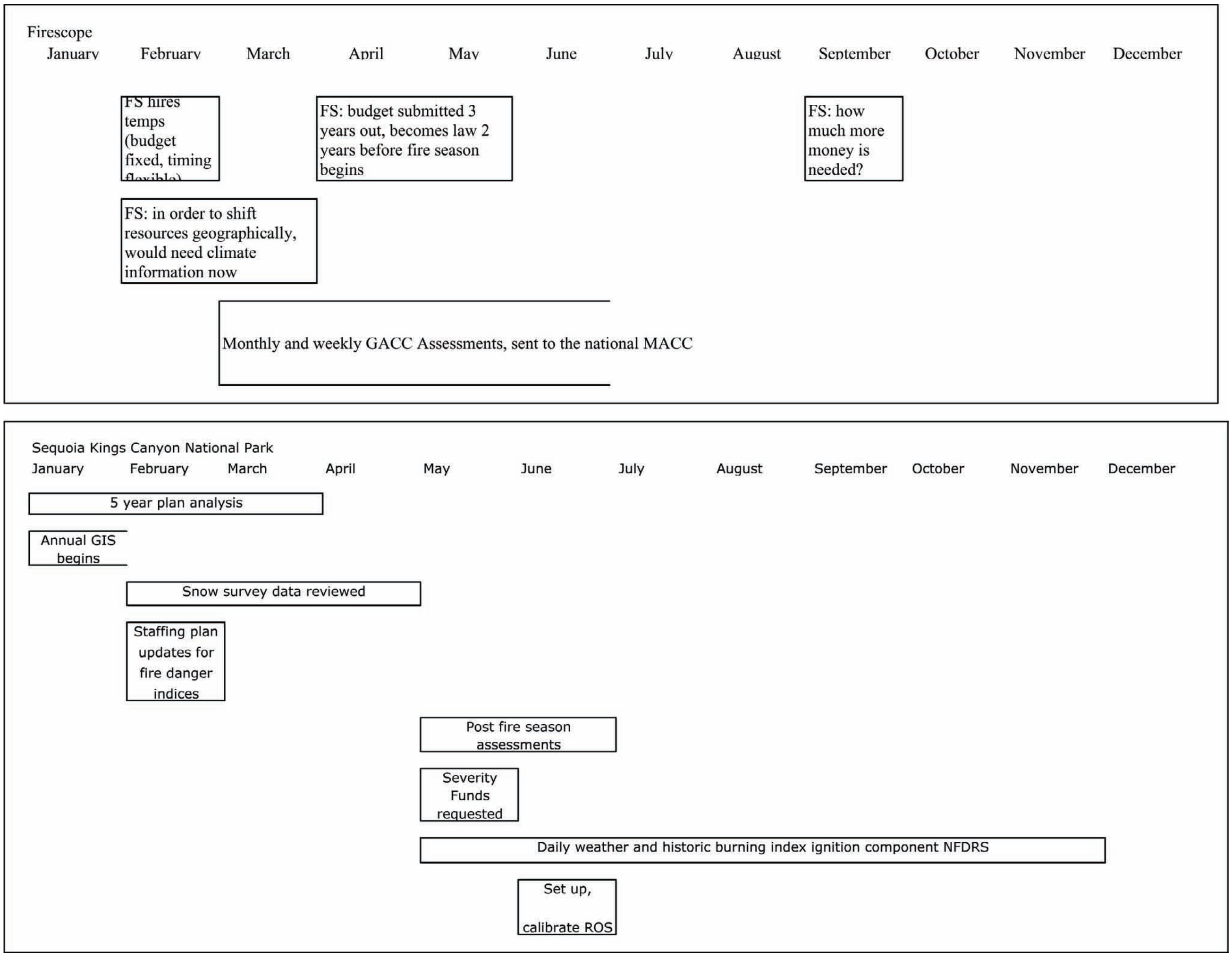

Figure 5b.

monthly climate forecasts, and through a standardized and integrated use of climate information products and climate forecasts.

