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Integrating values and risk perceptions into a decision support system

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Abstract. One of the thorniest challenges to effective wildland fire management is integration of public perceptions and values into science-based adaptive management. One promising alternative is incorporation of public values into place-based decision support technologies that are accessible to lay citizens as well as to fire-management experts. A survey of individuals, including residents, fire and fuels managers, volunteer firefighters, and others living in or near four mountain areas of the US Southwest, identified a set of personal values and perceptions about wildland fire risk that could be spatially represented in a geographic information science-based decision support system designed for wildland fire strategic planning efforts. We define values, in this context, as phenomena that are not necessarily quantifiable but that strongly attract and connect individuals for whatever reasons to particular areas. Inclusion of this type of information into interactive decision tools for fire management may contribute to improved understanding and finer-scale spatial visualisation of public perceptions of fire risk. The integration of such factors in decision support tools offers opportunities for improving interactions between managers and the public involved in strategic planning processes for fire management.

Additional keywords: geographic information science model, strategic planning, US Southwest.

Introduction

Existing cognitive maps and computer modelling technologies are fairly good at representing the biophysical components of fire hazard, but integration of factors representing public values and perceptions remains underdeveloped. Existing models tend to focus on a relatively narrow range of quantifiable assets such as homes and other structures, and certain socially important ecosystem services such as timber production and watershed functions.

A multi-year research effort, undertaken to develop a new system useful for wildland fire strategic planning, introduced several innovations, one of which was designed to capture a broader range of public values than typically are integrated into modelling frameworks. The resulting decision support system (DSS), entitled Fire–Climate–Society, Version 1 (FCS-1) (Fig. 1), is a web-based prototype model based on geographic information science (GIS) technology. The model is specifically designed to promote interaction among a broad spectrum of individuals ranging from fire and fuels managers to decision makers, policy makers, and other stakeholders, including the general public (Morehouse *et al*. 2006). Consisting of nine components, five representing factors influencing fire probability and four representing the influence of public values that could be threatened by wildfire, the DSS produces information about overall fire risk for four mountain study areas. The study areas include the Catalina–Rincon Mountains adjacent to Tucson, Arizona, the Huachuca Mountains and Chiricahua Mountains in south-eastern Arizona, and the Jemez Mountains near Los Alamos, New Mexico (Fig. 2). The maps produced by FCS-1 provide information at a scale of 1 km^2, the smallest scale at which the underlying climate data can be provided with reasonable scientific robustness.

FCS-1 allows users to explore, based on the specific climate–fuel moisture scenario they have chosen and the relative weights they have assigned to the various model components, the likelihood of a fire of greater than 250 acres occurring somewhere within the selected study area (Morehouse and Orr 2007, p. 206). Assignment of relative weighting (i.e. priorised importance) to the different components occurs when users complete a pairwise comparison process in which they assign a score of zero to nine to each pair of components in the two submodels and an additional score indicating how the two submodels should be weighted relative to each other. Selection of zero indicates that the user considers the indicated pair of components to be equally important; an assignment of nine indicates that the component given this number is exclusively important, relative to the other component in this pairing. Based on Analytic Hierarchy Process (AHP) (Saaty 1991, 2000), this comparison process provides input that the system needs to produce the final-stage output, a

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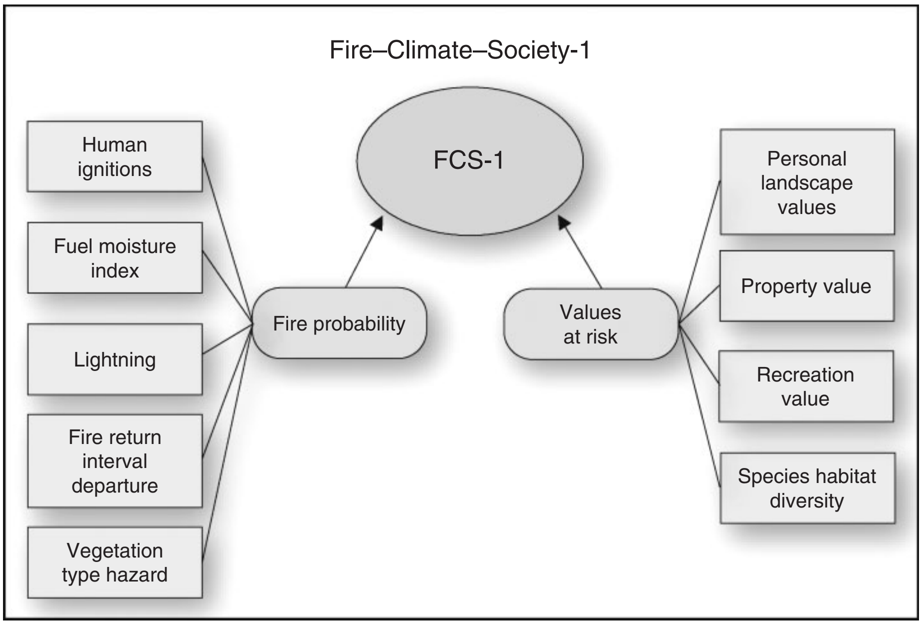

Fig. 1. The Fire–Climate–Society (FCS-1) model.

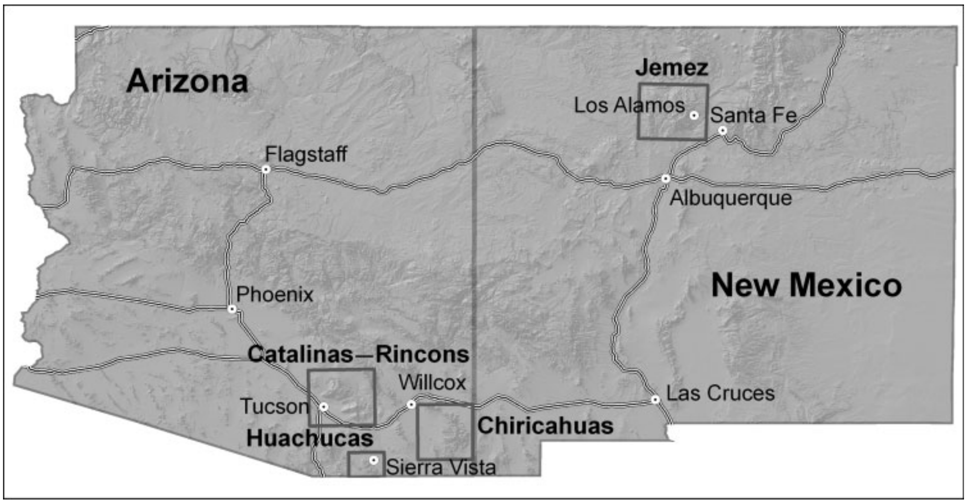

Fig. 2. Map of study areas: Jemez Mountains in New Mexico and the Chiricahua, Huachuca, and Catalina–Rincon Mountains in Arizona.

combined fire risk map of the selected mountain range, detailed to a scale of 1 km^2.

In this paper, we discuss the research process that produced the 'values at risk' component of FCS-1. This process was driven by two research questions: (i) what areas of the mountain landscapes within our study areas do local stakeholders and residents most use and value (even if they don't visit the areas); and (ii) how might we capture this information in a way that can be represented in a GIS-based DSS?

We begin with a brief review of studies focussed on public values and perceptions of risk in the context of wildland fire management. We then describe the methods we used to gather information about these values and risk perceptions from individuals located in the four mountain ranges included in our study. We also explain how we used this information to develop a values at risk component for integration in FCS-1.[A] We follow this with an analysis of the results of our investigation and conclude with a discussion of the value of this

[A]In this study, we define perceptions as individual awareness and personal understanding of the social and ecological dynamics of wildland fire as well as the risks that may accompany these dynamics. (For a review of perception studies of wildland fire, see Daniel 2007.) We define values as the not necessarily quantifiable worth, importance, esteem or utility that individuals accord to phenomena, for whatever reason. In our case, these values contribute to social constructions of wildland fire risk.

approach for other DSS efforts, as well as suggestions for further research.

