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Beyond wildfire: perspectives of climate, managed fire and policy in the USA

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Abstract. Climate–wildfire relationships have been widely addressed by the scientific community over the last two decades; however, the role of climate in managed fire in the US (i.e. prescribed fire and wildland fire use) has not yet been addressed. We hypothesised that if climate is an important component of managed fire, the fire community would already be aware of this and using climate information in order to mitigate risks associated with managed fires. We conducted 223 surveys with fire managers to ascertain how climate information is utilised in managed-fire decision-making. We found that wildland fire use managers consider climate to be an important aspect of managed fire and use various types of climate information, but prescribed-fire managers do not generally consider climate or use climate information in their planning activities. Survey responses also indicate a lack of agency training on climate information and decision-support tools. This is partly attributed to obstacles in US fire policy that inhibit widespread utilisation of climate information. We suggest these results are indicative of a broader conflict in US wildfire policy, which does not directly address climate despite two decades of scientific research showing climate plays a key role in wildfire regimes.

Additional keywords: fire risk, prescribed fire, wildland fire use.

Introduction

Although climate has always been an underlying factor in wildland fire management, only recently has it been recognised as more prominent. Advances in the understanding of climate change and societal impacts have been a primary driver of this recognition, starting with studies that attempt to resolve links between climate and wildfire. In many cases, these studies are providing quantitative evidence of what fire suppression personnel are seeing on the ground – changes in fire severity and regimes that are at least partly related to drier and warmer climate conditions. Further, efforts by Predictive Services in the US relate both historical and forecast climate conditions into integrated seasonal assessments and predictive efforts providing climate-related decision-support tools to improve firefighter safety, mitigate fire risk to communities and reduce overall costs for wildfire suppression (Beck *et al*. 2002; Crawford *et al*. 2006; Ochoa *et al*. 2008).

These efforts to integrate climate information are primarily the result of two decades of research efforts that reveal climate as a driver of dynamic wildfire regimes in the western US (e.g. Swetnam and Betancourt 1990; Westerling *et al*. 2003; Millar *et al*. 2007). However, efforts to integrate climate information in the US have been concentrated primarily in the fire-suppression realm, where climate information is used to prioritise suppression resources (i.e. the Preparedness Level system employed by the National Interagency Coordination Center (NICC)), mobilise firefighting equipment proactively, and reduce firefighter injuries and fatalities by increasing situational awareness (USFS 2003). For example, following the tragic Thirtymile Fire in 2001, the US Forest Service (USFS) began requiring that all fire supervisors be supplied with Fire Danger Pocket Cards that identify current climatic conditions in the context of local historical thresholds of fire danger, and that all firefighters receive training on the use and interpretation of this information (USFS 2003).

Climate impacts on wildfire have been widely addressed in the US because it is recognised that understanding climate–wildfire relationships allows the fire management community to mitigate risks. In stark contrast, climate impacts on prescribed and wildland fire use (WFU) fires (hereafter collectively referred to as *managed fire*) have not been addressed, despite the need to mitigate many of the same inherent risks. Over the last decade, an annual average of 950 000 ha have burned under managed fire in the US, nearly 40% of the total annual area burned by wildfire (http://www.nifc.gov/fire_info/fire_stats.htm, accessed 11 March 2010). Given the increasing numbers of managed fires each year, it is logical to assume that if understanding climate–wildfire relationships helps to mitigate wildfire risks, then understanding climate-managed fire relationships should help to mitigate managed fire risks and better meet management objectives.

Our initial objective was to address climate-managed fire relationships in order to develop tools for mitigating the risks associated with managed fires. The idea was to quantitatively analyse climate data in conjunction with prescribed fire and WFU records. We quickly determined that because these data have only been collected uniformly in the US since 1998 (http://www.nifc.gov/fire_info/fire_stats.htm), this

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approach would not yield significant results. However, as managed fire occurs only after a detailed decision-making process, we reasoned that we could determine how climate is related to managed fire simply by asking the land managers who rely on their experience, training and a host of ancillary information sources to plan and implement these fires. Specifically, we hypothesised that if climate impacts managed fires, the individuals who plan and execute these fires would not only perceive and understand climate impacts, they would be using a variety of climate information sources in decision-making processes to mitigate fire risks.

Climate information and risk management

As an objective is to address to what extent climate information is being used by managed fire programs, it is critical to briefly highlight how risk is being defined in this study, and what climate information we are referring to. Risk is an exceptionally value-laden term; there are numerous different types of risk associated with wildfires, such as the risk of occurrence, rapid expansion, high consumption levels, property loss and many more that have been widely reviewed (Chuvieco 2003; Preisler *et al*. 2004; Schoennagel *et al*. 2004; Hardy 2005; Lentile *et al*. 2006). However, risks in managed fire have not been as commonly addressed. In the scientific community, a wildfire that is of record size or severity, or that results in fatalities, is often the subject of numerous post-fire research studies that characterise the meteorological, climatological, biological and human conditions that affected the outcome of the fire. By examining these conditions, researchers are able to define thresholds of risk for potential future events. Few similar studies exist with regard to prescribed fires. For example, a comparison of literature related to the 2002 Hayman wildfire in Colorado, US, and the 2000 Cerro Grande escaped prescribed fire in New Mexico, US, yields over twice as many published studies on the former (Graham 2003), despite the substantially greater amount of personal property lost in the latter event (National Interagency Fire Center 2000). Other recent US escaped prescribed fires yield no results at all in the scientific literature. Virtually non-existent are papers that directly address the role of climate on meeting prescribed fire or WFU management objectives.

