Wildfire Management and Forecasting Fire Potential: The Roles of Climate Information and Social Networks in the Southwest United States

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ABSTRACT

Continuing progress in the fields of meteorology, climatology, and fire ecology has enabled more proactive and risk-tolerant wildland fire management practices in the United States. Recent institutional changes have also facilitated the incorporation of more advanced climate and weather research into wildland fire management. One of the most significant changes was the creation of Predictive Services in 1998, a federal interagency group composed, in part, of meteorologists who create climate- and weather-based fire outlooks tailored to fire manager needs. Despite the numerous forecast products now available to fire managers, few studies have examined how these products have affected their practices. In this paper the authors assess how fire managers in the Southwest region of the United States perceive and incorporate different types of information into their management practices. A social network analysis demonstrates that meteorologists have become central figures in disseminating information in the regional interagency fire management network. Interviews and survey data indicate that person-to-person communication during planning phases prior to the primary fire season is key to Predictive Services' success in supporting fire managers' decision making. Over several months leading up to the fire season, predictive forecasts based on complex climate, fuels, and fire-risk models are explained to fire managers and updated through frequent communication. The study's findings suggest that a significant benefit of the information sharing process is the dialogue it fosters among fire managers, locally, regionally, and nationally, which better prepares them to cooperate and strategically plan for the fire season.

1. Introduction

In 2000, wildfires raged across the western United States. At the end of the season, over 120 000 fires had burned more than 8.4 million acres of land, with suppression costs totaling $1.3 billion (U.S. dollars; Machlis et al. 2002). The Cerro Grande fire, one of the first major wildfires that season, was a prescribed burn that accidentally escaped from Bandelier National Monument into Los Alamos, New Mexico, ultimately consuming 48 000 acres and 235 homes (Machlis et al. 2002). While the fire season spurred drastic changes in wildland fire management for the United States, the Cerro Grande fire in particular revealed a defining moment because the fire resulted from attempts by forest managers to *reduce* vulnerability to wildfire.

Bandelier National Monument had a history of particularly stringent fire suppression measures due to its abundance of culturally and historically significant Native American sites, but increased scientific understanding

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of fire ecology in the Southwest cautioned that overly aggressive suppression practices could cause an unnatural and dangerous buildup of fuels in fire-prone landscapes (Arno and Allison-Bunnell 2002). Land managers at Bandelier initiated a 10-yr plan to reduce fuel hazards. The Cerro Grande fire began as a controlled burn, but anomalously dry vegetation and high winds caused the fire to escalate into an uncontrolled disaster. In a formal review and analysis of the event, investigators indicated that the management plan had not accounted for these dangerous conditions (National Park Service 2001). Furthermore, these conditions were, in part, associated with a climate pattern caused by the La Niña phase of the El Niño–Southern Oscillation (ENSO) pattern, which had been accurately predicted by forecasters in the region (Morehouse 2000).

The Cerro Grande fire illustrates a paradigm shift that occurred in fire management at the dawn of the new millennium. Land management practices that acknowledged fire as an intrinsic part of a healthy ecosystem also required the implementation of advanced scientific knowledge and forecasting to ensure fire management's prime directive—protection of human life and property. However, the successful use and implementation of climate-based forecasts is largely determined by how users of such information receive and comprehend complex information in contexts that often require decision making under duress, with potentially large consequences for both human populations and the natural environment.

As the relationship between climate forecasting and fire management continues to evolve, it is beneficial to evaluate the current role that climate information plays among the suite of other types of information available to wildfire managers. In line with this goal, the purpose of our study is to identify: 1) how wildfire managers in the U.S. Southwest apply climate information to long-term strategies and everyday practices and 2) how information is disseminated within a regional network of fire management professionals.

Wildfire management presents a compelling perspective from which to view perceptions and uses of climate forecasts. We hope that our study yields useful insights for those seeking to understand the potential role of climate forecasts in a wide variety of applications and settings. Much of the literature on climate-based decision making in the U.S. Southwest has focused on agriculture, water management, and related public policies, which have potentially major economic impacts and can be critical for reducing human vulnerability to climate variability and change (e.g., Colby and Frisvold 2011; Gober and Kirkwood 2010; Jones and Colby 2010; Liverman and Merideth 2002; Pagano et al. 2002). Fire management also represents a high-stakes application of climate forecasting, but with an even greater degree of forecasting uncertainty (Kolden and Brown 2010; Corringham et al. 2008). Drought conditions may make a region especially vulnerable to fire outbreaks during a given season, but the actual causes of fire are multiple, including human (such as careless campfires or arson) or natural (primarily lightning strikes), and may simply fail to materialize in a given season (Machlis et al. 2002).

While fire *conditions* are predictable with an increasing level of accuracy, forecasting fire *occurrences* is much more problematic. Forecasters can only provide outlooks for significant fire *potential*, a measure of anticipated occurrence of wildfires requiring fire management resources from outside the region where the fire originated. Even when forecasts accurately predict a season with significant fire potential, large-scale fires may not happen because ignitions do not occur or because fire managers are adequately prepared to respond rapidly to suppress fires before they become large-scale events. Conversely, a season with significant fire potential may still produce multiple large wildfires even though fire managers are fully prepared to suppress fires in terms of resources and planning. The 2011 fire season provides a perfect example. In December 2010, meteorologists and climatologists noted that La Niña conditions and regional impacts were consistent with the worst fire seasons in the Southwest. Predictive Services personnel and fire managers in the Southwest were aware of the likelihood for a season with a high level of significant fire potential. A safety advisory was issued in early January 2011, warning fire managers to prepare for a tough, long, and early starting season in the Southwest. Early fire season preparation was explicitly discussed at staff meetings at the regional Predictive Services office in New Mexico (C. Maxwell 2010, personal communication). Products were issued showing above-normal levels of significant fire potential across the Southwest.

