

geospatial technologies

# Participatory Geographic Information Systems as an Organizational Platform for the Integration of Traditional and Scientific Knowledge in Contemporary Fire and Fuels Management

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Traditional knowledge about fire and its effects held by indigenous people, who are connected to specific landscapes, holds promise for informing contemporary fire and fuels management strategies and augmenting knowledge and information derived from western science. In practice, however, inadequate means to organize and communicate this traditional knowledge with scientists and managers can limit its consideration in decisions, requiring novel approaches to interdisciplinary and cross-cultural communication and collaboration. We propose that Participatory Geographic Information Systems (PGIS) is one platform for the assemblage and communication of traditional knowledge vital to fire and fuels management, while preserving linkages to broader cultural contexts. We provide summaries of four preliminary case studies in the Intermountain West of North America to illustrate different potential applications of a PGIS tool in this context and describe some remaining challenges.

**Keywords:** fire and fuels management, traditional knowledge, indigenous knowledge, Participatory Geographic Information Systems

For thousands of years, indigenous peoples have used fire to manage their landscapes for a wide variety of subsistence and cultural purposes, including promoting the growth and yield of crops and certain native plants, minimizing pests, im-

proving habitat for game animals and hunting, protecting areas from wildfire, and clearing areas for travel and other activities (Mason et al. 2012, Huffman 2013, Voggesser et al. 2013, Christianson 2015). At local and regional scales, traditional fire

knowledge entails a multifaceted understanding of how subsets of multiple social and ecological elements interact and influence one another, producing many pyrogeographies of considerable nuance and sophistication (Huffman 2013). In other words, culturally linked fire regimes have emerged as a result of time-tested knowledge regarding the effects of fire on culturally valued resources, both for increasing resource predictability and promoting resilience to changes in the environment (Voggesser et al. 2013). In addition to human-ignited fire regimes, tribal cultures are believed to have adapted their subsistence strategies and socioeconomic systems in response to climate and changing nonanthropogenic fire regimes for millennia. They observed and adapted to the effects of fire on ecological processes at various scales, from local habi-

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tats to landscapes encompassing diverse ecosystems (Vogge et al. 2013). Traditional phenological knowledge has been used to inform both fire prescription and adaptation to wildfire events, including postfire recovery (Armatas et al. 2016).

In North America, some of this knowledge has been lost to time and forced assimilation, although some persists in the oral tradition and practices of contemporary native communities (Kimmerer and Lake 2001). It is well documented that the frequency and extent of both human-ignited and naturally ignited fires were greatly reduced after European colonization and that "...the current American landscape reflects the historical legacy of one worldview superimposed on another—the colonial overlaying the traditional..." Nowhere is this history more apparent than in attitudes toward fire made manifest on the landscape (Kimmerer and Lake 2001, p. 36).

According to Guyette et al. (2006), throughout North American history, fire frequency and human population density were positively correlated at early periods of lower levels of human habitation (presettlement and early settlement periods), but became negatively correlated at later times of higher population density. Europeans arrived in North America with the conviction that fire was destructive and hazardous to humans based on their past experiences, which was in stark contrast with the beliefs of indigenous peoples, who embraced the benefits of burning and were skilled in applying fire to the landscape. Although some purposive fires were used by the settlers for clearing and maintaining grazing lands, fire history studies suggest that use of fire in the southern United States advanced through several stages. After European settlement, low-intensity brush fires occurred mainly for agriculture purposes through the end of the 18th century, but in the 19th and early 20th centuries human-caused fires were more likely to be stand replacement fires for industrial purposes (Fowler and Konopik 2007).