Background

Wildland fire management continues to meet with some unique challenges, particularly with regard to integrating into planning and decision processes highly subjective perceptions of risk and notions of landscape value held by the public. McCaffrey (2008) observes that risk defies ready definition, and that it is more than a scientific idea: it is also a cultural concept that is shaped by societal and individual values alike. Considerable variability in definitions and perceptions of risk exists within and between scientific and lay-person communities, including the extent to which each sector takes into account risk based on probability of fire occurrence *v.* risk associated with post-fire outcomes. Given the lack of consensus among experts about fire risk, McCaffrey notes,

> 'it is unlikely that laypersons will be any more consistent in their risk assessments. Instead, they tend to use various mental heuristics, such as denial or attributing complete protection to adjustments (such as flood levees) that provide only partial protection' (McCaffrey 2008, p. 13; see also Slovic *et al*. 1987).

Focus group sessions that McCaffrey conducted revealed that the public actually possesses a comprehensive perspective on fire risk, and that those living in fire-prone areas may actually have a lower perception of fire risk than individuals living in less-exposed locations. In part, residents in fire-prone areas may have made a decision – whether consciously or unconsciously – that the benefits of living where they do warrant the risk they take. This paradox, in which increases in public knowledge and awareness do not directly lead residents to engage in risk-reduction activities, is found at both community and individual levels (McCaffrey 2008).

Cohn *et al*. (2008), in a report on a case study, explored the question of where responsibility for risk mitigation should reside. They conducted interviews with community members living in areas that had recently experienced large wildfires. The authors identified a tendency for communities to accept responsibility for managing risk on their own property but to expect others, such as land management agencies, to be responsible for risk reduction on surrounding public land. When fires occur, they note, the blame tends to be placed on inappropriate management of fuels, leading to heavy fuel loads; on weather; or on ineffectiveness on the part of firefighters. In concluding comments, the authors observed that interviewees had many reasons for not carrying out risk-reduction efforts – not the least of which was their belief that a recent fire reduces near-future risk of recurrence and their reluctance to reduce vegetation on their properties.

Given the findings of researchers such as those cited above, thoughtful integration of public values, defined as 'the central beliefs of individuals or society' (Machlis *et al.* 2002, p. 167), as well as perceptions[A] into science-informed decision processes becomes increasingly important (Montgomery 1996). If such values and perceptions play an important role in how fire risk is assessed, then questions arise about the extent to which reliance on scientifically informed management produces desired outcomes. This issue is not trivial, given the political–economic–social complexity as well as time and resource costs connected with wildland fire management. To be sure, public values thus defined constitute an important variable in efforts to manage human dimensions of wildland fire risk (Machlis *et al.* 2002). The social acceptability of fire-management techniques, including fuels reduction, prescribed fire, wildland fire use, and fire suppression, have been found to be determined largely by public values and perceptions of risk. As Shindler notes, 'To gain public acceptance, decisions must also account for public values. This requires involving citizens and understanding their interests' (Shindler 2007, p. 38).

Relatedly, perceptions have been found to play an important role in how people envision the short- and long-term future of natural environments (Fath and Beck 2005). In the context of fire in the wildland–urban interface (WUI), perceptions of fire risk have been shown to influence inhabitants' willingness to create defensible space around residences (Bright and Burtz 2006; see also Cart and Gorman 2002). Individual values affect the public's trust of management agencies, perceptions of agency competence, and opinions about policy alternatives (Brown and Reed 2000; Winter *et al*. 2004). Public support for fire-management decisions is also influenced by perceptions of ecosystem health (e.g. forest condition), as well as by locally derived factors such as the proximity of fire-prone lands and management activities, local history of wildfires, and forest use patterns (Bright *et al.* 2007).

Studying human values and perceptions within the framework of values at risk provided an essential structure for our research. A term with many potential meanings, 'values at risk' may be seen to encompass variables such as the desirability of an area, its scenic beauty, or related economic benefits (Clay and Daniel 2000). Availability of outdoor recreation opportunities constitutes another form of important public value that may be at risk, one typically taken into account in fire planning. For example, input to fire-management zoning efforts in Alberta, Canada, involved development of spatially explicit indicators of recreation in order to map values at risk (Neupane *et al*. 2004). A study comparing wildfire suppression expenditures against similar values at risk generated useful insights for a post-fire analysis of the economic effectiveness of suppression activities during the 2003 western Montana fire season (Calkin *et al*. 2005). In the context of decision support tools, a project to develop a GIS tool for hazard-risk assessment in the Idaho Panhandle National Forests featured a values at risk submodel, which employed yet a different mix of values, including caribou habitat, timber, human structures, and recreation areas (Harkins 2000).

Also important is understanding the public's sense of place. Because perceptions of management activities are so closely tied to residents' physical proximity to and patterns of use of managed landscapes, research suggests that the public's sense of place and the importance of special places should be taken into account in fire-management planning (Eisenhauer *et al*. 2000). However, the public's role in fire-management decision making has traditionally been minimal. Few clear mechanisms exist for public participation in such activities, aside from the relatively limited public review and comment process (Morehouse and O'Brien 2008). Even in cases where fire managers and other decision makers have some knowledge of public values and perceptions, it is often unclear how these values might be specifically incorporated into the planning process.

In this paper, we discuss a map-based survey methodology used to gather information on a specific set of values and perceptions important to wildland fire management, and to integrate that information into the spatially explicit FCS-1 DSS tool. We summarise the public values and perceptions we collected in our survey of individuals living in and near the four mountain ranges represented in the DSS, and we discuss how the data were integrated into FCS-1. We also discuss key non-spatial insights acquired during the interview process. The incorporation of both physical and social spatial information into a DSS for strategic planning in fire management was, to our knowledge, unique at that time. The effort represented an experimental first step toward representing local values and perceptions of risk in DSS tools designed for collaborative use by individuals ranging from fire experts to local citizens.

Project description and methods

From April to August 2003, researchers working on FCS-1 at the University of Arizona developed and conducted a survey to gather information useful for integrating personal values and perceptions of wildfire risk into a web-based GIS system (http://walter.arizona.edu, accessed 13 August 2009). Designed by an interdisciplinary team of researchers, FCS-1 was specifically intended to support participatory strategic planning for wildland fire management under differing climate-influenced fuels conditions. The goal was to create a GIS tool that would facilitate monthly to seasonal and longer-term wildland fire strategic planning activities, and that would encourage interaction between fire and forest managers and interested members of the public. To this end, the research team developed a model that integrated, at a 1-km pixel resolution, layers of fire probability data with layers representing a wider array of human values data than had traditionally been included in fire models at that time (Fig. 1). These layers, which could be examined individually as well as in aggregation, were designed to be combined in a manner that produced a 1-km pixellated map for the indicated study region of: (i) relative fire probability; (ii) relative level of human values vulnerable to fire damage; and (iii) relative overall vulnerability to fire.

FCS-1 specifically allows users to assign weights to the different layers of the model, and to indicate which (if either) of the two submodels should be accorded more importance than the other. This is where the AHP comes in. AHP allows users to compare variables in pairwise progression, determining for each pair which (if either) is the more important within the context of fire-risk management. In FCS-1, the user first selects a mountain range and a combined climate and fuels scenario. The user then conducts comparisons, first for the components on the fire probability submodel, then for the values at risk submodel. The final comparison is between the two submodels, with the end result being a map showing overall fire risk for the selected site.[B]

The values at risk[C] submodel includes components reflecting recreation values, property values, species habitat richness, and – as discussed in this paper – personal values. As noted earlier, FCS-1 was built based on data for four mountain ranges in the US Southwest: the Catalina–Rincon, Huachuca, and Chiricahua Mountains in Arizona and the Jemez Mountains in New Mexico (Fig. 2). The team chose these four mountain ranges based on the similarity of their attributes in terms of fire regimes and fire history. Practical reasons for selection of these mountains included their proximity to the home base of the researchers involved, availability of substantial amounts of data and previous research findings, and access to private and public sector individuals deemed to be key to the project's success.

Models like FCS-1, which integrate an array of variables that represent human values obtained through carefully designed surveys, offer opportunities to introduce best-available science and state-of-the-art geospatial technologies into forest- and fire-management practices. Such models provide a broader base of information about values at risk than is ordinarily available, and offer opportunities for encouraging fire-management discourse that is both science-based and open to public participation.

Our survey was designed to capture, for each study area: (i) pertinent demographic, land use, and recreation data; (ii) interviewees' perceptions of fire risk; (iii) information on personal values; and (iv) fire-management concerns. The spatial data collected during the survey process provided direct input into development of the 'personal landscape values' component of FCS-1 (Fig. 1). Incorporation of both spatial and non-spatial data allowed for comparison of values and perceptions within and among different user groups and across the four study areas.