For the purposes of this study, we define the greatest risk to the managed fire community as a managed fire becoming an escaped or uncontrolled fire that must be suppressed (the second primary risk is not meeting the original management objective, e.g. hazardous fuel reduction, invasive species eradication, wildlife habitat maintenance). When a managed fire escapes control, the best-case scenario is that it is easily suppressed, with minimal additional costs. The worst-case scenario can include negative publicity for the fire agency, air-quality violations and fines, enormous additional costs for suppression, loss of public or private property, or fatalities (Brunson and Evans 2005). The negative consequences of an escaped burn usually outweigh any benefits that might have been gained in achieving some of the original intended management objective.

Our definition of risk as the potential for an escaped fire also stems from the myriad safety precautions that fire managers are required to comply with before initiating a prescribed fire. For example, all prescribed burn bosses in the US federal land-management agencies have a 'Go–No Go' checklist that they must complete before igniting a prescribed fire, such as details of the firefighting resources that must be on hand, the spot weather forecast that must be obtained, and the air quality and other authorities that must be notified (USDI 2003). By completing this checklist, the boss in charge of the burn hopes to mitigate the risks of an escaped fire along the entire spectrum from best case to worst case.

The second definition we must address is climate, and what constitutes climate information. Weather is more easily conceptualised by high-frequency atmospheric conditions on timescales ranging from instantaneous observations to generally less than 1 week in length. Climate, in contrast, represents lower-frequency atmospheric conditions that operate on monthly to decadal timescales. In this study, we use the term climate to describe not only the historical atmospheric conditions (e.g. the 30-year climatological normal defined by the National Oceanic and Atmospheric Administration), but also climate variability that represents deviations from the historical climatology. Whereas the former defines fire regime characteristics (e.g. mean length of the fire season), the latter plays a strong role in enabling dramatic fluctuations in interannual wildfire activity. Climate teleconnections describe patterns that are connected temporally and spatially by a global-scale process, such as the El Niño–Southern Oscillation (ENSO), a teleconnection that has been frequently cited as impacting on wildfire regimes in the US (Swetnam and Betancourt 1990; Brenner 1991; Westerling and Swetnam 2003).

Examples of climate information that can inform fire management decisions include simple descriptions of climate averages and departures from normal (e.g. temperature and precipitation anomalies). Value-added indices are also used that incorporate climate information to highlight drought or pluvial conditions (e.g. Palmer Drought Severity Index (PDSI); Keetch–Byram Drought Index (KBDI); Standardized Precipitation Index (SPI)), and others are fire-specific by indicating fire potential and danger (e.g. National Fire Danger Rating System (NFDRS); National Fuel Moisture Database (see http://72.32.186.224/nfmd/public/index.php, accessed 11 March 2010)). Predictive information, such as US seasonal outlooks of temperature and precipitation and the National Wildland Significant Fire Potential Outlooks (see http://www.nifc.gov/nicc/predictive/outlooks/outlooks.htm, accessed 11 March 2010), is also now used extensively.

Survey development and methods

We conducted two surveys in three phases to assess whether climate is perceived to impact managed fire, and if so, how and what climate information is being utilised in managed fire planning and implementation. Our first survey addressed the prescribed fire community, initially for California and Nevada (95 respondents), and in a second phase, the remainder of the US (97 additional respondents), for a total response pool of 192 fire managers from the five major US land management agencies, as well as state and local municipal agencies. The second survey asked 31 WFU managers about climate information specifically

Table 1. Comparison of prescribed-fire and wildland fire use (WFU) survey respondents who agreed with statement, utilised information sources, or noted obstacles to use of managed fire
WFU respondents were not asked about finding climate information

	Prescribed fire	WFU
Climate has an impact on managed fire program	75%	97%
Use of weather information		
Remote Automated Weather Stations	93%	100%
National Weather Service	93%	100%
Use of climate information		
Use more than 1-year historical data	19%	95%
Monitor large fuel moisture	52%	72%
Use Predictive Services	46%	100%
Keetch–Byram Drought Index	33%	71%
Palmer Drought Severity Index	28%	77%
US Drought Monitor	19%	74%
Obstacles		
It is easy to find climate information	53%	–
Funding	75%	3%
Permits (e.g. National Environmental Policy Act or Air quality)	50%	19%
Internal or public acceptance of managed fire	32%	52%

for WFU events. The surveys consisted of both closed and open-ended questions inquiring about objectives for managed fire, uses of specific types of climate information, obstacles both to using climate information and to utilising prescribed fire, and WFU as a management tool.