Despite this preseason knowledge and preparation, the 2011 fire season turned out to be the worst in recorded history for both Arizona and New Mexico in terms of number of acres burned; approximately 981 000 acres in Arizona and just under 1 255 000 acres in New Mexico burned in 2011 (Southwest Coordination Center 2011b). While it would be impossible to count how many lives, land acres, or resources were saved by using climate forecasts in preseason planning, forecasts played a visible role in early season planning processes and management responses during the 2011 fire season. Results from this study help illuminate the role of climate forecasts among an assortment of information available for wildfire management.

We conducted a regionwide survey and series of interviews in the Southwest that targeted a diverse group of fire managers, from local crew captains to national intelligence officers. The study participants represent a full spectrum of relevant state and federal land management agencies, including Arizona and New Mexico State Forestry Divisions, the National Park Service, the Bureau of Land Management, the Fish and Wildlife Service, the Bureau of Indian Affairs, the U.S. Forest Service, and the National Weather Service. Our study is also situated in the context of recent structural changes that influenced cooperation and collaboration between these agencies.

Questions from our surveys and interviews focus on preferences and applications of information, the challenges managers face in using forecasts and various spatial and temporal scales, as well as social ties within the wildfire management community. We specifically asked participants about seasonal fire potential forecasts because these forecasts directly incorporate climate information and also comprise the largest geographic and temporal scales of any forecasts available for fire management. We analyze trends in what types of information fire managers use, how information is disseminated within the fire management network, and whether these two variables can be empirically linked. We hope our findings from interviews, surveys, and a social network analysis (SNA) provide valuable feedback for the fire management community as well as the climate science community.

2. Background

While the integration of climatology into fire management is barely a decade old, the effects of natural climate fluctuations, such as ENSO, on the character of wildfire in the Southwest are well understood in the context of current and past climates (Swetnam and Betancourt 1998, 1992; Westerling et al. 2003). Seasonal, interannual, and interdecadal variability in precipitation and temperature influence soil moisture and the production of fuels (e.g., grasses, woody brush, and trees), which can influence fire ignition rates. During El Niño phases of ENSO, for example, winter and spring conditions tend to be colder and wetter in the Southwest, suppressing spring and summer fires; during La Niña phases, conditions tend to be warmer and drier, causing more areas to burn than during El Niño phases (Westerling et al. 2006; Swetnam and Betancourt 1998). Paleoclimate records dating to the 1700s depict synchronous fire activities in the region that are often tied to episodes of extreme drought (Swetnam and Betancourt 1998). Regional impacts during both ENSO phases are also correlated to positive and negative phases of the Pacific decadal oscillation (Sheppard et al. 2002). Another complicating factor is how these relationships may change with changing climate (Williams et al. 2010; Westerling et al. 2006; Brown et al. 2004; McKenzie et al. 2004). Increasing temperatures and diminishing humidity associated with projected climatic changes in the Southwest will likely increase the length of the fire season and change desert ecosystem dynamics (Williams et al. 2010). Such changes, for example, may favor the spread of invasive grass species, making desert lowlands more susceptible to wildfire (Abatzoglou and Kolden 2011). Connections between atmospheric circulation patterns and their impacts on regional climate and weather variability and subsequent fire regimes are parts of a dynamic system that can be difficult to predict and apply to wildfire management.

Several other factors in the mid-1990s and early 2000s contributed to institutional and political support for increasing the integration of climatic and ecological considerations into wildland firefighting policy. After decades of advancement in fire ecology, the final report of the Federal Wildland Fire Management Policy and Program Review [(1995), revised in 2001 and commonly referred to as the National Fire Plan] called for federal agencies to innovate beyond the historical practice of attempting to suppress all wildfires (Interagency Federal Wildland Fire Policy Review Working Group 2001). Increases in both the costs and dangers of fighting wildland fires over the previous several decades were primarily attributed to two factors: 1) the accumulation of hazardous fuels as a result of aggressive suppression practices of the twentieth century in fire-adapted ecosystems and 2) increased residential development in rural and wildland areas (Machlis et al. 2002). Since the 2001 update of the National Fire Plan, a third factor has become increasingly evident: climate change is likely to exacerbate fire activity, including area burned, occurrence, and severity (Flannigan et al. 2009). To mitigate increased fire risk, the National Fire Plan called for the use of prescribed and managed burns—which require greater interagency cooperation for planning purposes—and mandated that federal agencies make use of the latest scientific knowledge to form land management policies reflecting more complex and ecologically sound objectives.

Coinciding with these developments were changes within the National Weather Service (NWS) that threatened to affect wildland fire management. For decades, fire managers depended on both NWS meteorologists who specialized in fire weather forecasts and decision-support products specifically tailored to fire management. However, NWS modernization initiatives in the 1990s threatened to phase out these fire weather specialists in favor of more general incident meteorologists (IMETs), who would provide forecasts for multiple types of natural disasters (Interagency Federal Wildland Fire Policy Review Working Group 2001). Though fire weather forecasts would still be available through the IMETs, the disappearance of fire-specific meteorologists alarmed administrators in various federal land management agencies, and they began to strategize ways to ensure advanced meteorological information was readily available to fire managers, including access to fire weather forecasters (Winter and Wordell 2010; T. Wordell and R. Ochoa 2010, personal communication; C. Maxwell 2010, personal communication).