Fire suppression, as a new factor of influence on the landscape, began soon after colonization, with human-ignited fire all but disappearing from even the West by 1899, where fire-prone ecosystems dominate the landscape, culminating in the fire suppression mentality of the 20th century (Mason et al. 2012, Christianson 2015). Driven by this turnover in land management and compounded by the effects of climate change, wildfire activity in the western United States

increased suddenly in the mid-1980s, with higher large wildfire frequency, longer incident durations, and longer fire seasons (e.g., Westerling et al. 2006). Currently, across the country, the use of prescribed fires of mixed intensity and frequency is the goal of ecosystem restoration policies (Fowler and Konopik 2007, Ryan et al. 2013) but is facing intense social and regulatory barriers in many states.

Given these profound challenges for contemporary fire and fuels management, fire scientists and managers are increasingly turning to traditional knowledge of fire to help inform current management strategies (Kimmerer and Lake 2001, Mason et al. 2012, Huffman 2013), recognizing that the same traditional strategies that were used to increase biodiversity and productivity for subsistence while minimizing risk in the past could also be used to enhance and maintain biodiversity for the goals of ecosystem health and human safety. Ray et al. (2012) identified numerous other potential advantages to incorporating both traditional knowledge and science in fire management, including the addition of fine-scale, local details and historical context, detection of changes yet undocumented in scientific studies, indication of which regional studies apply to a given locale, reduction of conflict over resource management, and consideration of legal precedents for including traditional knowledge and values in fire management. Although the incorporation of traditional fire knowledge is not a cure-all for the problems resulting from a century of fire suppression compounded by the effects of climate change, traditional knowledge should be an integral part of strategies for restoring ecosystem integrity and informing human adaptation to changing fire regimes.

In this article, we discuss current efforts to integrate traditional and scientific fire knowledge in fire and fuels management in the United States and consider some of the challenges associated with this process. We propose that Participatory Geographic Information Systems (PGIS) offers a platform for addressing some of these challenges, and we provide summaries of four preliminary case studies to illustrate different potential applications of a PGIS tool in this context.

## Knowledge Integration in US Fire and Fuels Management

To manage the scope, complexity, and uncertainty of rapidly changing environmental issues, it is imperative to take into account different types and sources of knowledge. In forest management and inventory, arguments have been advanced for the importance of considering indigenous knowledge in protecting traditional uses of native material by native people (cf., Emery et al. 2014, Hummel and Lake 2015). Recognizing that modern problems cannot always be solved with singular, science-centered solutions, successful management increasingly depends on pluralistic courses of action that include partnerships between managers and locally knowledgeable groups, such as indigenous people (Moller et al. 2004, Diaz et al. 2016). In environmental management, this combining of different knowledge systems is most commonly referred to as knowledge integration (Bohensky and Maru 2011) or blending (Hummel and Lake 2015). Despite profound theoretical, political, and practical challenges, there is widespread and growing interest in, as well as legislative and policy support for, knowledge integration that includes traditional knowledge and science. This attention is

### Management and Policy Implications

Participatory Geographic Information Systems (PGIS) can offer a powerful approach for enhancing current decisionmaking by allowing for the integration of traditional and scientific knowledge systems with spatial environmental data in an interactive participatory process. Integrated data sets can allow traditional and scientific knowledge experts to share, explore, manage, analyze, and interpret multidimensional data in a common spatial context to develop more informed management decisions. Such combined data sets could provide a more comprehensive assessment of fire-related ecological change than is currently used in decisionmaking and enhance inclusion of effects on local resource utility values and areas of cultural significance. The use of a PGIS interface creates opportunities for traditional knowledge holders to share information and potential prescriptions while maintaining confidentiality. Knowledge integration efforts using PGIS as an organizational tool would help to bridge the communication gap that commonly exists between scientists, managers, and traditional knowledge holders as ecosystems continue to be altered through processes of land management and climate change.

rapidly growing, fueled by motivations to enhance biocultural diversity, promote social justice for indigenous peoples, supplement scientific studies, and provide new prescriptions for environmental management (Bohensky and Maru 2011). Although these motivations are neither mutually exclusive nor entirely harmonious, all acknowledge that we need new ways to address longstanding as well as emerging complex social-ecological challenges.