To develop survey questions, we relied on four primary sources of information. First, we reviewed US fire policy documents, such as the Prescribed Fire Handbook and the National Fire Plan, to determine what information requirements and terminology were pertinent to our hypothesis. Second, we reviewed the decision-support tools and products available on the internet through NICC and its affiliates: the Geographic Area Coordination Centers (http://gacc.nifc.gov/), the Predictive Services group (http://www.nifc.gov/nicc/predictive/predictive.htm) and the USFS Wildland Fire Assessment System (http://www.wfas.net/) (all websites last accessed 11 March 2010). Third, we relied on agency reports for escaped prescribed fires, such as the Cerro Grande Report (National Interagency Fire Center 2000) and the Lowden Ranch Report (USDI 1999). Finally, we conducted informal pre-surveys with 22 experienced fire managers to help us better understand the decision-making process, and shape the wording of the final survey questions.

We synthesised these four sources of information to develop the final prescribed fire survey, and then revised some of the questions for the WFU survey. In general, our synthesis revealed that there are no policies requiring fire managers to utilise any specific or published sources of climate information, so we developed our questions based on all of the primary products we knew were widely available, mentioned somewhere in fire training handbooks, or utilised for decision-making in wildland fire suppression. The questions fell generally into five primary categories: (1) information used for planning managed fires; (2) information used to implement managed fires; (3) whether climate is perceived to impact managed fire; (4) obstacles to using climate information; and (5) climate training and education. The full methods and results of these surveys are detailed in Kolden and Brown (2008); results of selected survey questions pertinent to our overall objective are given below in the context of climate and fire risk.

Survey results and discussion

Survey respondents indicated that, overall, climate information is not widely used in the planning and implementation of prescribed fire, but is used much more extensively in the implementation of WFU (Table 1). Although more than 90% of the prescribed-fire respondents indicated that they utilise information describing weather, such as data from Remote Automated Weather Stations (RAWS) and spot forecasts from the National Weather Service (NWS), only one-quarter to one-half use information and indices (e.g. drought, historical analogues, climate forecasts) that track climatology and departures from normal. Over 80% of the prescribed-fire respondents analyse less than a year of historical data from RAWS, indicating that they are not contextualising observations with respect to historical conditions, and hence not directly realising departures from normal or extreme meteorological events (e.g. a record dry period). Additionally, less than half of the prescribed-fire respondents monitor large (1000-h) dead and live fuel moistures, which are indicators of vegetation stress and availability to burn, and are linked to climate through equilibrium fuel moisture content.

In contrast to prescribed-fire respondents, WFU respondents widely utilise information and indices that track climate conditions. Over 95% of the respondents utilise historical data, seasonal outlooks from Predictive Services (100%), the KBDI (71%) and the PDSI (77%), along with other climate information resources that are used to varying extents (Fig. 1). WFU respondents sample large dead and live fuel moistures at a higher rate (72%) than prescribed-fire respondents (52%).

Although there are discrete differences between how prescribed-fire and WFU managers utilise climate information, both groups indicated that climate impacts on their managed fire programs. Climate information is important for 97% of the WFU respondents, who indicated that long-term, climatological conditions affect their ability to plan and implement WFU. This

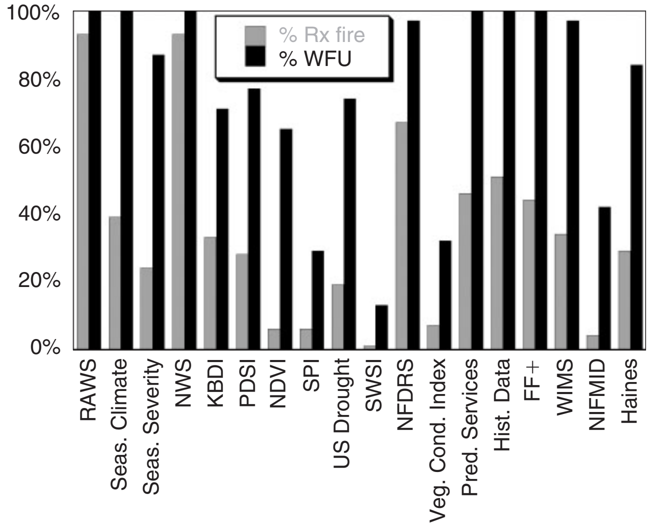

Fig. 1. Use levels for a variety of indices and tools for both prescribed-fire (Rx) (grey) and WFU (wildland fire use) (black) respondents suggest greater use rates in WFU management, particularly for long-term climate trend trackers. Indices include: Remote Automated Weather Stations (RAWS), Seasonal Climate Forecasts, Seasonal Severity Outlooks, National Weather Service (NWS) forecasts, Keetch–Byram Drought Index (KBDI), Palmer Drought Severity Index (PDSI), Normalized Differenced Vegetation Index (NDVI), Standardized Precipitation Index (SPI), US Drought Monitor, Surface Water Supply Index (SWSI), National Fire Danger Rating System (NFDRS), Vegetation Condition Index, Predictive Services, historical data, FireFamily Plus (FF+), Weather Information Management System (WIMS), National Integrated Fire Management Integrated Database (NIFMID), and Haines Index. (From Kolden and Brown 2008.)

is particularly the case when determining the *size* of the Maximum Manageable Area (a polygon defining the maximum area that a WFU fire is allowed to burn, beyond which it will be suppressed), and the *potential* for the fire to reach that size (87% of the WFU respondents). Whereas only 30% of the prescribed-fire respondents were certain that climate trends have a significant impact on their use of prescribed fire, 45% of the respondents indicated that climate has some sort of impact, with the remaining 25% indicating that climate does not significantly affect their program, or that they were not sure if it does. The results for this question highlight a contrast among prescribed-fire managers: they perceive that climate impacts on prescribed fire, but they do not generally utilise climate information. For example, over 50% of the respondents recognised drought conditions having a negative impact on their ability to complete prescribed burns, but less than 30% use drought indices in the planning and implementation of prescribed fires.