At the local level, hiring, training, and staffing decisions are made leading up to the fire season, and could benefit from specific forecasts of expected fire season timing, length, and severity. The internal allocation of resources to suppression and prescribed fire activities is conducted before and during the fire season, as is the setting of annual targets for prescribed fire, fire use, and fuels treatment. These decisions could be improved through greater reliance on seasonal forecasts. External budget requests are made annually a year in advance, to regional offices, and could be set more accurately with the aid of annual climate forecasts, potentially reducing the need to rely on severity funds during the peak season.

From a longer-term perspective, Fire Management Plans (FMPs) are revised on a five-year cycle in conjunction with land management plans. In addition to responding to political and economic pressures, these FMPs could also be tuned to climate outlooks (for example, setting burn targets, prescriptions, and boundaries conditional on long-range climate trends and cycles). A potential difficulty involves the varying levels of access to climate information and to trained climatologists from unit to unit. A program could be established through which Predictive Services meteorologists at the GACCs provide oversight and assistance.

Also considering long-term objectives, at the national level the Joint Fire Science Program (JFSP) Board sets the national wildland fire research agenda. A greater emphasis on climate information systems and the role of climate forecasts in wildland fire management decisions could lead to improvements in the quality of forecasts available to wildland fire managers.

Institutional Barriers to Using Seasonal Forecasts in Fire Management

Several important institutional barriers exist to the use of seasonal forecast information by fire managers. One is the federally required two-year budget cycle,