In the United States, fire and fuels management has incorporated traditional knowledge on a very limited basis, despite considerable traditional knowledge about historic fire regimes (Lake 2007, Carroll et al. 2010). A growing number of federal, state, and tribal governments and academic institutions have held workshops to discuss the potential benefits and challenges of knowledge integration for fire management (Alvarado et al. 2011, Mason et al. 2012), whereas others are conducting research about the benefits and feasibility of such efforts (Ray et al. 2012). However, little fire knowledge integration work has actually been performed and assessed.

There are some exceptions to the current sparseness of on-the-ground implementation in the United States. Active efforts are underway to preserve, rejuvenate, and/or share traditional fire knowledge, with the intent of expanding the application of traditional practices in landscapes where traditional fire management was once the norm (Huffman 2013, Voggeser et al. 2013). Several landscapes in the US Fire Learning Network (USFLN) have begun to rejuvenate their traditional fire knowledge systems. The USFLN, a cooperative program of the US Department of Agriculture (USDA) Forest Service, the four fire agencies of the Department of the Interior, and The Nature Conservancy, supports multi-stakeholder, multiscale efforts to restore fire-adapted social-ecological systems (Butler and Goldstein 2010). Over the past decade, 13 Native American tribes have engaged as partners in the USFLN, with the rejuvenation of traditional fire knowledge a direct or indirect result of the restoration of landscapes formerly dominated by traditional fire regimes. Participating groups are members of the Apache, Caddo, Crow, Eselen, Ho-Chunk, Karuk, Klamath, Paiute, Pueblo, Shoshone, Warm Springs, Washoe, and Yakima Tribes (Huffman 2013, USFLN 2014). Other interagency-tribal partnerships are also expanding. Although

the rejuvenation of traditional fire knowledge is not the explicit intent, these partnerships are important to increase investment and sense of ownership, enhance social capital and cooperation, and disrupt the power dynamics that in the past led to the exclusion of indigenous groups from fire management decisions that have affected and continue to affect them. These include tribal engagement in Landscape Conservation Cooperatives, collaborative networks designed to coordinate conservation science and better address local and regional concerns, and other region-specific partnerships to help mitigate the effects of climate change and wildfire (for a review, see Voggeser et al. 2013).

With respect to applied traditional fire knowledge integration research in the United States, perhaps the most notable and relevant work includes ongoing efforts at the USDA Forest Service Pacific Southwest Research Station in collaboration with the Department of Natural Resources of the Karuk Tribe in California. The Karuk Tribe reported development of an Eco-Cultural Resources Management Plan that incorporates tribal perspectives, including extensive traditional knowledge of prescribed fire and the landscape's dependence on seasonal fire-induced change (Lake 2007, Lake et al. 2010, Karuk Tribe Department of Natural Resources 2014).

Based on extensive review of 21st century social science research about indigenous wildfire management in the United States and elsewhere, Christianson (2015) concluded that these efforts may be limited not because of a lack of interest but by obstacles to conducting research with indigenous communities, including ethical requirements, added time needed to build relationships, and differences in worldviews. Many others have argued that traditional and scientific knowledge systems are radically asymmetrical, and, in the extreme, incommensurable, in addition to numerous other place-specific environmental, social, and political issues (e.g., Nadasdy 1999, Dickson 2009). Oftentimes, inadequate means to organize and communicate traditional knowledge with scientists and managers can limit its consideration in management decisions. Scientists most commonly communicate knowledge with scientific papers that managers rely on heavily to justify decisions, whereas the more traditional indigenous method of knowledge transfer might be with stories (Watson et al. 2012). Such challenges

require novel approaches to cross-cultural communication and collaboration.