Survey methods

For the landscape values component of FCS-1, we conducted personal interviews with 117 individuals: 36 from the Catalina–Rincon Mountains, 21 from the Huachucas, 20 from the Chiricahuas, and 40 from the Jemez Mountains. These individuals were selected as representing the categories of public land and resource managers, fire managers, fire department members, resource-based business owners, homeowners and residents, educators, recreationists, and environmental advocates. In some cases, interviewees lived or worked, or both, in cities and towns directly adjacent to the mountain range in question. Initial subjects were identified based on prior interactions early in the project, or through informal recommendations we solicited from others. Subsequent subjects were selected using snowball sampling. We employed this method, widely used by social scientists engaged in qualitative research, because we placed a priority on finding subjects from diverse demographic and stakeholder groups rather than attempting to collect data from a large, totally

[B]AHP overcomes the problem of how to compare variables that are not intrinsically comparable by allowing like variables to be grouped into submodels and weighted within those submodels. Thus, in the case of FCS-1, users can weight the fire probability variables separately from what the Forest Service terms 'values at risk' (property value, recreation, animal habitat, and personal landscape values), but at the same time indicate the relative importance of the two submodels for strategic planning purposes. It is this last comparison that integrates the various model components into a single risk map.

[C]We note here that the values at risk title for this latter submodel emerged from interactions that occurred during early model evaluation meetings attended by fire experts and managers: participants were clearly most comfortable with this term.

random sample. To the extent possible we tried to include roughly equal numbers of interviewees and to assure balanced representation in terms of sex and ethnic background for each of our study sites. Due to the wide variation in population numbers across the sites the actual number and mix of participants varied for each area.

We recognised at the time that, for maximum analytical robustness, a larger number of individuals would have been preferable. Indeed, this research was part of a larger effort to develop a prototype DSS that could be refined for operational use at a future time. Such a follow-on phase, when funding becomes available, would include provision of access to the map survey through our project website. This web-based survey would have potential for generating increased participation and input to the model. The web-based survey would also allow automation of the time-intensive process of archiving the data and digitising individuals' maps into the GIS-based DSS (in our prototyping enterprise, all data had to be manually entered into a database, and all maps had to be manually digitised).

We specifically designed our survey instrument to include both closed- and open-ended questions, as well as a component requiring responses to a subset of these questions to be marked on a large-format map of the pertinent study area (discussed in more detail below). Most closed-ended questions focussed on demographic data such as sex, ethnicity, years of residence, employment and property ownership. Some of these questions also sought information on respondents' recreational use patterns at sites they delineated during the map-based portion of the survey.

Map-based questions requiring individuals to respond by marking on their map were included because these techniques can provide insights into respondents' geospatial knowledge and values, as well as the relationships between these data and more abstract information about individual values and perceptions. By digitising the map-based responses into the GIS system, we were not only able to capture geospatial information useful for the model, but were also able to make comparisons both across individual maps and between groups of maps to attain a better understanding of individual and group perceptions and values in each of the study areas.

The map-based portion of the survey was specifically designed to collect spatial data that could be digitised for inclusion in FCS-1. Collection of these data required the creation of special maps and map-based survey questions, which were converted into digital spatial data. This innovative approach to spatial data collection was developed by Diane Austen for a transportation study conducted in the late 1990s (Austin 1998; Austin and Halmo 2001). In our study we followed her methodology, though we did modify it to fit our specific research questions and the different scale of our project areas. It is important to note in this regard that the survey was designed to identify geographical areas that various interest groups valued and used, not to test how well the interviewees could predict wildfire probability.

Large-format maps were created for each of the four project areas using a digital elevation model and a variety of vector-based reference layers. Each respondent was given a map on which they could provide us with mapped answers to our questions, and another that they could keep. The digital elevation model facilitated depiction of shaded relief, allowing the participant to understand and discern elevation and terrain for their mountain range.

Superimposed on the shaded relief were selected reference features such as major roads, land ownership boundaries, rivers and streams, and significant landmarks. These features were intended to make it easier for interviewees to orient themselves and find the areas and features they wished to reference while at the same time minimising the potential for introducing survey-based bias by providing too much information. The survey, which was pre-tested and refined using University of Arizona student volunteers, directed each participant to locate on the map answers to the following questions:

- What three natural or outdoor areas do you visit most often?
- Which routes do you use to access these areas?
- What areas do you value but have not visited?
- What areas do you believe to be at high risk for damage or destruction by wildfire?
- What is the one area you think too important to lose to fire?

The latter two questions were crafted to elicit responses specifically about respondents' concerns about potential losses of features or functions they prized for whatever reason, not to assess the potential benefits of fire (e.g. to restore healthy forest conditions), nor to predict any specific probability of wildfire burning in these areas. Although we acknowledge that some calculus of probability may have entered into their assessment, the intent was to obtain spatially specific information about respondents' concerns about fire risk, whether accurate by expert standards or not.

Additional open-ended follow-up questions were posed to obtain further insight into their responses. For example, with regard to the question about what areas respondents believed to be at high risk from wildfire, respondents were also asked why they considered the indicated areas to be at particular risk of fire. As noted later in this paper, some respondents volunteered information about the need for fire, indicating awareness of the potential benefits of some fire activity.

Integration of map data into FCS-1

Once all interviews were completed, spatial data from the map-based portion of the survey were incorporated into the GIS. In our GIS laboratory, the marks the participants had made on the maps were digitised as vectors in the GIS, then rasterised and subjected to map algebra to identify those areas the participants valued. Because participants were provided with different-coloured markers for each question, it was a simple matter to create spatial data for each question for each participant's map.

The result of the digitising process was a series of polygon feature classes representing participants' responses to the five map-based questions. These feature classes were converted to binary rasters where '1' represented areas the participants had included in response to a question and '0' denoted areas left unmarked. The rasters for each individual question were then summed to provide total scores for each question. For example, if a particular picnic ground had been identified by 13 participants as an area they visited regularly, then the sum of the scores