One explanation for this apparent incongruity lies with the number of obstacles that prescribed-fire managers face in incorporating climate information. Respondents gave several reasons they do not use climate information, including a lack of availability, and conflicting agency directives that preclude its use for prescribed fire planning and implementation. Over half of the prescribed-fire respondents (53%) said it was relatively easy to obtain climate information, while an additional 23% said it was moderately difficult. A total of 6% indicated it was regularly difficult to find the information they sought, but 18% said they do not know how difficult it is because they do not use climate information in prescribed burn planning and decision-making. Many respondents indicated via open-response questions that they often have difficulty finding climate information in the spring and autumn seasons when they are burning because they perceive that Predictive Services is not staffed outside the wildfire season. As the Predictive Services units are staffed year-round, but certain products may only be published and circulated during the wildfire season, this may indicate a communication problem between the prescribed burning community in the US and Predictive Services. Monthly and seasonal outlooks are updated every month, but products that depend on RAWS data will not be available if the station is not year-round.

Over 75% of the prescribed-fire respondents indicated that they are limited by their funding and the agency directive to treat a specific number of hectares each fiscal year (Fig. 2), and thus have no flexibility to deal with the interannual variability of climatically optimum burning conditions, defined as 'burn windows'. Half of the respondents stated that they are hampered by permitting processes (e.g. the National Environmental Policy Act (NEPA); air district burn permits; state burn permits), which strictly regulate when they can use prescribed fire no matter what the climate conditions are. This means that a longer-than-normal 'burn window' in a given year may be underutilised because of permitting obstacles, or that prescribed fire may be implemented under less favourable and riskier climatic conditions (such as drought) because of the funding deadlines and permit limitations. Other obstacles cited by prescribed-fire managers included lack of support from within the agency, and a lack of qualified personnel, or air-quality restrictions at times when burn windows occur. Air-quality issues were widely noted by prescribed-fire respondents as problematic. For example, acceptable conditions from an air-quality standpoint, such as sufficient wind to disperse smoke and haze, can be unacceptable conditions from a prescribed fire standpoint if the same dispersion winds produce unpredictable and potentially uncontrollable fire behaviour. Similarly, on-the-ground burning conditions might be good, but wind conditions may limit smoke dispersion, and hence air-quality regulatory exceedances are incurred. Specifically, many prescribed fires are low-intensity burns, which can be problematic for air-quality restrictions in that insufficient smoke transport can be produced by night-time inversions that may trap the smoke at lower elevations and in valleys.

In contrast to prescribed-fire managers, WFU respondents enjoyed far greater support for fire use, in terms of both information availability and fewer obstacles. Although the US federal agency prescribed fire handbooks do not specify the use of climate information in implementing a prescribed burn, the Wildland Fire Implementation Plan (WFIP) Stage 3 (National Interagency Fire Center 2005) requires WFU managers to determine the potential duration and extent of a WFU incident through an assessment of conditions compared with normal. WFU respondents are able to obtain information more easily because WFU events generally occur during wildfire season, and resources are more widely available. Unlike the funding-driven objectives of prescribed-fire respondents, 52% of the WFU respondents indicated that local acceptance of WFU as a fire-management tool has the greatest impact on their ability to initiate WFU. Thirty-five percent indicated that the timing of

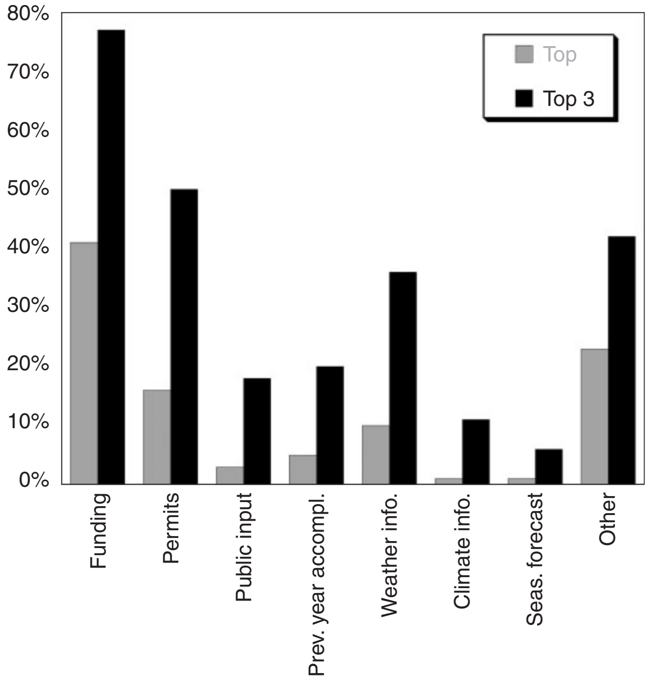

Fig. 2. Percentage of respondents indicating each factor was the top (grey) or one of the top three (black) influences on their prescribed fire long-term (annual or greater) planning. (From Kolden and Brown 2008.)

the ignition (i.e. what fire severity is currently being experienced, and what percentage of the fire season is already past) was the most critical component. Severity is related to climate largely through vegetation stress, and can readily be assessed by fuel moisture and on-the-ground observations.