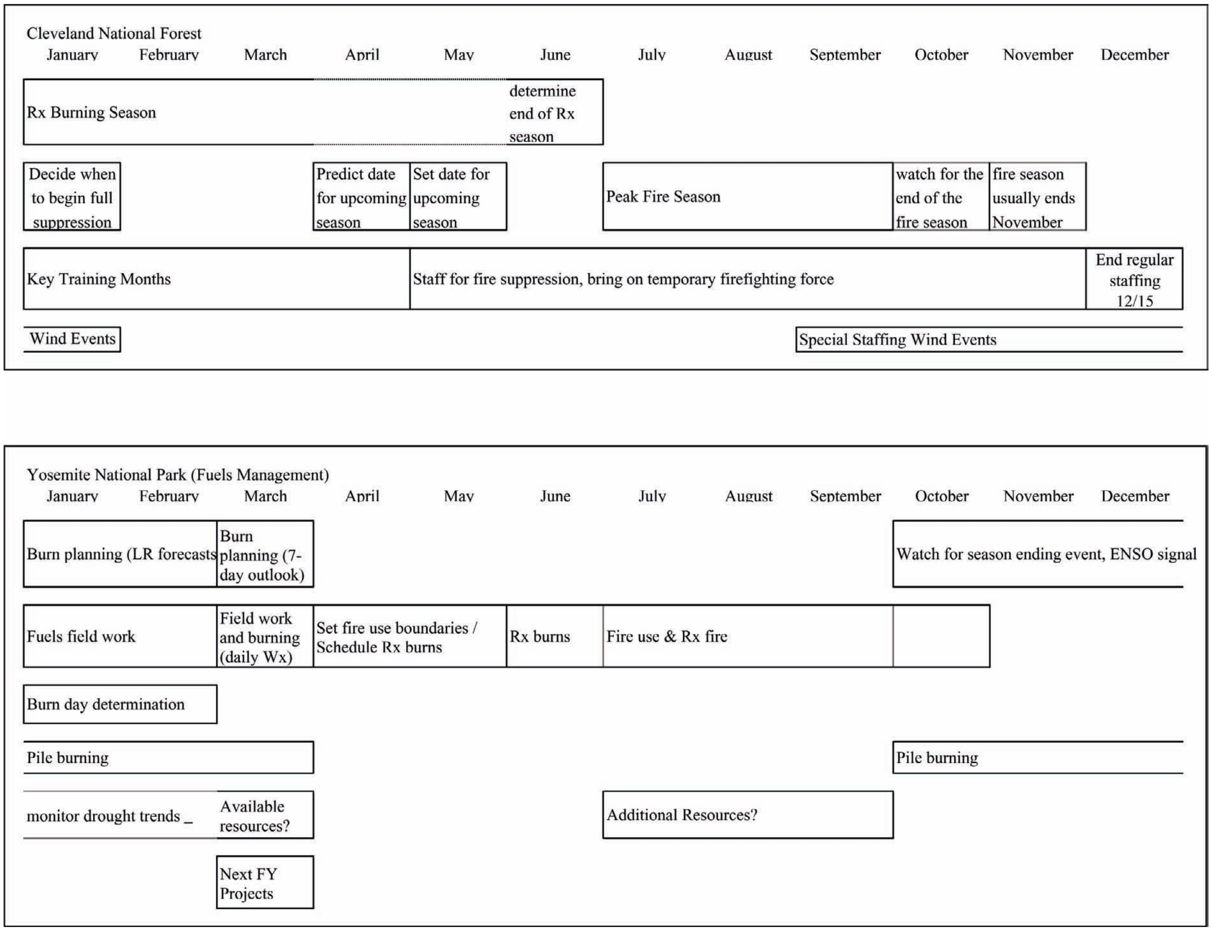

Figure 5c.

which allows little latitude for shifting funds regarding forest treatment activities based on climatic conditions that arise after budgets are submitted and approved. For example, given the high probability of La Nina conditions producing anomalously dry conditions during the winter in the Southwest (Gershunov and Barnett 1998), a reasonably confident La Nina prediction the winter before a fire season should prompt a new analysis of budget allocations to address the emerging fire risk for that season. However, current policies afford little room for such adjustments to allocations of funds to avert or suppress fires in the region.

This institutional constraint is related to another barrier, the lack of flexibility in authorizing legislation, at the federal level, to make regional or local-level modifications in policies that reflect ground-level realities. For example, fire managers argue that it should not be so cumbersome to obtain permission from the USFWS to treat areas protected by the Endangered Species Act. Climate information offers another tool for assisting both fire managers and USFWS specialists in arriving at management strategies that take into account the vicissitudes of environmental variability and change, as well as the strong mandate to protect threatened and endangered species.

A third area of institutional disjuncture between availability and effective use of climate information involves the lack of flexibility in the fire planning process itself. Organizational inertia is partly to blame. As Lach and Ingram (2003) have shown for water managers, changes only tend to be made when extraordinary conditions result in the inability of existing practices and policies to address the problems. Understanding how and when innovation can occur (such as the use of climate information and forecasts to make fire management decisions) is crucial for devising ways to communicate appropriate information, and to providing the information at the appropriate time, to the appropriate people. Understanding the decision calendars of fire managers provides a means of beginning this task.

The fourth area of constraints involves the mismatch between decision calendars and forecast time horizons. One solution is to adjust the timing and content of forecasts to fit the temporal and spatial patterns of decision making. Recent efforts to establish annual fire-climate-fuels assessment processes for the US West and the US Southeast, for example, have included the development of specific consensus climate forecasts for the time periods of most concern to fire and fuels managers, particularly those associated with pre-season planning for resource allocation (Garfin and others 2003).

A more challenging solution would be to alter the timing of funding decisions, and planning horizons to recognize and respond to the spatial and temporal vicissitudes of environmental variability and change. If congressionally allocated funds could be spent for prescribed burns and other treatments over inter-annual or decadal time horizons, or if tradeoffs in funding could be made over larger regions, it would be easier for managers to adjust their fire management plans to reflect forecasts and impacts of ENSO conditions, including multi-year combinations of wet and dry conditions.

Conclusions and Recommendations

Climate information is currently widely used by fire managers, but there is potential for greater and more effective use of available information. The results presented here could be readily extended to other land management agencies, and to State and local fire agencies. In some cases the science and technology is available to integrate climate information into decision making, although organizational changes may be required to fully realize the value and increased efficiency of climate forecasts and information. In other cases, forecast accuracy will have to be increased before decision makers in the fire management sector will be willing to change their management strategies in a manner that integrates such information.

On the basis of our survey results, we recommend a review of management procedures to make various decision processes more flexible, and to allow forward-looking use of climate information and climate forecasts. For example, climate forecasts could be used to set more realistic fuels management goals at the unit level, and to strategically set priorities for fuels management and prescribed fire treatments. We also recommend a review of wildland fire budgeting procedures at the local, regional, and national levels, again taking climate considerations into account.