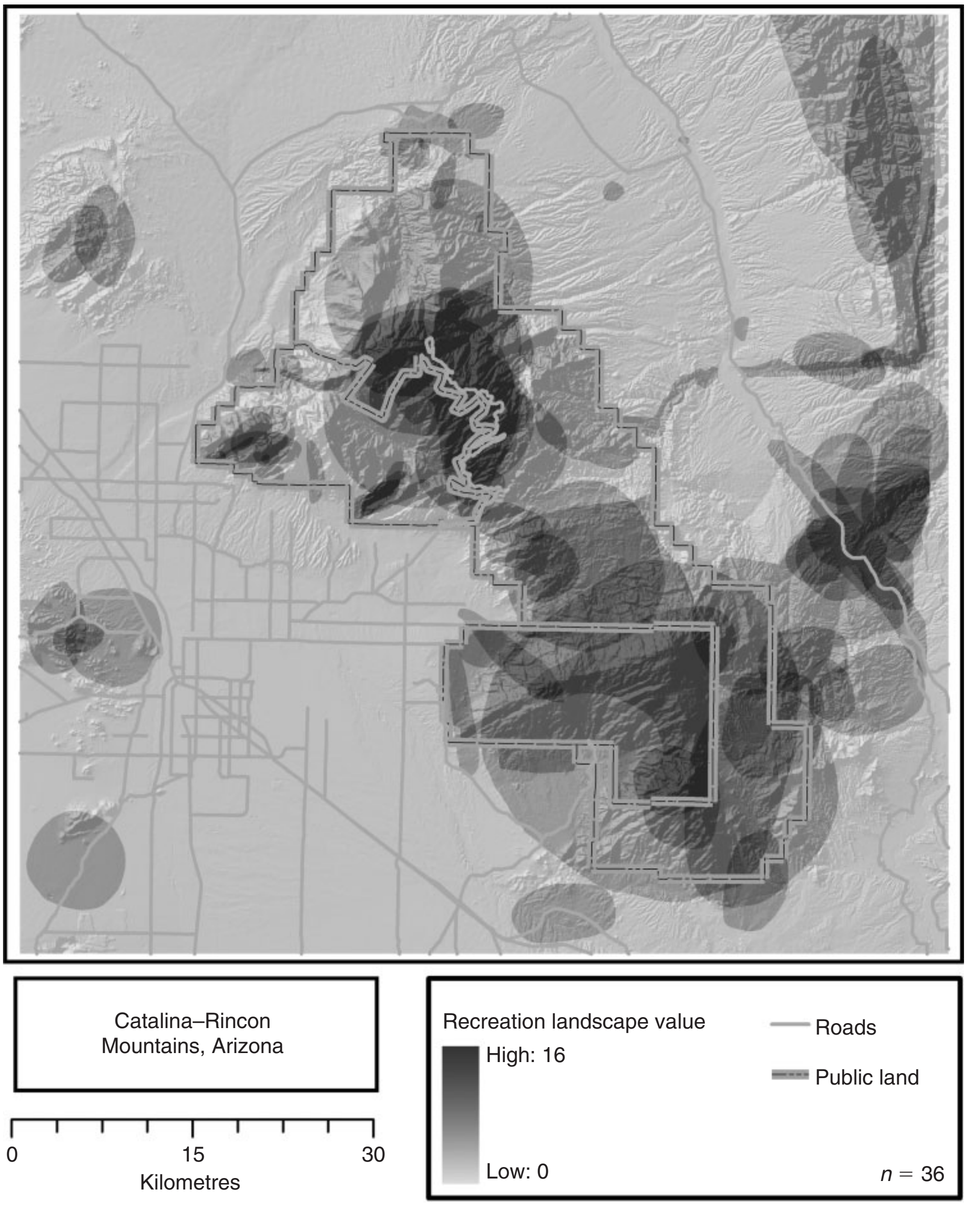

Fig. 3. Sum of recreation areas selected by participants for the Catalina–Rincon Complex, Coronado National Forest. The boundaries on the map indicate public land areas. The fine lines are major roads.

for the raster cells corresponding to that picnic ground would contain a value of 13. This summed value could be compared to other values in the raster map to determine overall importance of the designated area relative to other locations on that mountain (Fig. 3). Finally, the summed rasters for each interview were themselves summed to create a composite map showing the aggregate landscape value for each raster cell in the study area (Fig. 4).

We emphasise here that, although interesting insights may be gained from examining individual maps, the aggregation of all maps for a particular study area within the values at risk layer of FCS-1 allows spatial representation within the model of the areas most and least often delineated by interviewees. The components aggregated to create this GIS layer represent public behaviours (e.g. what places they visit and what routes they take) as well as attitudes about the landscapes in question: i.e. places they value but have not visited, places they deem likely to burn, and places they consider too valuable to let burn.

We emphasise that, for purposes of the model, it was not necessary for this layer to represent scientific truth for it to be valuable. Indeed, the truth of this layer lay in its reflection of the use patterns and subjective feelings that people expressed about the landscape. For example, in the Catalina–Rincon Mountains, participants in the survey viewed the two mountain complexes

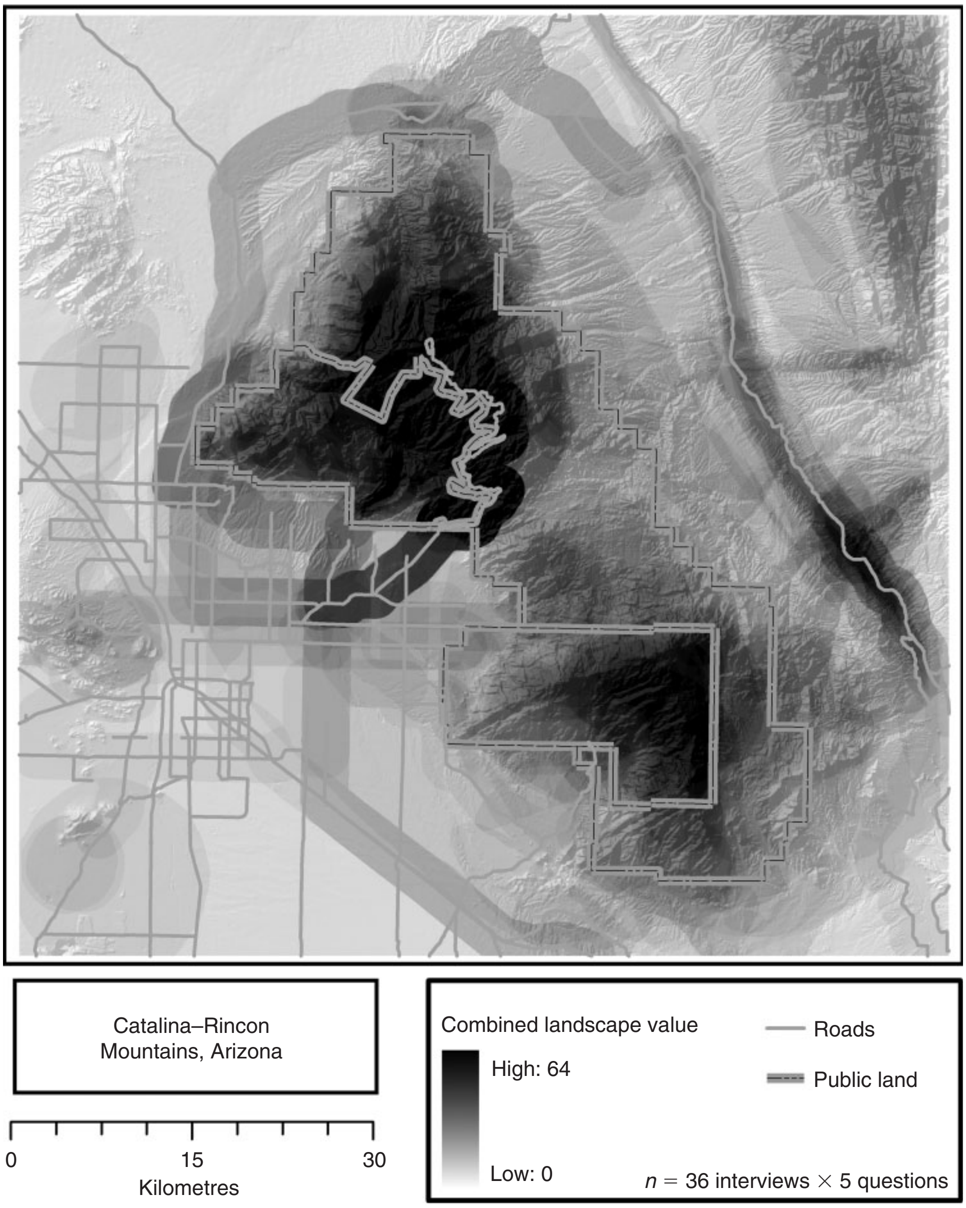

Fig. 4. Aggregate of all questions from all participants for the Catalina–Rincon Mountains, Coronado National Forest. The boundaries on the map indicate public land areas. The fine lines are major roads.

as equally prone to fire. On the other hand, their map markings revealed that their personal experiences were largely located in the more readily accessible Catalina Mountains – and it was here that most respondents indicated areas that were too valuable to let burn. Anecdotes from the local land managers reinforce this interpretation: in their experience, fires in the Rincon Mountains raise little worry among locals; however, even small fires in the Catalinas elicit concern from large numbers of individuals.

Further, it is important to note that the aggregate landscape value layer does not provide fire probability information to the model; rather, it allows a first approximation of areas valued by local stakeholders and the public. This information is valuable especially to forest superintendents, who must answer questions from the public about the chances that a fire will destroy publicly valued areas, such as prized recreational locations.

In terms of the overall function of the FCS-1 model, the landscape values data provide information that the model uses to construct composite fire-risk maps. As discussed earlier in this paper, AHP provides the means for assigning weights to the different components of the model (Saaty 1980, 1991). AHP facilitates the analysis of complex problems through: (i) structuring a problem into a hierarchy consisting of a goal and subordinate features of that problem; and (ii) allowing use-controlled pairwise comparisons between elements at each level.