The season length is also related to climate anomalies. Both severity and season length can be assessed by the use of climate information to determine the potential for a longer- or shorter-duration fire event, which helps to explain why climate information is more widely utilised by WFU respondents. To determine the potential duration of a new WFU event, respondents use a variety of indices and information to describe three aspects of the new ignition in the context of climate: timing of the ignition, seasonal severity level and drought level (Fig. 3).

Overall, the survey results indicated three primary factors related to the use of climate information for prescribed fire and WFU. First, prescribed-fire respondents report low use rates of climate information in the planning and implementation of prescribed fire, whereas WFU respondents report high rates of use. Second, for many prescribed-fire managers that recognise climate significantly impacts their managed fire program, some indicate a lack of convenient availability during the primary prescribed-fire seasons (autumn and spring), but most indicate a range of policy-related obstacles that force prescribed-fire managers to attempt managed fires during marginal burn windows, and preclude prescribed burns during optimal burn windows when risk of an escape is lowest.

Finally, the survey results reveal the importance of making climate information directly relevant to the planning and implementation process in order to ensure that fire managers seek it out. We asked prescribed-fire (but not WFU) respondents whether they had taken any sort of course or advanced training that covered climatology, and whether they felt they had received adequate climate education in their agency training courses. Only 32% of the respondents had any in-depth training or education in climatology, but half of the respondents (50%) felt they received adequate climate education in their agency training courses. As many prescribed-fire respondents feel the training they receive is adequate, but in fact they do not actually receive any training, this indicates that they feel they do not need it (which many stated through free response during the survey). For fire managers, this also indicates a critical gap between a feeling that climate significantly impacts managed fire, which many respondents have (especially those representing WFU), and understanding exactly what those impacts are, and more importantly, how they manifest as fire risk and what information can be utilised to mitigate that risk.

The climate gap: science and policy

In addressing the reason a gap exists, and why climate information is apparently so poorly integrated into managed-fire programs in the US, we return to the logic of our original hypothesis. In the introduction to this study, we briefly highlighted scientific literature that has explored the links between climate and wildfire. We hypothesised that the relationships found between climate and wildfire would translate to a perception among fire managers that climate influences managed fire as well, and that they would be utilising climate information for managed fire. We made two key assumptions associated with this hypothesis, which we further examine here.

First, we assumed that a relationship exists between managed fire and climate, but that fire data were inadequate to show significant links. We based this assumption on an occasional mention of the role of climate anomalies in escaped fires in the agency reports that investigate these events. For example, the report for the 2000 Cerro Grande Fire in Los Alamos, New Mexico, indicated that (among many other compounding factors) drought indices would have been helpful in identifying the degree of risk associated with the prescribed fire that subsequently escaped (National Interagency Fire Center 2000), but fire managers are not trained to use these indices even when they are readily available.

We also based this assumption on the results of a preliminary test of Brown and Betancourt's (1999) hypothesis suggesting favourable conditions for prescribed burning windows could be forecast months in advance if the relationships between burn windows and climate indices were found. We conducted an analysis of all California managed fires reported in the federal fire occurrence database from 1972 to 2002. This analysis showed that in northern and central California, 75% of managed fires have occurred when the PDSI normalised value was -1.0 or larger (Fig. 4*a*). A total of 94% of managed fires occurred above a Multivariate ENSO Index (MEI) normalised value of zero or larger (Fig. 4*b*). (Note that the federal fire database does not distinguish managed fires before 1998.) These results suggest that fire managers are making decisions to ignite (for prescribed fire) or manage (for WFU) fires under the local conditions associated with those climate signals (both regional and global). For