## Fire Knowledge Integration via PGIS

We propose that PGIS offers a means of providing an organizational platform for the assemblage and communication of traditional knowledge vital to fire and fuels management, while preserving linkages to its broader cultural contexts. PGIS provides a framework for assembling and integrating such knowledge by providing a common map-based mechanism for the involvement of traditional knowledge holders in the description of and decisionmaking about processes related to space. PGIS avoids expert decisionmaking that can later be challenged simply for not being able to incorporate good understanding of local knowledge about local history and relationships with places.

From an information technologies perspective, PGIS provides a means to store, manage, and use contributed geospatial data through digital media, compare the patterns of these data to other GIS data sets, and enable data sharing among stakeholders (Carver et al. 2001, Elwood 2006). When coupled with textual data (e.g., participants' written comments), PGIS can allow the designation of landscape properties on the basis of the meanings people ascribe to locations and thus lead to a better understanding of spatial relationships between elements of humanized ecosystems (Carver et al. 2001). From the perspective of participatory action research (e.g., Chevalier and Buckles 2013), PGIS acts counter to the approach of command and control of environmental management issues by including traditional knowledge holders in the planning process, with the goals of including their perspectives on the problem and promoting shared knowledge, understanding, and trust between all parties to avoid conflict and/or facilitate conflict resolution.

A few studies have demonstrated that there are many benefits to integrating traditional and scientific knowledge in a GIS spatial framework, which include incorporating inputs and policies at various levels of spatial aggregation, promoting spatial and temporal thinking about issues and concerns, and creating opportunities for learning and sharing of responsibilities (e.g., Bethel et al. 2011). However, we are unaware of examples of applied spatial knowledge integration research from traditional and scientific