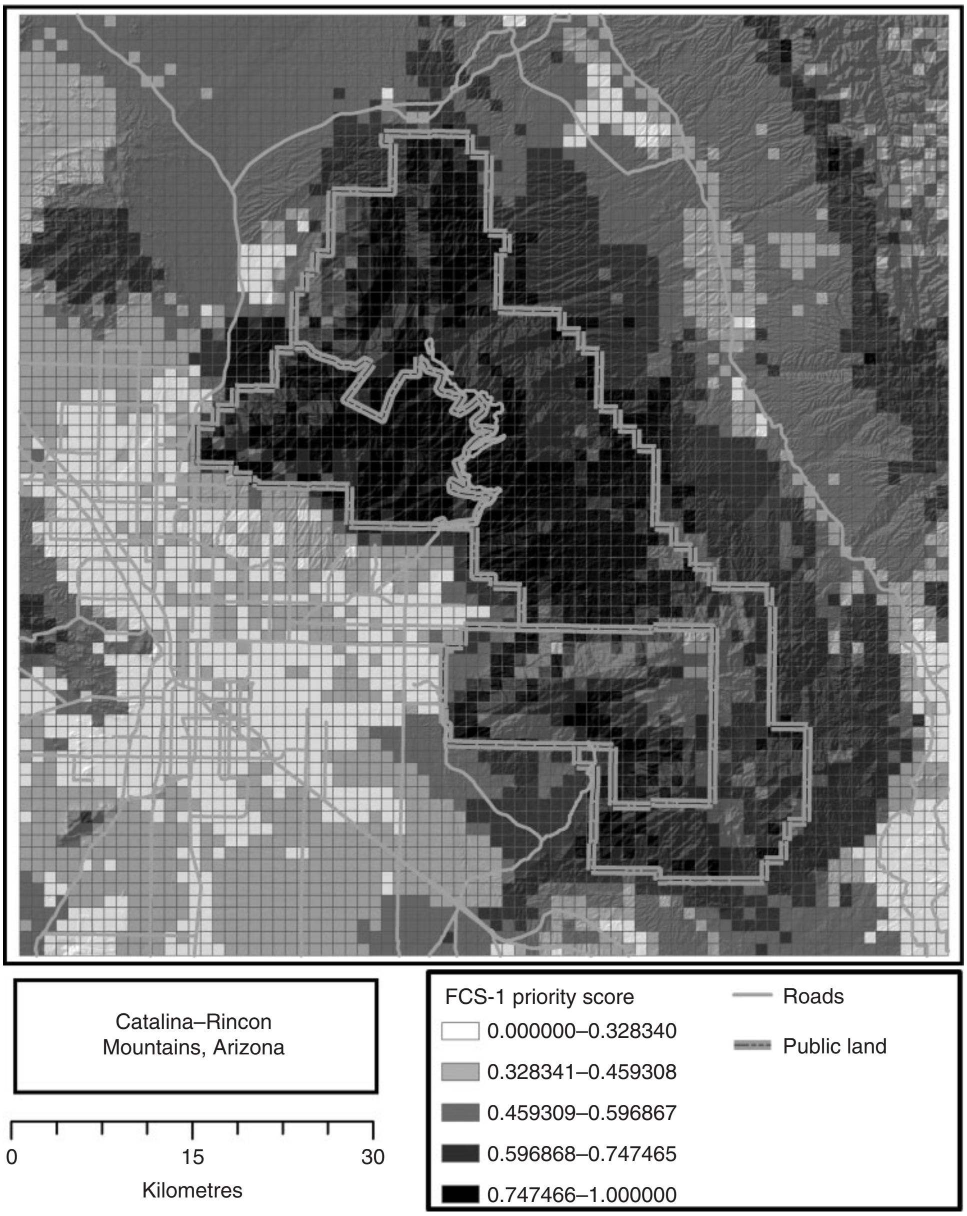

Fig. 5. Fire–Climate–Society (FCS-1) output for the Catalina–Rincon Mountains. The boundaries on the map indicate public land areas. The fine lines are major roads.

Matrix algebra is used to compute the respective user-assigned weights of the variables (Saaty 1980, 2000; for more about FCS-1 see Grunberg *et al*. 2004 and Morehouse and Orr 2007).

Fig. 5 represents a sample map output from FCS-1 produced during the β test carried out with stakeholders associated with the Catalina–Rincon Mountains. In this example, the AHP-weighted score for personal landscape values, assigned by the participants, was 0.335. Of the four variables in the values at risk submodel, this was the highest weight. For the three other study areas, aggregate AHP-based weights for personal landscape values ranged from 0.113 in the Chiricahuas (in this case, the lowest score of the four variables in the submodel) to 0.182 in the Huachucas and 0.243 in the Jemez Mountains. In both of these latter cases, personal landscape values scored second highest among the four components in the values at risk submodel. Taken together, these weights reinforce the point that landscape elements are important to many people and that this component is a significant variable within FCS-1.

Analysis and results of the survey

Non-spatial factors

The qualitative analysis of non-spatial survey results focussed on two key questions: (i) what do residents and other users of the WUI value in the fire-prone landscapes of their particular study area mountain range; and (ii) what areas do residents and users perceive as being at risk of fire, and why? These two questions directly address concerns among fire managers and planners about the public values and perceptions that need to be considered in their planning and decision processes. The questions employed in this section of the survey were designed to generate an approximation of an admittedly larger scope of public risk perceptions and values. The intent was to identify a set of perceptions and values that could be used by stakeholders and experts alike to analyse and discuss the outputs of runs of the FCS-1 model.

The research team recognised that transitioning the model from prototype to operational status would entail a larger survey effort. However, the team also recognised that the information generated in this structured sample would prove useful in understanding important values and concerns that local stakeholders would likely bring to the table in a wildland fire strategic planning process.

What would WUI residents value in fire-prone forests?

Because recreation and tourism account for the majority of uses of the forests in the US Southwest, our survey focussed on these types of uses. We adopted the list of recreational activities used in the United States Department of Agriculture Forest Service's National Visitor Use Monitoring Survey (Kocis *et al*. 2002). As part of the map-based portion of the survey, participants were asked to examine the large-format map of their area and identify the three natural or outdoor places they most liked to visit. Then, for each of these sites, they were also asked to describe their recreational use patterns over the previous 5 years. They indicated: how many times per year, on average, they visited each site; what specific activities they took part in; and how many people typically accompanied them. The most common recreational uses included hiking, wildlife viewing, sightseeing, and picnicking (Table 1). These results were similar to the ones reported in the USDA Forest Service survey of the Coronado and Santa Fe National Forests: the most popular activities in that survey included hiking or walking, wildlife viewing, viewing natural features, and driving for pleasure (Kocis *et al*. 2002, 2004). In our survey, 'other' responses reflected an impressive array of activities, from ranch work and mineral prospecting to conducting ecological research and leading educational tours. Some Native American respondents emphasised the importance of the public lands for subsistence food gathering.

Our survey also asked participants to identify an area on the map that they valued highly but had never visited, and to describe their reasons for valuing that place. Although this question was intended to elicit information about non-use values, 15% of responses included some discussion of recreation opportunities (Table 2). Respondents most frequently mentioned valuing the qualities of natural areas, including beauty, isolation, and wilderness values. Many described unvisited areas, especially canyons, peaks, and large areas of designated wilderness, as 'primitive', 'unique', 'remote', 'pristine', and 'undisturbed'. Several participants stated that they saw isolated, undeveloped areas as increasingly rare refuges in a 'sea of development'. The second most common response indicated that participants valued unvisited areas for their provision of what we would view as ecosystem services (e.g. clean water and air), and as habitat for wildlife. Many respondents showed a keen awareness of mountainous and forested areas as areas of high biodiversity and as economically important water sources. Some mentioned habitat for specific species, such as bighorn sheep, mountain lions, rattlesnakes, migratory birds, or rare amphibians. Many others described snowpack and streams in unvisited high-elevation areas as water sources for downstream towns and recreational areas. Finally, many participants stated that they valued unvisited areas for the cultural or historical resources located there (e.g. Native American ruins, sacred areas, and other cultural sites), or because they viewed the areas as threatened by or at risk from development, fire, overuse and other factors.

Table 1. Respondents' recreational uses of the study areas
Not all recreational activities are available in all four study areas. Participants were allowed to indicate more than one category

Use	Responses *n*	%
Hiking	245	18
Wildlife viewing	171	12
Sightseeing	155	11
Picnicking	151	11
Other	112	8
Camping	92	7
General recreation	76	5
Horseback riding	58	4
Off-road driving	57	4
Big game hunting	47	3
Biking	39	3
Small game hunting	38	3
Fishing	38	3
Swimming	28	2
Rock climbing	27	2
Snowmobiling	16	1
Cross-country skiing	14	1
Downhill skiing	12	1
Float boating	5	>1
Motor boating	1	>1
Waterfowl hunting	1	>1

Table 2. Reasons respondents valued areas they did not use
Participants were allowed to give more than one reason

Reason	Responses *n*	%
Intangible attributes (wilderness, beauty, isolation)	58	41
Ecosystem values or wildlife habitat	41	28
Recreational attributes	22	15
Cultural or historical attributes	15	10
Threatened or at risk	8	6

Why do people perceive specific areas to be at risk of fire?