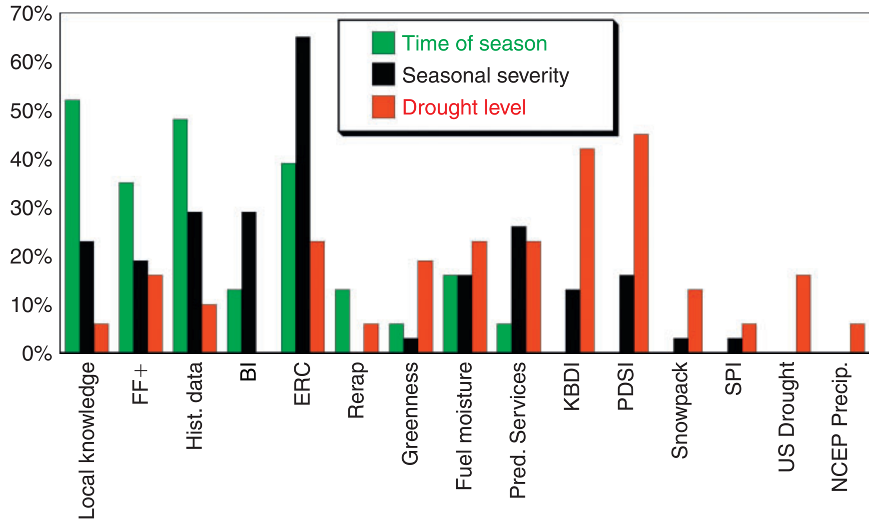

Fig. 3. Percentage of respondents who utilise each source of information to determine time of season (grey), seasonal severity (white), and drought level or seasonal severity (black) for Stage III of the Wildland Fire Implementation Plan (WFIP). Information sources include local knowledge, FireFamily Plus (FF+), historical data, Burning Index (BI), Energy Release Component (ERC), Rare Event Risk Assessment Process (Rerap), remotely sensed greenness index, fuel moisture measurements, Predictive Services, Keetch–Byram Drought Index (KBDI), Palmer Drought Severity Index (PDSI), snowpack measurements, Standardized Precipitation Index (SPI), US Drought Monitor, and the National Centers for Environmental Prediction precipitation forecasts (NCEP Precip). (From Kolden and Brown 2008.)

example, most burns are done during normal or wetter conditions (when the PDSI for a given climate division is near zero or positive) rather than drier conditions. The ENSO result implies that all of these managed fires took place in tropical Pacific neutral or El Niño conditions.

In the context of risk, one might conclude that all fires should take place in normal to wet conditions to reduce the risk of escape. This type of result is of interest because (1) it indicates the underlying climate conditions under which managed fires are taking place, and (2) it begins to quantify the risk of managed fire (i.e. wetter conditions are less conducive to rapid spread, high-severity burning and perimeter escape). If these are the optimal conditions for managed fires in northern and central California, what might then explain the 25% of fires that took place under drought conditions?

Several factors are possible, and to begin with, one must know the management objective of the fire. For example, certain invasive vegetation types such as yellow star thistle (*Centaurea solstitialis*) require drier spring conditions after a winter burn to meet an eradication objective (Rusmore 1995). In other cases, local wetting from recent weather may have brought the prescription levels to satisfactory even though there was an underlying drought (similar to the case of Cerro Grande). It is indeed possible that many of these fires were at elevated levels of escape risk, but fortunately, no negative outcome occurred. For other cases, it is possible that the PDSI value was not truly representative of the local conditions. PDSI is currently calculated as area values, and in the western US, these areas can be quite large, with widely separated observations.

Finally, the lack of a national standardised database of managed fires makes it difficult to analyse these fire types with higher precision and study managed fires in a historical context in relation to climate and climate change; thus some fires may be simply misclassified. As the managed fire database is temporally limited, the short time period (1998–present) inhibits longer-term analyses. This is unfortunate because while suppression policy took precedence over managed fires for much of the US (especially the policy dominating the West) since the early 1900s, managed fires did begin their western comeback by the 1970s (while persisting in the south-eastern US throughout the century) so that the number of managed fires began to increase with time, though it is difficult to quantify events and relate them to climate. One of the primary interests in managed fires over time is their relationship to changing climate and climate variability.

The second assumption we made en route to our hypothesis was that a flow of information existed between the scientific community and the policy-makers that would allow US federal fire policy to respond and adapt to new information on climate–fire relationships with objectives and specific actions that target climate impacts on fire. To better illustrate this flow of information and the inherent feedback process with fire management and policymakers, it is useful to briefly review the history of managed fire as an example.

During the first half of the 20th century, US fire-management policy was primarily reactive, stemming from response to large wildfire years in the still largely unsettled western US, such as the great fires of 1910, or the Tillamook fire of 1933 (Stephens and Ruth 2005). Policies such as the USFS '10 a.m.' mandate made suppression of all fires the foremost objective of fire management (Pyne 1982). However, during the 1920s and 1930s, numerous proponents of 'light burning', the precursor of prescribed fire, showed its efficacy not only in the south-eastern

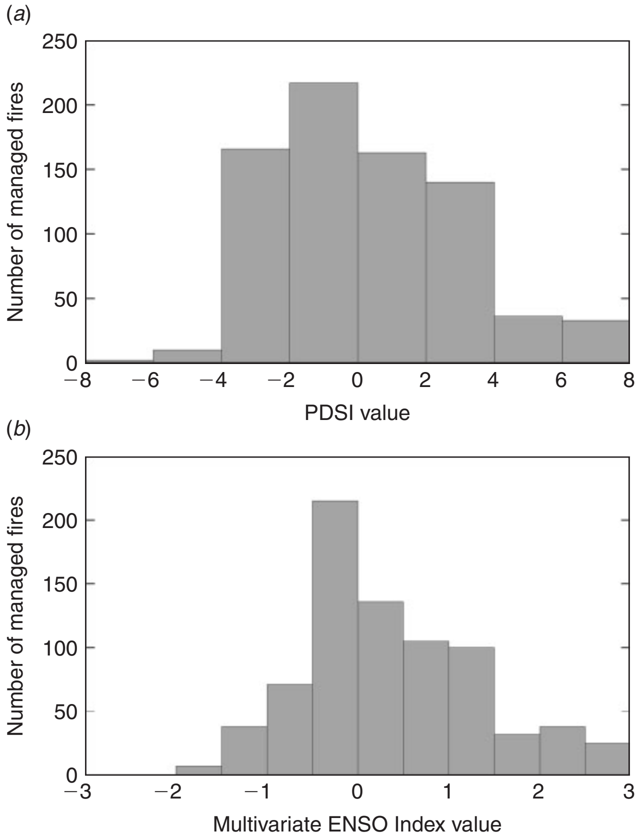

Fig. 4. Associated (*a*) Palmer Drought Severity Index (PDSI); and (*b*) Multivariate El Niño–Southern Oscillation (ENSO) Index values for managed fires occurring in northern California from 1972 to 2002.