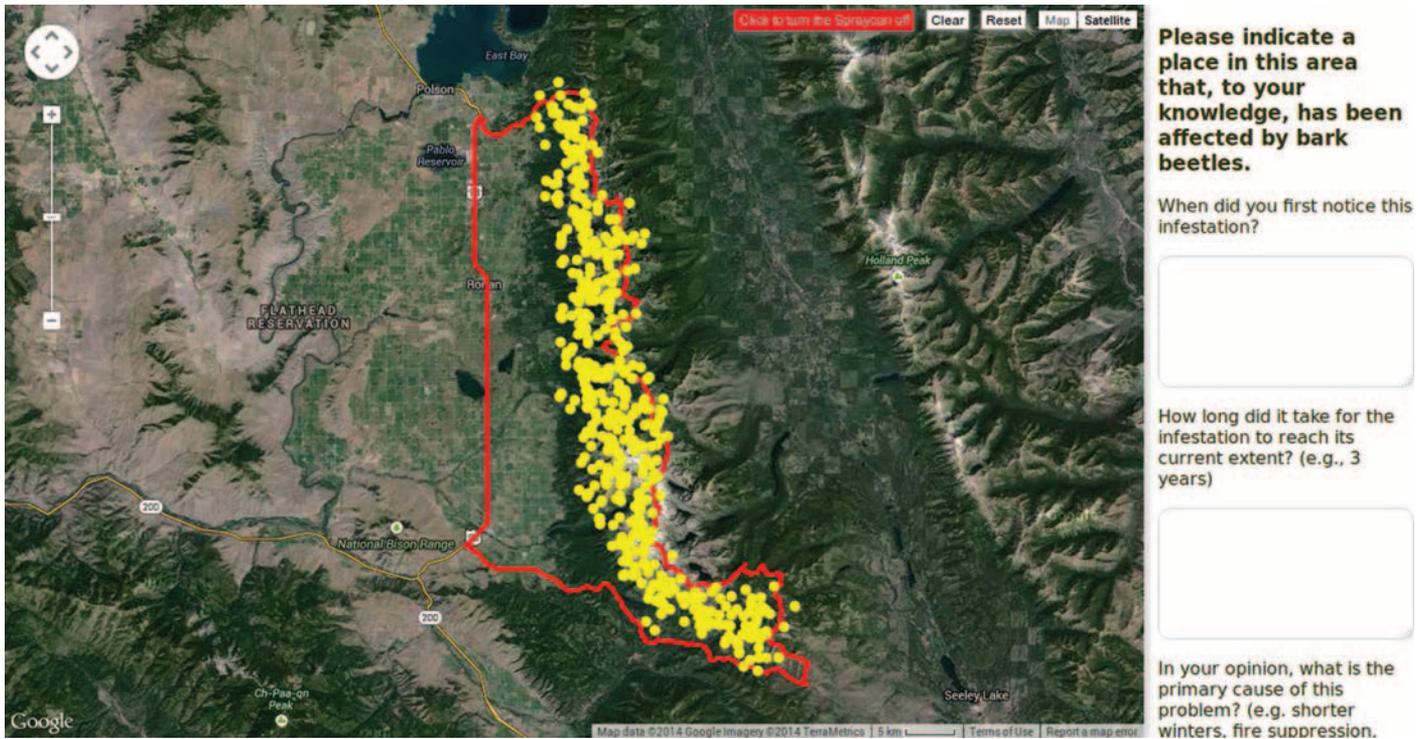


Figure 1. Map-Me user interface. Terrain model from Google Imagery and TerraMetrics.

knowledge sources to inform decisionmaking in fire and fuels management.

We suggest that fire knowledge integration efforts might focus on collaborative GIS methods for integrating traditional and scientific knowledge systems with spatial environmental data in an interactive participatory process. Ultimately, this would allow traditional and scientific knowledge experts to share, explore, manage, analyze, and interpret multidimensional data in a common spatial context to develop more informed fire management decisions. Fire planning decision-support tools that incorporate traditional and scientific bodies of knowledge could provide a more comprehensive means of assessing ecological change that can benefit both ecosystem sustainability and human community adaptability by including greater local and historical context. Such research would represent an innovative effort to merge diverse spatial, biophysical, and traditional knowledge systems about fire into a format suitable for informing current fire decision-support processes at a resolution suitable for localized decisionmaking. It would also engage users directly in the process of analyzing current conditions and anticipated effects of fire-related management efforts. Such combined data sets could provide a more comprehensive assessment of fire-related ecological change than is currently used in decisionmaking and that in-

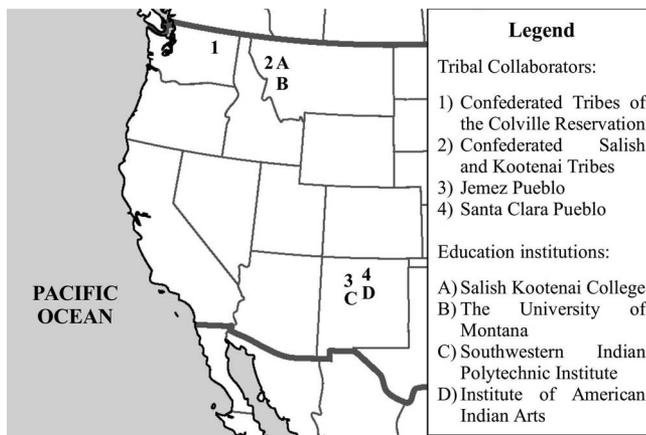
cludes effects on local resource utility values and areas of cultural significance.

By seeking collaborative partnerships for assessing impacts and uses, public and tribal officials as well as scientists engaged in the fire management analyses may also gain support from commercial and other users because the latter are brought in as partners to contribute to the sustainability of the ecosystem on which they depend. Such research would continue to increase the dialogue and discussion among multiple groups, local ecosystem users and scientists/government officials, fostering mutual respect and knowledge transfer that will be sustained beyond the term of a given study. If such a goal is achieved, local residents may continue to provide researchers with insight, informed suggestions, and critique, thus aiding the mapping process and interpretation of mapped images and ultimately helping to inform the fire decisionmaking process for the foreseeable future. Such efforts would address the general lack of understanding about the information value that traditional fire knowledge offers to contemporary management and start to bridge the communication gap that typically exists between public land managers and traditional knowledge holders as ecosystems continue to be altered through processes such as fire management and climate change. Much as Diaz et al. (2016) suggest that better education of local

people about ecological conditions will foster understanding of fire management strategies, this article posits that better education of fire managers about local cultural knowledge of the ecosystem will foster generation of more effective and efficient adaptive fire management strategies.