Fire-management decisions reflect underlying perceptions of risk and of the causes of such risk. An intangible element in individual behaviour and social process, risk perception can

Table 3. Reasons respondents gave for considering areas they designated to be at greater risk from fire
Participants were allowed to give more than one reason

Reason	Responses	
	n	%
Fuel characteristics	96	26
Policy, management, governance issues	91	25
Likelihood of ignition	55	15
Risk to humans, property	44	12
Very highly valued (non-specific)	30	8
Difficulty in suppression or evacuation	29	8
Everything is at risk	11	11
Everything should burn	11	11

nonetheless quite strongly influence human preferences for different options, willingness to adopt chosen alternatives, and capacity to respond effectively to risk-laden situations (Gardner *et al*. 1985; Daniel *et al*. 2003).

During the map-based portion of the survey, interviewers asked respondents to indicate on their map the three natural areas they considered to be most at risk of damage or destruction by fire. The interviewers then asked what specific traits put each of those areas at greater risk. About one-quarter of respondents described at least one of their designated areas as being at risk of fire because of specific fuel characteristics (Table 3). They viewed fuel density and structure, species composition, and topography as major drivers of fire risk. Roughly one-quarter of respondents also considered policy, management practices, or the activities of federal agencies to be a factor in fire risk. Both of these answers probably reflect, in large part, the well-publicised argument that 100 years of suppression had led to catastrophic fires through the build up of hazardous fuels. However, participants also identified as important to them a broad range of government and governance issues, including agencies' balance of extractive and non-extractive uses on public lands, corruption of government at all levels, and the appropriateness of federal management of local lands. Many respondents also considered areas to be at risk of fire due to the likelihood of ignition (either human- or lightning-caused) or because any fire would pose a significant risk to humans and property. Small minorities believed that everything on the map either was equally at risk of burning, or equally in need of being burned over (i.e. there is 'no such thing as a bad fire').

Broader public debate over fire management would tend to suggest that disagreements in this realm are sharply divided according to interest. That is, it is usually assumed that environmentalists blame extractive industries like logging and ranching for catastrophic fires, that rangers and logging companies blame environmentalists for holding up fuel-reduction projects, or that homeowners blame the Forest Service for incompetent management and vice versa (Jensen 2006). Our interviews included numerous examples of this kind of rhetoric, but responses about actual values and risk perceptions differed very little across these social categories. Overall, agency employees, environmental advocates, business owners, and recreationists gave very similar answers about what they valued in the landscape and what they perceived to be the causes of fire risk. Similarly, answers varied little between men and women, locals and non-locals, short-term and long-term residents, property owners and renters, and even between those who reported having been previously affected or not affected by wildland fire.

Spatial factors

The map-based portion of the survey also provided information about what makes an area valuable for stakeholders. The clearest connection was between high values and access. Public lands that were accessible for recreation or other activities nearly always scored higher values, relative to areas that were much more difficult to reach. The best example of this was in the Catalina–Rincon Mountains, particularly with regard to Mount Lemmon and the Rincon Mountains, which lie, respectively, north and east of Tucson. Of these two areas, Mount Lemmon has the easiest access, with a paved road leading to the town of Summerhaven near the summit. There are several Forest Service picnic areas, campgrounds, and vista points along the way. The Rincon Mountains have several hiking trails, but the mountains themselves are not accessible to motor vehicles. Both mountains are well known to residents in the area. Controlled burns and wildfire on both peaks are visible to hundreds of thousands of people, but the number of visitors to the two peaks is overwhelmingly skewed toward the more easily accessible Mount Lemmon area.

Fig. 6 shows areas that participants believed to be most at risk from wildfire. Here, the highest-risk areas, in terms of potential damage from fire activity, are Mount Lemmon (the dark area to the north-west on the map) and the Rincon Mountains (the dark area to the south-east). Fig. 7 shows areas that participants did not want to lose to destructive forms of wildland fire. In this map, the Rincon Mountains show diminished importance when compared to the results shown in Fig. 6. Areas on Mount Lemmon that respondents indicated as the ones they would most hate to see damaged were those visible from, or close to, the highway leading to the summit and those areas containing the heaviest concentration of features such as hiking trails and picnic areas.

Discussion: integrating public values into DSS models

Different people perceive and value natural resources and landscapes differently, and they expect different outcomes from fire management. When discussing fire, users of fire-prone wildlands and areas within the WUI frequently use emotionally laden language and seek to assign blame to other users. However, the results of our survey suggest that user groups are not as divided politically as public discourse would lead us to believe. Our survey suggests that groups such as environmental advocates and agency employees, commonly viewed as being deeply divided (and indeed may consider themselves so), may more often be in basic agreement about what they value in fire-prone local areas and about the origins of fire risk. For example, strong consensus exists that the watershed area above the village of Summerhaven must be protected because it is essential to the water supply of Mount Lemmon. Likewise, protection of the forested landscapes of the Chiricahua Mountains from stand-destroying fire is a value shared by entities living and working in that study area. Shared values such as these provide a useful starting point

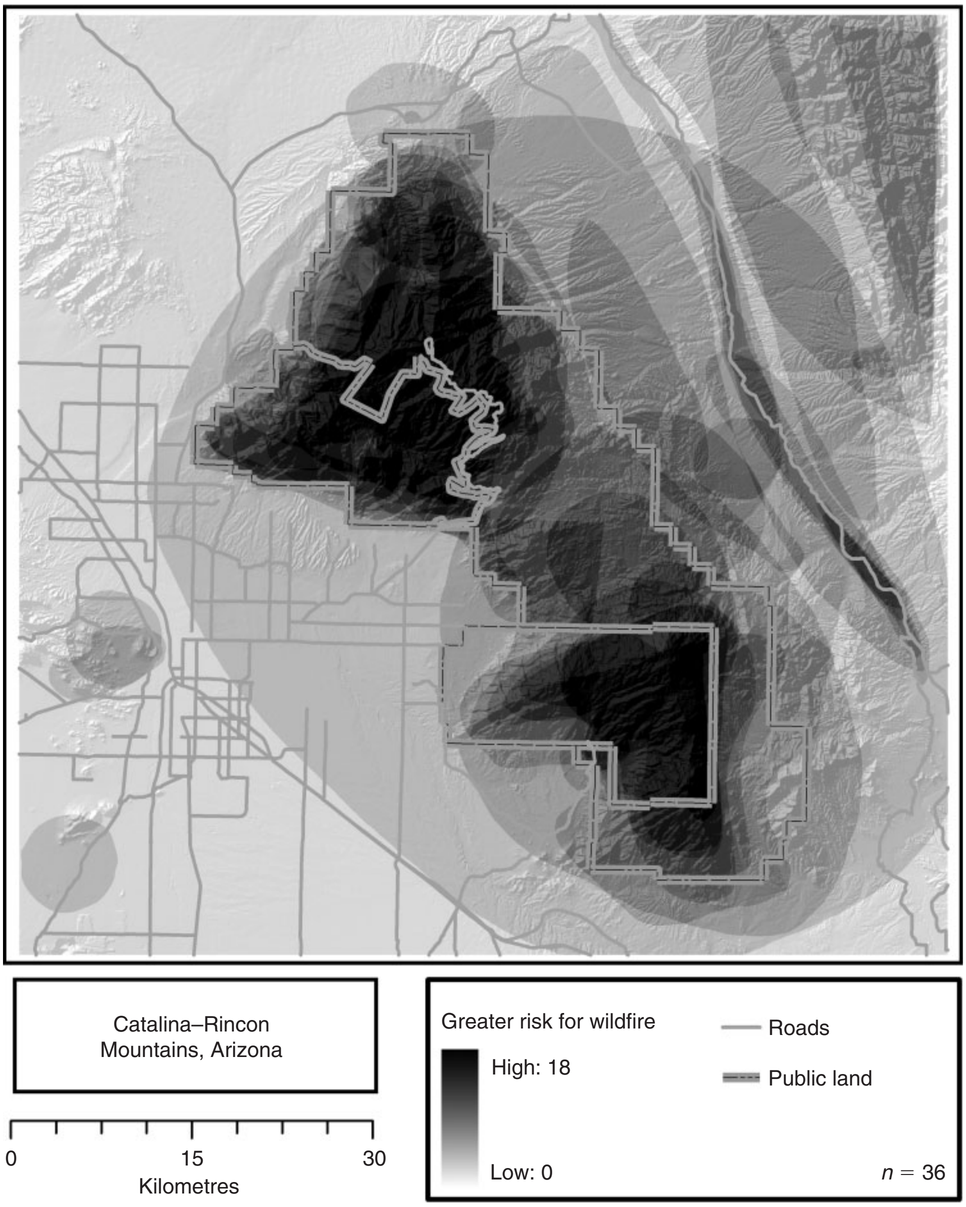

Fig. 6. Example of map showing areas thought to be most at risk of wildfire (Catalina–Rincon Mountains). The darker the shading, the greater the number of responses indicating that area.

for broad-based discussions of fire-management strategies, and for collaborative use of strategic-planning tools such as FCS-1. Such discussion, indeed, may be facilitated considerably when wide access is available to information such as that generated in our survey, as well as to the GIS-based maps produced from the survey process.