While these institutional and structural changes were unfolding, the record 2000 fire season was one of the worst on record for many western states, giving new urgency to implement the policy directives in the National Fire Plan. A portent in the changing direction of fire weather forecasting, climatologists correctly predicted a severe fire season in several regions of the United States in large part because of the 1999–2000 La Niña event (Morehouse 2000). Some climatologists made concerted efforts to discuss these forecasts with officials in the fire management network, reflecting the increasing potential for climate science to better prepare fire managers for severe fire conditions. The Fire and Climate Workshop at The University of Arizona in 2000, for example, brought together 45 participants, a mix of fire managers, climate, weather, and ecology specialists.

The confluence of new mandates embedded in the National Fire Plan, impending changes in NWS services, advancements in predictive climatology based on ENSO modeling, and burgeoning modes of dialogue between scientists and fire managers were contributing factors in the creation of Predictive Services, a federal interagency group composed of meteorologists specializing in fire weather applications, along with wildland fire analysts and intelligence officers. In 2001, the Department of the Interior hired 20 meteorologists as dedicated fire weather forecasters; two were located at the National Interagency Coordination Center (NICC) and the others were distributed at Geographic Area Coordination Centers (GACCs) throughout the country (see Winter and Wordell 2010; Machlis et al. 2002). The following year, a new charter was drafted for Predictive Services that included the charge to help integrate climatology into fire weather forecasts.

The creation of Predictive Services has led to a dramatic shift in the types and quantities of information available to fire managers. In addition to meteorologists, Predictive Services draws on the expertise of fire managers, fire behavior and fuels analysts, and climate scientists to synthesize fuels, weather, and climate information into innovative forecasts for fire potential on time scales from daily to seasonal.

One of the more ambitious products stemming from the creation of Predictive Services is generated during the National Seasonal Assessment Workshops (NSAWs), where fire weather, fire management, fuel analysts, and climate specialists gather to collectively produce a national assessment of the upcoming fire season. These assessments are designed to enhance proactive wildland fire management and test the geographic and temporal limits of predictive forecasting capabilities. Like the initial Fire and Climate workshop in 2000, early NSAW meetings were characterized by several important processes: 1) climate scientists educating fire managers and meteorologists on the relevance of atmospheric circulation patterns, such as ENSO, to weather and fire forecasting, the limits and abilities of climate forecasts, and the differences between climate and weather; 2) fire managers educating climate scientists on their needs, the types of forecasts that would be most useful, and in what formats information would be most effectively delivered; and 3) opening a national dialogue for fire managers at different agencies and in different regions to discuss and strategize for the upcoming fire season (Garfin and Morehouse 2001, 2005). Currently, workshops are held twice a year, one in the eastern United States in January and one in the western United States in April. The western meeting includes specialists from Canada and Mexico.

The product resulting from the workshop is a seasonal assessment, including a color-coded national map where green denotes areas of below-normal fire potential, white denotes areas of normal levels, and red denotes areas of above-normal levels. This map is accompanied by a report detailing climate, fuels, and potential weather information pertinent to the upcoming fire season. One of our research objectives was to evaluate the utility of the NSAW seasonal assessments and better understand their implications for wildfire management.

3. Study overview

Fire managers have access to many types of information through a wide range of sources. However, it is not well known how these different types and sources of information influence fire management since few evaluations of particular products or websites have been conducted. In our study, we surveyed a population of fire management professionals in the Southwest (see Fig. 2 for a list of different categories of jobs in fire management) to understand how climate-related products are perceived and used in fire management practices and how these relate to other types of commonly used information. Through a social network analysis, these preferences were viewed in the context of personal, professional, and institutional ties that affect the distribution and acceptance of new forms of information.

Some definitions and commentary on terms used in our survey and interview questions help frame our results. First, throughout the survey we inquired about information preferences and management practices in the *prefire season* and the *peak fire season*. Based on fire decision calendars by Corringham et al. (2008), we defined the prefire season as the months leading up to the time when wildland fires typically begin. During this period, fire managers generally conduct prescribed burns, allocate resources, and hire staff based on seasonal budgets. Planning for the Southwest region usually occurs during February, March, and April.

Peak fire season is defined as the period when firefighting resources are primarily dedicated to suppression. While the beginning and ending dates of the Southwest's peak fire season vary annually, most wildfires occur between April and August. Between 1990 and 2008, Arizona averaged 53 large (more than 100 acres) wildfires per year, while New Mexico averaged 47. Of these, 91% in Arizona and 76% in New Mexico occurred between April and August (Southwest Coordination Center 2011a).

Second, we asked respondents about five categories of information that are common within their profession: 1) fire climate, 2) fire weather, 3) fuels/fire danger, 4) intelligence, and 5) significant fire potential (Table 1). Four of these categories were based on the information categories on the Southwest Coordination Center (SWCC) Predictive Services website and were already familiar to most people surveyed. Fire climate did not have its own information category on the website but was a subcategory in the Fire Weather section. The term was important to our study because one of our goals was specifically to better understand how climate information applied to fire management.