### Applying a PGIS Tool: Mapping Meanings

One PGIS tool, called Mapping Meanings (Map-Me<sup>1</sup>), developed cooperatively by the Aldo Leopold Wilderness Research Institute and the Universities of Leeds and Lancaster in the United Kingdom, has previously been applied for examining and resolving contentious issues surrounding fire and fuels management to support restoration of fire on tribal lands (Carver et al. 2009, Watson et al. 2009). Map-Me allows participants to answer standard demographic and thematic questions and then proceed to a number of geospatial questions using a “spraycan” tool on a Google Maps layer (Figure 1). The spraycan tool enables participants to locate phenomena on a map in a fuzzy manner (Huck et al. 2014). They can also use this technology to “spray” more or less intensely to indicate levels of importance or depth of feelings on an issue. And in a text box, they can explain this intensity through their own stories about specific places, specific experiences, or important



**Figure 2. Locations of tribal collaborators in the Intermountain West of the United States.**

symbolic or emotional meanings attached to specific areas. The mapping data collected using Map-Me can be compared across subgroups of subjects, and they can be statistically compared with other data sets and GIS layers, such as land cover, land use, fire regime history, and others, to look for patterns and correlates suggesting reasons for and the rationale behind participants' responses and their relationships with the landscape.

Building on existing research partnerships, we initiated four case studies to explore the potential of using this PGIS tool as a platform for integrating traditional and scientific knowledge to inform fire and fuels management in the Intermountain West of North America (Figure 2). We conducted a series of outreach initiatives with tribal collaborators to (1) discuss the problems and potentials of integrating traditional and scientific knowledge in fire and fuels management, (2) gain understanding about the most pressing research and stewardship/management needs related to fire and fuels management in the place(s) they are knowledgeable about, (3) introduce them to PGIS and Map-Me as a means of assembling traditional and scientific fire knowledge to inform management strategies, and (4) collaboratively develop a series of new questions and propositions to guide future initiatives to incorporate traditional knowledge in fire and fuels management.

Our introductions to Map-Me for study collaborators ranged from informal discussions to full-day workshops on PGIS fundamentals and applications, with a focus on relevant previous case studies as examples (e.g., Carver et al. 2009, Watson et al. 2009). Workshops also involved demonstrations of Map-Me, brainstorming sessions about local environmental management issues that might be explored using it, and

hands-on training, with small groups each working to generate new Map-Me modules that could be used to explore their respective integration questions. In this way, partners and collaborators became familiar with the Map-Me tool and realized its potential for addressing their needs.

Once we had gained understanding of the fire and fuels management issues at hand and collaborators had gained familiarity with Map-Me, we engaged in in-depth conversations with collaborators to identify how Map-Me might best be used. We then worked in some cases to implement collaboration projects based on this problem definition or to communicate participants' ideas in the form of new questions and propositions to help guide future initiatives in these places.