On the other hand, these kinds of evidence may exacerbate existing tensions about how fire risk in certain areas should be managed. The map-based portion of our survey indicated, for example, a tendency among respondents representing members of the public to place higher value on areas that are more accessible.[D] This pattern was not as discernible among fire-management experts participating in the survey. The insight, by itself, would probably be widely acknowledged in any case. However, having clear evidence, such as that produced by FCS-1, of relative fire risk in and near these valued areas may open the door to more productive dialogue and identification of potential areas of agreement.

As the examples in this paper illustrate, the relationship between public and management perceptions and values is far from simple. Yet managing the relationship may be as important as managing the fire-prone landscapes themselves. Our

[D]As we noted earlier in this paper, we define values in this context as not necessarily quantifiable phenomena that strongly attract and bind individuals to the areas in question.

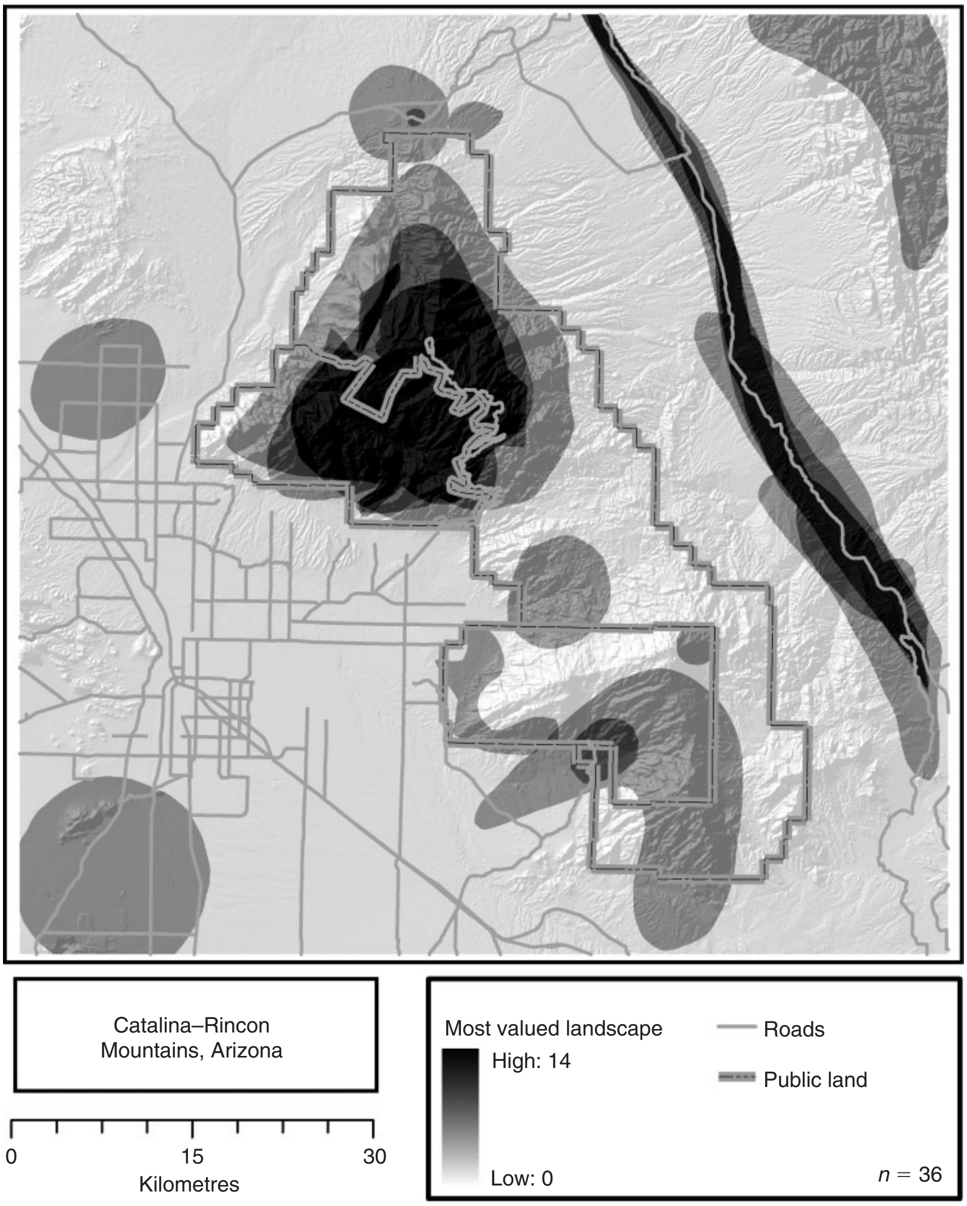

Fig. 7. Example of areas thought to be too valuable to lose to wildfire (Catalina–Rincon Mountains). The darker the shading, the greater the number of responses indicating that area.

study suggests that introduction of GIS-based DSS technology into efforts to integrate a broader range of citizens into fire-management strategic planning processes may be strengthened through improving representation of public values and perceptions. These insights, in turn, hold promise for improving interactions among science, policy, and management processes.

Conclusions

With increased politicisation of fire planning and management, intensified by marked increases in fire activity, need is escalating for decision support tools that allow more effective and complete integration of personal values. This situation became increasingly apparent during the course of developing the FCS-1 DSS and working through the α and β testing procedures conducted in collaboration with participants from the four study areas. Models such as FCS-1 that integrate qualitative as well as quantitative values hold considerable promise for expanding the nature and scope of variables used by fire managers to address wildland fire risk. To be maximally useful, however, design of such tools should be carried out in direct collaboration with at least a subset of local residents and stakeholders.

In the course of our survey we found that community members have considerable interest in fire planning and in having information about their values and risk perceptions taken into account in the model-building process. As FCS-1 neared completion, we held a workshop in each of the four study areas to bring together interviewees, fire managers (some of whom were also interviewees), and scientists. The purpose of the workshops was to subject the model to guided user testing and to elicit feedback from participants about the model's usability, usefulness, and accuracy. We found the feedback encouraging. For example, fire managers attending the testing sessions found the model process and outputs to be reasonably good representations of fire risk and potentially useful in strategic planning. Non-expert participants who had participated in the survey process were quite interested in how their values had been represented in the model, and seemed to agree with the representations the model produced for their study area. However, they found the model difficult to use and its outputs difficult to interpret. Much of this difficulty can be attributed to lack of experience with interpreting complex GIS-based maps and inexperience with interactive computer tools. Had it been possible to provide a separate computer to each person and to provide sufficient time and individual support to all participants, these participants could readily have improved their ability to use the model and interpret its outputs.

Given that FCS-1 is web-based, organising training at the local level should not be difficult, so long as a computer and internet connection are available. However, the limited resources available to the research team made this option infeasible, a dilemma typical of government-funded science projects such as ours. Expansion of Cooperative Extension, or other public-oriented outreach programs into technological support for model-based strategic planning activities (e.g. such as those carried out for wildland fire planning) should be explored.