4. Methods

a. Survey and interviews

We collected data from November 2009 to June 2010 through two methods: 37 semistructured phone interviews lasting approximately 45 min each and 40 online surveys, which were an abbreviated version of the phone interviews. We employed a structured snowball sampling method, starting with 13 regional directors of the five federal, tribal, and state agencies involved in fire management in Arizona and New Mexico. Each respondent was asked to identify the ''top five'' individuals with whom they most closely collaborated when making fire management decisions. We then contacted each of these top five individuals and conducted the same phone interview with those willing to participate. Through the interviews and surveys, we gathered quantitative and qualitative data about preferences for forecast information in the prefire and peak fire seasons, uses and perceptions of fire potential outlooks, and the social network of fire management professionals through which information is created and circulated. One section of the survey focused specifically on the seasonal outlook for significant fire potential produced annually at NSAW, to evaluate this particular product's utility and effectiveness in preseason planning for wildland fire management. The online survey was primarily used to gather additional data for a more extensive social network analysis, and was limited to basic demographic information, the respondent's closest collaborators, and their preferred sources of information.

We initiated our study within the geographical limits of the SWCC. Located in Albuquerque, New Mexico, the SWCC produces and distributes information to fire managers in Arizona, New Mexico, and a small portion of west Texas. Because of our sampling method, we interviewed a diverse range of wildland fire professionals that extended beyond this region, including national-level administrators and meteorologists at the National Interagency Coordination Center in Boise, Idaho, as well as regional-level fire management professionals at other Geographic Area Coordination Centers. Some of our research objectives, however, were specifically aimed toward fire management professionals in Arizona and New Mexico. Of our entire participant population, 25 semistructured interviews and 26 online surveys were conducted with people who worked in fire management in these two states. Most of our results, excluding the social network analysis portion, focus on fire management professionals located in Arizona and New Mexico.

b. Social network analysis

A critical part of our study was to identify interpersonal ties within a network of fire management professionals using a SNA to determine the key actors in the dissemination of useful information. SNA has proven useful across a diverse range of applications, including the spread of infectious diseases, military and wartime operations, and the structure of community relationships (Borgatti et al. 2009). SNA clarifies how node-to-node interactions create large-scale structures with identifiable patterns in a given dataset (see Wasserman

TABLE 1. The five categories of information used in fire management.

Information type	Fire climate	Fire weather	Fuels/fire danger	Intelligence	Significant fire potential
Description	Climate information relevant to long-term fire management	Weather information relevant to short-term fire control and smoke management	Levels of fuel moisture in soil and vegetation; fire danger classifications	Latest information on active fires and the resources currently committed	The likelihood that fire suppression will require outside resources
Examples	ENSO and drought indices; 30–90 precipitation and temperature outlooks	1–7-day forecasts; site-specific spot forecasts; temperature, precipitation, smoke, and lightning data	Fire danger ratings; energy release component charts; observed and forecasted fuel moisture	Incident management situation reports; maps and satellite imagery; historical data	Daily, 7-day, monthly, and seasonal fire potential outlooks
Selections from participant descriptions	"Gives a broad sense of what might be coming up."	"Follows daily changing conditions - the timing coincides with decisions made."	"The most immediate, on the ground information."	"The situation happening on the ground."	"Brings together fuels, weather, and climate data."
	"Helps us prepare for the upcoming season, in terms of timing staffing, and resources."	"Dictates fire behavior. It's the greatest influence on the fire environment."	"This is the real stuff going on."	"The difference between truth and prediction."	"Consolidates and distills the other forecasts."
Information sources most often mentioned	U.S. Drought Monitor	NWS fire weather reports	National Fire Danger Rating System (NFDRS)	National situation report	7-day fire potential outlook
	CLIMAS's Southwest Climate Outlook	NWS local area-forecasts	Wildland Fire Assessment System (WFAS)	SWCC morning briefings	SWCC meteorologists

and Faust 1994; Breiger 2009; Carrington et al. 2005). In our case, SNA was used to identify the interpersonal ties between fire management professionals regarding the sharing and production of information. Wildfires, as well as wildfire management, traverse institutional, administrative, and geographic boundaries. Understanding the range of characteristics that tie fire management professionals across these boundaries is a critical step in improving the diffusion of scientific knowledge and assessing its implementation.

In addition to generating our list of interviewees, the aforementioned top five individuals identified by each participant supplied the basis for the SNA. Using UCINET (Borgatti et al. 2002) and NetDraw software, we produced a network map of people involved in fire management in the Southwest that depicted the primary channels and influences for information flow. The SNA identified persons with the greatest number of ties to other individuals and places them at the center of the network, with less connected and presumably less influential members radiating outward to the periphery. Individual centrality measures assign values to nodes by which we can identify those most ''connected'' in a network, based on the number of connections that pass through them (Scott 1991; Borgatti 2005). Network centrality measures how central the network's most connected node is relative to the centrality of all the other nodes (Freeman 1979). Not all members of the fire management network were interviewed or surveyed; we simply did not have the resources to continue surveying until the extensive fire management network closed itself. However, the map still serves as a heuristic tool to identify the general composition and patterns within a given network.