US longleaf pine forests, but at selected sites in the western US as well (Pyne 1982). By the 1950s, pioneering science on the use of prescribed fire from Harold Weaver, Harold Biswell and others had begun to document the critical role of fire in ecosystems, and the benefits of prescribed fire specifically (Weaver 1957; Biswell 1977, 1999). Subsequent work by Bruce Kilgore explored the impacts of 'let-burn' (i.e. wildland fire use) fires in California national parks (Kilgore 1973). Findings from the science community slowly trickled into the fire-management community through hands-on workshops, publications aimed at fire managers and the development of decision-support tools (e.g. burning prescriptions). Through an iterative feedback process, these tools and the science supporting them were further refined, and continue to be a work in progress today. US federal fire policy has adopted many of the guidelines for using managed fire, and both the 1995 US Federal Fire Policy and its 2001 update finally specified the need to use managed fire to control hazardous fuels.

The process described in the above example is characterised by three primary components: applied science, technology transfer and policy integration. Most of US fire policy development has been reactionary, particularly as related to suppression. Suppression policy changes for the most part have resulted from key events, usually involving conflagrations or fatalities, though more recently, cost containment and the trend towards an appropriate management response are examples of finance- and resource-driven policy (though this is largely in response to mega-fires and wildland–urban interface events). But the increased use and acceptance of managed fire is largely based on scientific studies, along with on-the-ground recognition that reintroducing fire on the landscape is important to ecosystem health. We knew in developing our hypothesis that there was no scientific literature on climate-managed fire relationships, so we understood that there would be no training, no decision-support tools, no feedback, and no integration into US fire-management policy.

One might assume, however, that because climate–wildfire relationships have been demonstrated by applied scientific research, and subsequent technology transfer has put this information into decision-maker hands via decision-support tools, electronic media and workshops among other sources, there would be more direct integration of climate–wildfire relationships into US federal policy. But in reviewing the current US federal wildfire policy, there is no indication that climate is specifically targeted (National Interagency Fire Center 1995, 2001). Although recognising that large wildfires have become more frequent in the last two decades, US federal fire policy places emphasis squarely on hazardous fuels build-up and an expanding wildland–urban interface as the two primary causes of this trend. Nearly two decades after Swetnam and Betancourt (1990) published their seminal work on fire–climate relationships in the south-western US forests, the current US federal fire policy still has not specifically recognised climate as a critical element in fire management. Because there is no recognition of climate explicitly within the US federal fire policy, it is now evident why our survey results showed a lack of climate information being utilised in managed fire programs: the recognition of climate as a factor in fire management is completely voluntary, and has not occurred cohesively at the national level.

Until goals and actions are explicitly identified in the US federal fire policy to deal with climate impacts on wildfires, it is unlikely that the US fire management community will formally integrate climate information into managed fire. Some examples of how this integration could occur were discussed in our survey: developing long-term fuels treatment goals that allow for interannual variability in meeting prescription windows; developing better tools that predict seasonal potential for burn windows; developing resource sharing agreements between agencies to fully take advantage of regional burn window openings (such as is done in the south-eastern US on an *ad hoc* basis). But these solutions need both fiscal and administrative support, and this support only comes from changes in the federal fire policies.

The US Congress has received numerous testimonies by a host of fire professionals and scientific researchers that not only establish the links between climate and wildfire, but state the absolute necessity of identifying and taking actions to mitigate the hazards posed by climate change for wildfire-driven ecosystems (Morgan *et al*. 2000; Medler 2007; Pellant 2007; Swetnam 2007). Despite this record, the lack of US federal fire policy targeted at dealing with climate impacts indicates that a substantial gap must still be overcome. As noted above, it took many decades to integrate managed fire as a tool in federal fire policy, but given the speed at which climate change is altering forests and fire dynamics, US fire managers are seeking solutions and tools to deal with climate issues much sooner. This requires both a recognition from policy-makers that climate is a key issue for federal fire management, and continued efforts from the scientific community to bridge the gap by developing and testing decision-support tools for the fire community that integrate climate information. This research will be challenging for a variety of reasons, but necessary to progress further towards successfully mitigating the risks of wildfires and escaped managed fires and meeting land-management objectives, as all are associated with climate.