In terms of the modelling effort itself, combining biophysical data, fire history, and other such information with data on human perceptions and values at risk serves to enrich our understanding of the many factors involved in managing actual and perceived fire risk. To the extent that models such as FCS-1 and similar decision tools can be better designed to integrate human values and to accommodate access and use by non-experts – including community members – they hold promise for fostering collaborative fire-risk management as well as related community-based forestry activities and long-term land-use planning in fire-prone areas. Follow-up studies could very usefully expand our work into other geographical areas and environmental issues. These types of studies could also be extended to additional categories of interviewees, as well as to a larger array and range of values. One such study is currently underway in the Catalina Mountains where efforts are focussed on establishing long-term plans for fire management not only under current conditions but also under potential future conditions influenced by climate change. This effort, if funding at the required levels is made available, will provide an excellent opportunity to expand upon the research discussed in this paper.

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References

Austin DE (1998) Methodology. In 'Native Americans respond to the transportation of low level radioactive waste to the Nevada test site'. (Ed. D Austin) pp. 8–22. (Bureau of Applied Research in Anthropology: University of Arizona, Tucson)

Austin DE, Halmo DB (2001) The American Indian low-level radioactive waste transportation study. In 'American Indians and the Nevada test site: a model of research and consultation'. (Eds RW Stoffle, MN Zedeño, DB Halmo) Department of Energy, Report Number DOE/NO/13046-2001/001, pp. 169–179. (US Government Printing Office: Washington, DC)

Bright AD, Burtz RT (2006) Creating defensible space in the wildland–urban interface: the influence of values on perceptions and behavior. *Environmental Management* **37**(2), 170–185. doi:10.1007/S00267-004-0342-0

Bright AD, Newman P, Carroll J (2007) Context, beliefs, and attitudes toward wildland fire management: an examination of residents of the wildland–urban interface. *Human Ecology Review* **14**(2), 212–222.

Brown G, Reed P (2000) Validation of forest values typology for use in national forest planning. *Forest Science* **46**(2), 240–247.

Calkin D, Hyde K, Gebert K, Jones G (2005) Comparing resource values at risk from wildfires with Forest Service fire suppression expenditures: examples from 2003 western Montana wildfire season. USDA Forest Service, Rocky Mountain Research Station, Research Note RMRS-RN-24WWW. (Fort Collins, CO)

Cart J, Gorman T (2002) The nation: hot trend: a home in the woods. Fires: western residents flock to forest living, often disregarding the risks. Widespread drought means tragedy is inevitable. *Los Angeles Times*, 22 May 2002, section PA, p. A-13.

Clay GR, Daniel TC (2000) Scenic landscape assessment: the effects of land management jurisdiction on public perception of scenic beauty. *Landscape and Urban Planning* **49**, 1–13. doi:10.1016/S0169-2046(00)00055-4

Cohn PJ, Williams DR, Carroll MS (2008) Wildland–urban interface residents' views on risk. In 'Wildfire risk: human perceptions and management implications'. (Eds WE Martin, C Raish, B Kent) pp. 23–43. (Resources for the Future: Washington, DC)

Daniel TC (2007) Perceptions of wildfire risk. In 'People, fire, and forests: a synthesis of wildfire social science'. (Eds TC Daniel, MS Carroll, C Moseley, C Raish) pp. 55–69. (Oregon State University Press: Corvallis, OR)

Daniel TC, Weidemann E, Hines D (2003) Assessing public tradeoffs between fire hazard and scenic beauty in the wildland-urban interface. USDA Forest Service, North Central Research Station, General Technical Report NC-231. (Washington, DC)

Eisenhauer BW, Krannich RS, Blahna DJ (2000) Attachments to special places on public lands: an analysis of activities, reasons for attachments, and community connections. *Society & Natural Resources* **13**, 421–441. doi:10.1080/089419200403848

Fath BD, Beck MB (2005) Elucidating public perceptions of environmental behavior: a case study of Lake Lanier. *Environmental Modelling & Software* **20**, 485–498. doi:10.1016/J.ENVSOFT.2004.02.007

Gardner PD, Cortner HJ, Widaman KF, Stenberg KJ (1985) 'Forest-user attitudes toward alternative fire management policies.' (Springer: the Netherlands)

Grunberg W, Dale JC, Haseltine M, Lerman N, Olsson A, Orr B (2004) Web-based map-algebra challenges: a polygon solution. In 'Proceedings of the 24th annual ESRI international user conference', 9–10 August 2004, San Diego, CA. Available at http://gis.esri.com/library/userconf/proc04/docs/pap1665.pdf [Verified 15 June 2006]

Harkins KC (2000) The Idaho Panhandle National Forests wildfire hazard-risk assessment. In 'Proceedings of the Joint Fire Science Conference and Workshop: Crossing the Millenium: Integrating Spatial Technologies and Ecological Principles for a New Age in Fire Management', 15–17

June 1999, Boise, ID. (Eds LF Neuenschwander, KC Ryan, GE Golberg, JD Greer) pp. 92–100. (University of Idaho: Boise, ID)

Jensen SE (2006) Policy tools for wildland fire management: principles, incentives, and conflicts. *Natural Resources Journal* **46**(4), 959–1003.

Kocis SM, English DBK, Zarnoch SJ, Arnold R, Warren L (2002) 'National visitor use monitoring results, August 2002.' USDA Forest Service Region 3, Coronado National Forest. (Tucson, AZ)

Kocis SM, English DBK, Zarnoch SJ, Arnold R, Warren L, Ruka C (2004) 'National visitor use monitoring results, June 2004.' USDA Forest Service Region 3, Santa Fe National Forest. (Santa Fe, NM)

Machlis GE, Kaplan AB, Tuler SP, Bagby KA, McKendry JE (2002) Burning questions: A social science research plan for federal wildland fire management. Report to the National Wildfire Coordinating Group: contribution number 943 of the Idaho Forest, Wildlife and Range Experiment Station, College of Natural Resources. (University of Idaho: Moscow, ID)

McCaffrey S (2008) Understanding public perceptions of wildfire risk. In 'Wildfire risk: human perceptions and management implications'. (Eds WE Martin, C Raish, B Kent) pp. 11–22. (Resources for the Future: Washington, DC)

Montgomery CA (1996) Risk and forest policy: Issues and recent trends in the US. *Ecological Economics* **16**, 65–72. doi:10.1016/0921-8009(95)00081-X

Morehouse BJ, O'Brien SE (2008) Facilitating public involvement in strategic planning for wildland fire management. *The Professional Geographer* **60**(4), 495–507. doi:10.1080/00330120802211836

Morehouse BJ, Orr BJ (2007) Walking the talk: Integrating science and community into decision support for wildland fire management. In 'Wildfire risk: human perceptions and management implications'. (Eds WE Martin, C Raish, B Kent) pp. 194–211. (Resources for the Future: Washington, DC)

Morehouse B, Christopherson G, Crimmins M, Orr B, Overpeck J, Swetnam T, Yool S (2006) Modeling interactions among wildland fire, climate and society in the context of climatic variability and change in the southwest US. In 'Regional climate change and variability: impacts and responses'. (Eds M Ruth, K Donaghy, P Kirshen) pp. 58–78. (Edward Elgar: Cheltenham, UK)

Neupane A, Boxall PC, Pelletier R (2004) Assessing the recreation values at risk from wildfire: an exploratory analysis. Selected paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, 1–4 July 2004, Denver, CO. Available at http://ageconsearch.umn.edu/handle/19986 [Verified 9 January 2010]

Saaty TL (1980) 'The analytic hierarchy process: Planning, priority setting, and resource allocation.' (McGraw-Hill: New York)

Saaty TL (1991) 'Multicriteria decision making: The analytical hierarchy process, extended.' (RWS Publishers: Berlin)

Saaty TL (2000) 'Fundamentals of decision making and priority theory with the analytic hierarchy process. Vol. 6.' (RWS Publications: Pittsburgh)

Shindler B (2007) Public acceptance of wildland fire conditions and fuel reduction practices: challenges for federal forest managers. In 'People, fire, and forests: a synthesis of wildfire social science'. (Eds TC Daniel, MS Carroll, C Moseley, C Raish) pp. 37–54. (Oregon State University Press: Corvallis, OR)

Slovic P, Finucane ML, Peters E, MacGregor DG (1987) Behavioral decision theory perspectives on protective behavior. In 'Taking care: understanding and encouraging self-protective behavior'. (Ed. N Weinstein) pp. 14–41. (Cambridge University Press: New York)

Winter G, Vogt CA, McCaffrey S (2004) Examining social trust in fuels management strategies. *Journal of Forestry* **102**(6), 8–15.

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