5. Results and analysis

Our findings indicate that climate-based forecasts are the most useful type of information in the months preceding the fire season, allowing managers to proactively plan for the upcoming fire season. Suppression processes during the peak fire season are primarily reactive and based on short-term weather forecasts and current fuel conditions. Additionally, we found that the acceptance and integration of climate-based information on the part of fire management professionals is largely due to person-to-person communication patterns. The following results and analysis elaborate these findings.

a. Usefulness ratings for categories of information used in fire management in the Southwest

Participants rated the usefulness of each of the five categories of information on a Likert scale of 1–5, with 1 defined as ''not at all useful'' and 5 defined as ''very useful.'' These questions helped determine which categories were most integral to their job duties and also whether the usefulness for each category changed temporally between the prefire and peak fire seasons. In the prefire season, fire management professionals in the Southwest rated significant fire potential highest (average = 4.07/5), followed by climate (3.97/5), and fuels/fire danger information (3.79/5). The latter two types of information are used to help determine significant fire potential so all three of these categories are likely used together to plan for the upcoming fire season. These types of information are aimed toward decisions made on time scales of weeks to months. Fire weather (3.66/5) and intelligence (3.17/5) are slightly less useful categories during the preseason, likely because they are directed toward decisions made on shorter time scales, ranging from minutes to days.

In the peak season, fuels/fire danger information was the highest rated category (average = 4.76/5), followed by fire weather information (4.72/5). During this time, fire managers must closely monitor how changing conditions affect active fires and therefore they need to know current on-the-ground conditions and short-term forecasts. Intelligence (4.38/5) and significant fire potential (4.45/5) were also perceived as more useful in the peak fire season than the prefire season. The only category of information rated less useful in the peak season than in the preseason was climate (3.41/5), which further supports the finding that climate information is more useful when fire managers begin longer-term preparations and planning.

b. Most useful categories of information for fire management professionals in the Southwest

After rating the different categories of information, participants were asked to choose one category of information they used most for decision making in both prefire and peak fire seasons. In the prefire season, 36% of respondents in the Southwest selected climate information, with fuels/fire danger (32%) and fire potential (25%) close behind (Fig. 1a). Interviewees who said they use climate, long-term fuels, and fire potential forecasts in the prefire season claimed it helped them look at the long-term patterns, which dictate if it will be an active season. This allows for planning in the prefire season, in terms of working with the other GACCs and the National Interagency Fire Center (NIFC) to set budgets and hiring additional staff or resources as needed. Based on our interviews, some respondents liked to know the detailed impacts of forecasted climate patterns, while others said they preferred a more consolidated outlook, such as the fire potential outlooks.

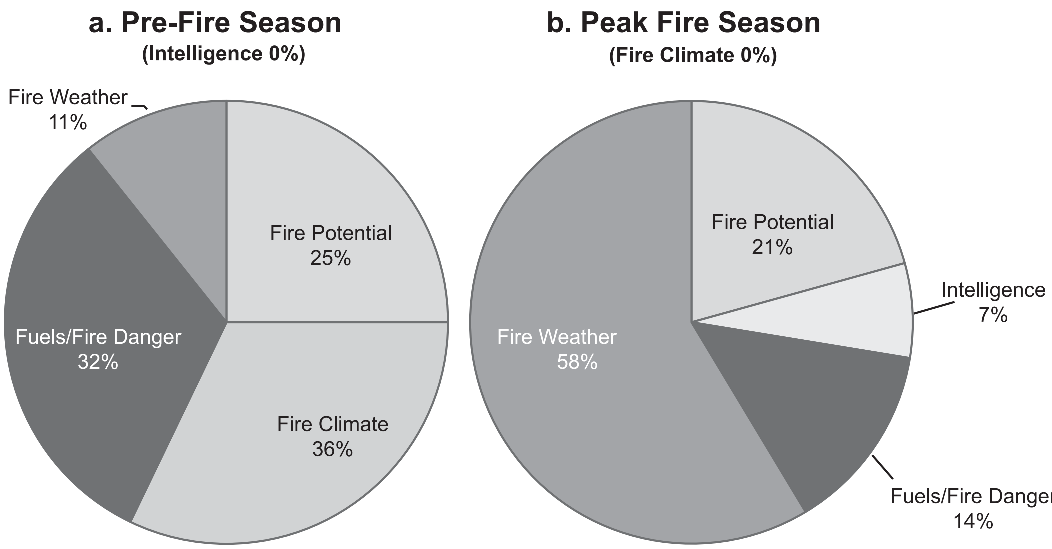

FIG. 1. (a) During the prefire season, fire climate and fuels/fire danger information are the most useful types of information. Intelligence information has less relevance during this period, when fire managers are typically planning for the upcoming season. (b) During the peak fire season, fire weather is the most useful type of information. Fire climate information is less useful during this period, when fire managers are devoting resources to fire suppression.

In the peak season, 58% of respondents in the Southwest selected fire weather as the most useful category of information (Fig. 1b). Weather forecasts are much more useful in the peak fire season, when decisions made are short term and often immediate. As one fire manager in New Mexico said in his interview, ''Weather is the best information on current conditions for staffing or determining allocation of resources. It gives us the next six to twelve hours with a high level of accuracy.''

c. Trustworthy sources of information: People versus products

Our results also suggest that some respondents consider particular categories of fire management information more trustworthy when communicated and discussed person to person, rather than gleaned from a product. Fire managers have access to a tremendous range of forecasts and real-time information, particularly as various federal agencies consolidate this information on official websites. However, few fire managers may be able to devote the necessary time to synthesize, analyze, and take action based on the vast range of services and forecasts available. Our results indicate that many fire managers throughout the Southwest have grown to trust the analyses of Predictive Services personnel regarding forecasts and real-time information.