A note on managed fire terminology

While this work describes prescribed fire and WFU as the two primary types of managed fire, we feel it is critical to acknowledge that new policies implemented in 2009 and beyond will likely change the terminology of managed fires, but not the fundamental need to use climate information for decision-making. In 2009, the US fire management community discontinued the WFU designation, and instead now recognises fire ignitions as either planned or unplanned, although a few units (e.g. Yosemite National Park) were still using the WFU designation in 2009. For purposes of this study, we used the WFU label, but we also contend that under the new definitions, the need to make informed decisions on all fires only increases. The new policy will effectively provide US fire managers a range of management options for wildfires, such that all wildfires have the potential to be managed for resource benefits (i.e. a WFU fire), or receive minimal suppression owing to prioritisation of firefighting personnel to other fires, or be fully suppressed, or a combination of all management options as deemed appropriate (e.g. a fire that has 60% of the perimeter fully suppressed, and 40% monitored but not fully suppressed as though it were a WFU incident). To make decisions about appropriate management strategies in a short amount of time, fire managers will need to have a full understanding of climate conditions, and how they contribute to seasonal severity levels, long-term outlooks, potential fire behaviour, smoke impacts, resource availability and the potential for anomalous events outside the historic range of variability. Hence, we maintain our findings about WFU–climate relationships are still applicable to these fires.

Conclusion

Risk mitigation is inherent in wildland fire management, and climate information can be a vital component of mitigating risk for prescribed fire and WFU incidents in the US. Climate information can be utilised to identify numerous conditions that may be conducive to undesirable events such as air-quality violations, firefighter injuries or fatalities, escaped prescribed burns that lead to property loss or not meeting land-management objectives. It can also likely be utilised to forecast prescribed burn windows where risk is low, allowing managers to take advantage of opportunities to utilise prescribed fire and WFU efficiently (mobilisation of resources and better managed costs) and effectively (maximise the benefits). Our survey results indicate that although many of the respondents believe that climate impacts their managed fire programs, it is not widely used for the planning and implementation of prescribed fires, but is used to a greater extent by WFU managers. We also found, however, that there are numerous obstacles to utilising climate information, with most of these obstacles relating to fire policy, permitting, agency objectives and annual targets that must be met by prescribed-fire managers, as well as a lack of climate information available to them.

In 2003, the Association for Fire Ecology (AFE), a US-based professional organisation composed of fire researchers and fire managers, published and subsequently testified before the US Congress on the San Diego Declaration on Climate Change and Fire Management (AFE 2003). This document summarised the major science findings that indicate the role climate plays in wildfire regimes, and specified the ways in which US land managers must react to effectively mitigate the negative impacts of climate change on wildfires. The take-home message from AFE was that US fire policy needs to adapt for climate change, and it must do so rapidly. However, this document is not policy, nor does it identify pathways of how climate should be integrated into planning and policy for managed fire.

Many of the recommendations made by AFE are applicable to the managed fire community as well. The same climate-change trends will undoubtedly alter the timing and extent of both the most favourable and the most hazardous 'burn windows' for implementing managed fire in the US and elsewhere. Climate change will also likely impact on certain management objectives, particularly those related to species conversion, invasive species and hazardous fuel reduction, the latter representing a major amount of agency work. Fire managers will only be able to monitor these windows through utilisation of climate information and indices. Climate information integrated into the planning and implementation of managed fires is a component of the risk-mitigation process, and will become critically important to completing managed fire, particularly under a changing climate.

Despite the urgency of the San Diego Declaration, the countless hours of testimony before the US Congress, and the overwhelming scientific evidence that developing strategies to deal with climate change is critical to the success of US fire management, the US federal fire policy has not yet been updated to reflect this. There is no policy designating that fire managers focus on or even deal with the climate issue, no requirement for training on climate information and wildfire links, no emphasis on developing decision-support tools that could allow fire managers to utilise climate information to mitigate risks, and certainly no indication that climate will play a role in funding policies for wildfire suppression or managed fire programs. This highlights a crucial gap between the applied science showing fire to be a critical factor for fire-management concerns and the US fire policy that actually dictates priorities for federal fire-management programs.

Numerous individuals have provided recommendations on how climate information should be utilised to better manage wildfires in the US, many of which are summarised in the San Diego Declaration (AFE 2003). To conclude, we offer the following specific actions, in no particular order, that we suggest could improve utilisation of climate information in managed fire:

- Recognise climate as an important component of management fire, from the local level up through federal fire policy.

- Include a climate element in the prescribed fire planning process and the Go–No Go checklists used by federal agencies.
- Offer climate training in several fire-management training courses, especially those that are related to management fires. Develop topical climate training courses for fire behaviour analysts, long-term analysts and prescribed burn bosses.
- Predictive Services and collaborators have done some applications work in improving the understanding of climate and prediction for the Geographic Areas. Increase this effort and support it nationally.
- Establish a process to deliver the science from the recent increase in the number of fire–climate studies to fire managers.
- Give consideration to how climate change might impact on the management objective of a managed fire.
- Make national fire policy more flexible, allowing prescribed burning to be more opportunistic given the interannual variability in environmental conditions associated with climate.

In summary, climate information is appropriately considered a decision-support tool, but this does not raise climate to its warranted level of importance given its overall impact on fire business. Climate can be both an inhibitor and enhancer of fire. As such, it is as important to fire risk as any of the other accepted factors such as the wildland–urban interface, fuels conditions and land use.

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