The National Fire Plan notes that "Critical to fire science program success are mechanisms to ensure that the information is transferred to land and fire managers in a usable form." (USDA/USDOI, 2001). The National Wildfire Coordinating Group (NWCG) Fire Weather Working Team has been charged with assessing current and projected requirements for fire weather products as part of its ongoing efforts to address fire weather issues. In this task, collaboration with Regionally Integrated Science Assessment groups (RISAs) could be highly productive. Training in the use of climate information could be provided at the Fire Management Leadership course at the National Advanced Resource Technology Center (NARTC).

Considering the wide variation in the use of climate information and forecasts, and in the climate-related expertise of wildland fire and fuels managers, we recommend that one clearing house for information be established, to allow the sharing of information and analysis across all agencies and at all institutional levels. Further, to ensure a high standard of use of climate information and forecasts we suggest that climate forecasts be explicitly considered in the National Interagency Mobilization Guide, in Geographic Area Mobilization Guides, in the interagency Wildland Fire Situation Analysis (WFSA), and in interagency Allocation of Resources protocols.

Realizing the full potential of climate information and forecasts will require the collaborative effort of several agencies and the climate science community. The potential gains from such an effort would be significant, however, and can be facilitated by a detailed understanding of the decision making processes involved in wildland fire agencies, the timing of such decision processes, and the kinds of information requested by fire managers across the United States.

References

US Departments of Agriculture and Interior. 2001. A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment: 10-Year Comprehensive Strategy. US Departments of Interior and Agriculture, in collaboration with the Western Governors Association. http://www.fireplan.gov/reports/7-19-en.pdf, June 25, 2004

Garfin, G.M. and B.J. Morehouse. 2001. Fire and Climate Workshops. Proceedings. February 14-16, 2001, March 28, 2001. Institute for the Study of Planet Earth, University of Arizona, Tucson, Arizona.

Garfin, G.M. 2002. Fire in the West Workshop. http://www.ispe.arizona.edu/climas/ conferences/fire.html.

Garfin, G.M., T. Wordell, T. Brown, R. Ochoa, and B.J. Morehouse. 2003. National Seasonal Assessment Workshop. Final Report. February 25-28, 2003, Mesa, Arizona. Institute for the Study of Planet Earth, University of Arizona, Tucson, Arizona.

Gershunov, A. and T.P. Barnett. 1998. Interdecadal modulation of ENSO teleconnections. Bulletin of the American Meteorological Society, 79(12): 2715-2725.

Hansen, James W., Alan W. Hodges, and James W. Jones. 1998. ENSO influences on Agriculture in the southeastern US. Journal of Climate 11(3):404-411.

Jacobs, K., and R. Pulwarty, 2003. Water Resource Management: Science, Planning, and Decision-Making. Water: Science, Policy, and Management. Water Resources Monograph 16. American Geophysical Union (ISBN: 0-87590-320-7)

Keeley, Jon E. 2004. Impact of antecedent climate on fire regimes in coastal California. IJWF Vol. 13 No. 2 pp. 173-182.

Lach, D., H. Ingram and S. Rayner. 2003. Coping with Climate Variability: Municipal Water Agencies in Southern California. In Climate and Water: Transboundary Challenges in the Americas, H. Diaz ed. Kluwer Academic Pub.

Miles, E. L., A. K. Snover, A. F. Hamlet, B. M. Callahan, and D. L. Fluharty. 2000. Pacific Northwest regional assessment: The impacts of climate variability and climate change on the water resources of the Columbia River Basin. Journal of the American Water Resources Association 36(2):399-420.

Morehouse, BJ. (ed). 2000. The Implications of La Nina and El Nino for Fire Management. Proceedings. Institute for the Study of Planet Earth, University of Arizona, Tucson, Arizona. February 23-24, 2000.

Sarewitz, D., R. Pielke, Jr. and R. Byerly Jr., eds. 2000. Prediction: Science, Decision Making, and the Future of Nature. Covelo, CA: Island Press.

Stern, P. and W.E. Easterling. 1999. Making Climate Forecasts Matter. National Research Council/National Academy of Sciences, Washington, National Academy Press.

Westerling, A., K. Gebert and J. Prestemon 2004: Statistical Forecasts of Western Suppression Costs for the U.S. Forest Service, (unpublished).

Wiener J.D. 2004. Small agriculture needs and desires for weather and climate information in a case study in Colorado. AMS 2004 Users Conference Pre-print, American Meteorological Society.