Participants were asked to name their three most trustworthy sources of information for each of the five categories and were told that their sources could either be products (such as a decision support tool, online data websites, or a written synthesis of information) or people (such as a particular person or a group of people). For some categories, particularly climate and fire potential, significantly higher percentages of participants named people as preferred sources rather than products.[1] For example, fire potential had the highest percentage of people identified as trusted sources of information (36%), followed by climate (26%), while general intelligence information had the lowest percentage of people identified (11%). This result suggests that person-to-person communication plays a more significant role in the dissemination of fire potential information than for intelligence information.

Additionally, survey data imply that the role of person-to-person communication varies throughout the fire year. In the prefire season, person-to-person communication plays a larger role than in the peak fire season.[2] Participants were asked to identify one preferred source of information for the prefire season and one for the peak fire season. We left the meaning of ''source'' open to interpretation of study participants. We wanted them to

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[1] Using a Pearson's chi-square test, we found a statistically significant difference between the ratios of people to products named as trustworthy information sources across the five categories of information, at the 95% confidence level.

[2] Using a Pearson's chi-square test, we found a statistically significant relationship between the source of information (a person vs a product) and the seasonal timing (preseason vs peak season), at the 95% confidence level.

feel free to mention a wide range of sources, including products, such as a website, raw data, or a decision support tool, or people, such as a supervisor, scientist, or colleague. In the peak season, the information most useful to fire managers are short-term weather forecasts, daily changes in fuel conditions, and information on where local and regional resources are being used. This information is best relayed in clear and direct reports so that managers can quickly mobilize resources. Interviewees selected a higher percentage of people as sources in the prefire season (38%) than in the peak fire season (7%). The information used during the prefire season generally includes climate, fuels, and seasonal fire potential forecasts, which contain high levels of uncertainty. Interpreting and applying this information can be difficult, and many fire management professionals perceive a benefit from discussing this information, rather than only receiving data and interpreting it themselves. Information used in the peak fire season includes more weather and intelligence data, which may be more readily available via a product or website.

Over half (52%) of study respondents in the Southwest identified regional Predictive Services meteorologists among their most trustworthy sources of information. In addition to being sources for climate, weather, intelligence, and fuels information, these individuals help produce the fire potential outlooks, which incorporate information from other categories. Follow-up interviews with regional Predictive Services personnel revealed that the meteorologists strategically developed interpersonal relationships with fire management professionals in their region to ensure that their clients felt comfortable asking them questions and discussing the different types of available information: ''When we first started this job, we didn't know exactly what we were doing [because the position and approach were new], so we focused on maintaining and building relationships with people.''

The meteorologists' focus on building relationships targeted existing skepticism over the predictive capabilities in weather and climate forecasting. The same meteorologist quoted above commented that when Predictive Services first began issuing seasonal forecasts, fire managers at meetings where seasonal forecasts were presented, literally laughed at the concept but later grew to implement such forecasts in their own preseason planning.

d. *The centrality of Predictive Services and fire meteorologists*

The social network analysis confirms interview data that Predictive Services meteorologists occupy vital

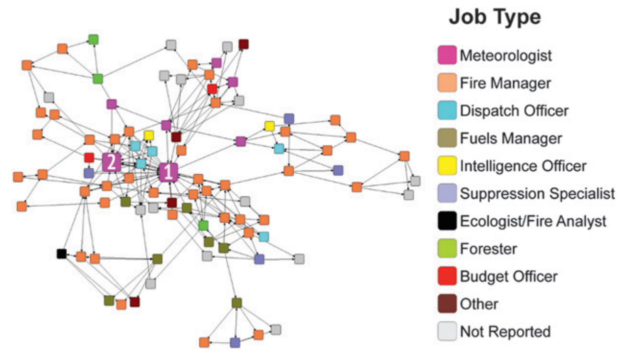

FIG. 2. The network of fire management professionals who participated in the SNA, color coded by job type. Note the central positions of the Predictive Services meteorologists—the most frequently cited contacts in the network—indicated by the two enlarged pink nodes. The node marked ''1'' has a degree centrality of 12.22, and the node marked ''2'' has a degree centrality of 7.69, compared to an average degree centrality of 1.35.

positions in the regional fire management network. Their centrality is visually apparent in the network map (Fig. 2) and verified by their accompanying centrality measures. One meteorologist, marked ''1'' on the network map, had a degree centrality of 12.22, the highest of anyone in the network. The other meteorologist, marked ''2,'' had a degree centrality of 7.69. All others in the network had degree centralities equal to or below 5.43, with an average degree centrality of 1.35. These measures demonstrate that in less than a decade, or since the Predictive Services program began, regional Predictive Services meteorologists have become some of the network's most influential members in terms of information production, distribution, and communication.

An illustrative exercise is to observe the network structure without the two Predictive Services meteorologists, as in Fig. 3a. Removing these individuals helps demonstrate how these key people bridge administrative and geographic boundaries that can be barriers for handling wildfires. The modified network becomes a more clustered, less integrated structure than the full network, largely breaking down into subgroups based on state affiliation. The network with the two Predictive Services meteorologists has a network centrality of 10.97%; without these two individuals, the network centrality drops to 3.41%. This result suggests that there is less of a central hub through which information flows. Though there are still multiple connections between these subgroups without the two Predictive Services meteorologists, such ties must travel greater distances. The central position of these meteorologists is not indicative of the hierarchical structure of the network from an administrative standpoint, but rather indicates

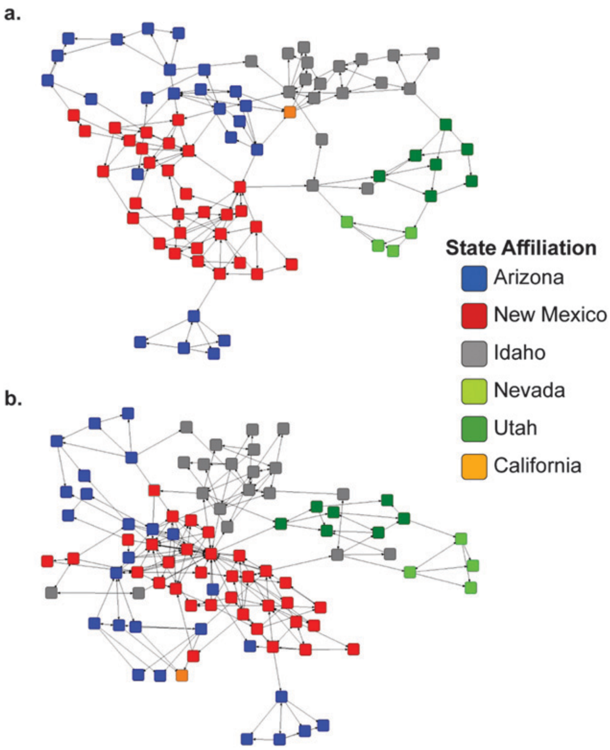

FIG. 3. (a) By hypothetically removing the Predictive Services meteorologists, the overall ''connectivity'' of the network diminishes, and geographic divisions become more pronounced, suggesting the critical communicative role of meteorologists in the network. The network centrality with the two Predictive Services meteorologists is 10.97%. Without these two individuals, the network centrality drops to 3.41%. (b) The network of fire management professionals who participated in the SNA, color coded by state affiliation. While members of the network are somewhat grouped by state, much interaction happens across state boundaries, suggesting that geographic location is not a determining factor in the frequency of interaction between fire management professionals.

preferred sources of information according to the members in the network. The fact that meteorologists occupy central positions in the network suggests an increasing trust on the part of fire managers to make use of climate and fire potential forecasts in their decision-making processes.

A factional network analysis[3] revealed subgroups within the overall network. Subgroups are clusters of individuals who have a high density of connectivity with each other when compared to individuals in the surrounding network. By identifying how the network divides according to demographic similarities or information preferences, the network image provides a good heuristic for targeting where and why certain patterns exist. Our analysis shows that while members in the Southwest network partially reside in subgroups based on geographic state (Fig. 3b), agency affiliation plays a greater role in determining with which individuals a member of the network most frequently interacts. Again, the major linkage between the various subgroups of the Southwest network involves the regional Predictive Services office and meteorologists.

e. Using outlooks for significant fire potential

Fire management professionals in the Southwest use fire potential outlooks on time scales that range from 7 to 90 days. As products designed, produced, and distributed by Predictive Services, they serve as a good case study to better understand how these and other products are used in decision-making processes. In our interviews, we asked participants specifically about the National Seasonal Assessment of significant fire potential for the western states, which is collectively produced by climatologists, meteorologists, fuels analysts, and fire managers during the NSAW.

The seasonal assessment produced at the NSAW is a map accompanied by a report detailing climate, fuels, and weather information for the upcoming fire season, and is updated monthly throughout the season. Some interviewees said they were interested in this background information, while others only wanted the map. For example, an assistant fire manager from New Mexico uses fire potential outlooks because ''they are simple. All I need to know is when the fire season is going to start and how bad it is going to be. I don't need all of these briefings with climate modeling and what's happening with El Niño. I'd rather stick a pencil in my eye - it would be less painful. Just give me the map and tell it to me in 60 seconds.''

Most participants (84%) from the Southwest region said they referenced the seasonal assessment at least once during the 2009 fire season. Participants from this group were asked to define and provide examples of how they used the seasonal assessment. A majority (90%) used the seasonal assessment to communicate or discuss the upcoming season with others, especially with colleagues. Participants mentioned discussing it during conference calls, meetings, and daily briefing sessions. Some participants talk about the product with other Geographic Area Coordination Centers and the National Interagency Coordination Center regarding resource sharing and planning. Two participants also use it as a communication tool for the general public and the media to raise awareness of fire conditions.

A large portion of respondents (76%) said they consult and consider the seasonal assessments. They consult

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[3] A factional network analysis is a tool in UCINET that divides the network into factions, or subgroups.

it as a general planning tool, to have an idea of the current trends and to gear up for the season, which potentially affects the timing or implementation of actions. One participant, a fire management officer in Arizona, said the seasonal outlook "gives an idea of where we're sitting, helps us watch the trends," while another said, "It's really about getting a picture of what the season's going to be like for us." Consulting and considering the seasonal outlooks involves developing a sense for the upcoming season, but respondents indicate that consultation of the product does not always translate into direct action.

Over half of the interviewees in the Southwest (57%) said they incorporate the seasonal assessments into their operations and decision making. Half of these interviewees specifically said they attach them to severity funding requests or to justify funding. When there is high potential for severe fire behavior or fires starting outside the usual fire season, requests can be made for additional suppression resources beyond what is locally and regionally available. Examples include increased firefighting staff, funding for use of aircrafts, and increased fire prevention activities. Participants explained that they also incorporate the seasonal assessment when prepositioning resources and planning prescribed burns. The assessment is generally only incorporated into operations and decision making when the map shows above-average fire potential for the region in question, spurring more action than an average or below-average rating. These types of uses for the seasonal assessment, particularly severity requests, are reflected in surveys of national fire program leaders at NIFC, who use them to make national severity requests and report on fire potential to national leaders in Washington, D.C. (C. A. Kolden et al. 2011, unpublished manuscript).

6. Discussion

Our results help verify the expectation that climate information is more useful during the preseason as fire managers begin planning for the upcoming season. Through frequent communication, fire managers begin to strategize where fires are most likely to occur and how resources may be allocated to where they are needed most. This capability opens up new possibilities for fire managers during the preseason, when activities were previously limited to activities such as training, budgeting, equipment maintenance, or furloughs. However, because there currently are institutional limits on how much preseason resource allocation is based on forecasting, fire managers are limited in how they can directly apply seasonal forecasts to management decisions. One exception is that fire managers use these forecasts to request severity dollars to receive additional assistance if they expect above-average fire potential.

Though the current impacts of forecasting tools are difficult to measure, our results suggest that the strengthening of network ties maybe an unforeseen but valuable outcome of incorporating long-term predictive forecasting into fire management. Based on survey and interview responses, seasonal and monthly forecasts appear to encourage fire managers to discuss expectations for the upcoming season by "socializing" the forecasts in their network, which may facilitate cooperation when the fire season actually arrives. When asked *how* fire managers used climate information and seasonal forecasts, and what they did to prepare in the preseason, many used language such as they wanted to develop "a feel," "a sense," or "a picture" of what the approaching fire season would be like. For regional fire managers, it was frequently cited as a talking point in meetings with local fire managers in preparing for the fire season. We believe that a primary function of such information is its role as a topic of frequent discussion among fire managers, which can help open channels for communication that facilitate cross-institutional and geographical cooperation when fires occur. The process by which such networks develop and strengthen, sometimes independent of agency structure or the functional intent of products and forecasts, is important to theoretical questions that would strongly benefit from future studies, in the context of fire management or the use of forecasts and scientific information more generally. Additionally, the utility of long-term forecasts may also lay partly in their ability to help fire managers mentally prepare for the approaching fire season, a time that likely encompasses a high degree of anxiety over the potential for disaster mitigation.

The Southwest Predictive Services meteorologists' emphasis on frequent, personal communication plays a central role in the socialization of forecasting information and the mental preparation of fire managers in the preseason. Communication may have important implications for the application of climate science in other fields of disaster mitigation. The complex and probabilistic nature of climate-based forecasting becomes more accessible to users when delivered by trusted experts who can explain and interpret forecasts. In the peak season, their role translates into direct decision-making support based on their interpretation of unfolding conditions they closely monitor during the preseason. A Predictive Services meteorologist explains, "It really seems like people in the field want the answers as to what to do. They want the supporting information, the numbers and the tables and so forth, but in the end they want to develop a relationship with somebody . . . They want a combination of the better science . . . and the communication with people that they've built relationships with to pull it all together to make decisions.''

The use of social network analysis in this study helps demonstrate how particular individuals in the network have helped spread climate information among wildfire managers in the Southwest. Similar studies that incorporate interview data into a social network analysis of fire managers in other parts of the country may reveal important differences in individual preferences, network structure, and diffusion of information. Comparisons to other regional networks would help us understand if the critical role that meteorologists play in the Southwest is representative of meteorologists in other regions as well. In the Southwest network's central cluster—those with direct ties to the two central nodes—information preferences were similar to the preferences of the entire network, indicating the information is well communicated throughout the network. However, a subgroup in a state outside the Southwest reported less favorable perceptions of the use of climate data in the peak season, and the usefulness of information in the preseason more generally, showing a greater skepticism of the effectiveness of forecasting on longer time frames. A possible explanation is that communication channels for the diffusion of information and forecasts have not been fully established in this region. Another possibility is that climate patterns, such as ENSO, have stronger impacts in some regions than others, and climate forecasts may simply not be as useful where impacts are weak. A more thorough network analysis and set of interviews for that region would be required to test these hypotheses.

7. Conclusions

There are many benefits to proactive wildfire management strategies that incorporate climate forecasts. Preventative measures go a long way toward protecting environments, human lives, and economies. Weather information provides short-term forecasts that are useful for short-term planning; climate information provides longer-term outlooks that can be useful for long-term planning. However, because of the probabilities and uncertainty inherent in climate outlooks, it has taken time to translate these outlooks into useful tools for fire management.

As capabilities for predicting climate trends and accompanying impacts have grown stronger, fire managers have adopted more products and information that integrate climate science and fire potential. The role of interpersonal networks looms large in the distribution of climate information among fire managers in the Southwest. The hub of this network is a pair of regional Predictive Services meteorologists, as demonstrated by the social network analysis and the data collected in surveys and interviews.

A sizeable amount of information pertaining to fire management is currently produced by various sources. Predictive Services personnel synthesize much of this information but also weed out information that may not be useful. Fire managers in the Southwest who rely on Predictive Services meteorologists for information generally have a high level of trust in these individuals. One way this trust is built is through consistent communication and interpersonal relationships. Climate and fire potential information do not replace other types of information, but rather add to a growing suite of information designed to encourage more proactive wildfire management and planning. The increasing ability of fire managers to make use of the preseason to plan strategically for the fire season is directly related to the improvement of fire-specific forecasts, which are dependent on advances in climate science.

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