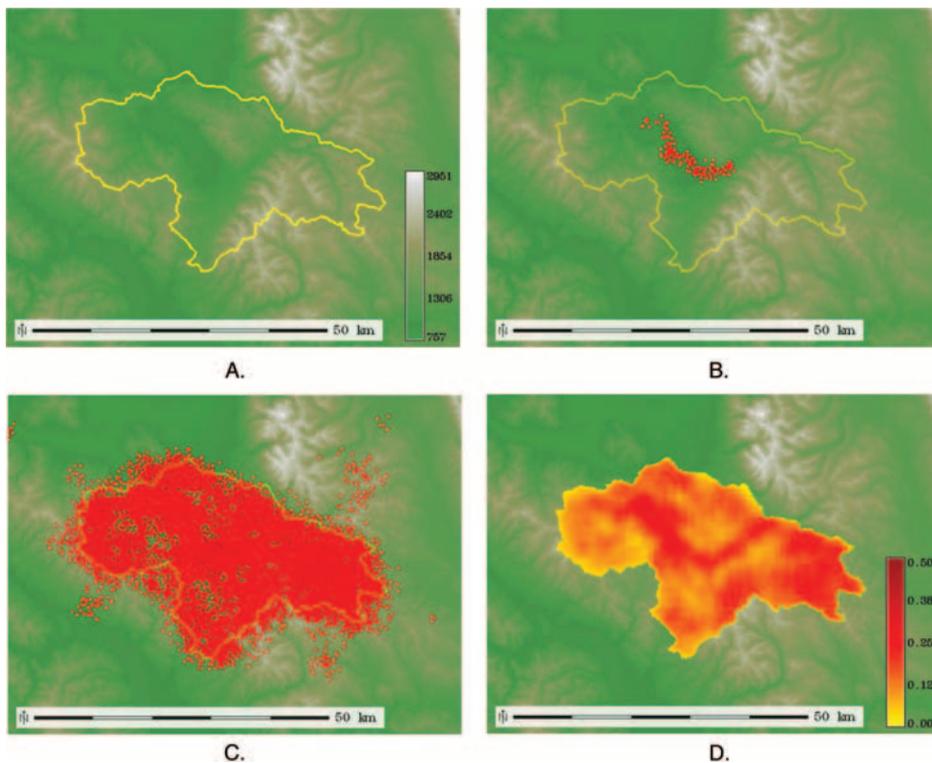
### **Flathead Indian Reservation, Montana**

The Forestry Department of the Confederated Salish and Kootenai Tribes (CSKT) is developing a section of the Flathead Indian Reservation Forest Management Plan that prescribes adaptive planning to mitigate the negative effects of climate change on tribal forestlands, particularly with respect to changing fire regimes. Discussion led directly to definition and recent completion of a project to determine climate change impacts to tribal resources in the Jocko Landscape Unit as outlined in the management plan (Matt et al. 2016). The Map-Me tool was used by the CSKT Forestry Department to identify areas tribal resource managers and reservation residents believed had changed, their perceptions about how these places have changed over time, the causes of those changes, and desired future conditions. Map-Me output was compiled to illustrate different perceptions of the landscape (Figure 3a–d). Tribal and nontribal residents identified different areas

that had become overgrown and/or have developed hazardous fuels accumulations, and they held different perceptions of where prescribed fire might be implemented to achieve future condition targets (Figures 4A–D).

With respect to areas that were identified as overgrown, tribal members identified the tribal primitive area on the eastern side of the Jocko landscape unit as well as the Middle Jocko Valley, whereas nontribal members focused on the Middle Jocko Valley (Figure 4A and B). With respect to where prescribed fire was suggested on the landscape, tribal members identified the tribal primitive area, whereas nontribal members identified the valley floor (Figure 4C and D). Interestingly, tribal members focused on the implementation of prescribed fire only in the tribal primitive area, even though they identified both the river valley and tribal primitive area as being overgrown (Figure 4A and C). Whereas tribal and nontribal residents differed in their perceptions of where the most change has occurred and where prescribed fire should be a method used to accomplish future goals, both groups suggested that traditional burning practices should be reintroduced into the landscape.

In cooperation with the CSKT Forestry Department, we determined that there are opportunities for further use of a PGIS approach to knowledge integration. Propositions include the following: Will a PGIS application be a useful means to organize and compare features of traditional fire knowledge about the landscape with local fire management plans implemented by tribal and federal land management agencies since the middle of the 20th century, providing further insights into how these knowledge systems and approaches have complemented and/or contrasted over time? and From an historical perspective, can demography-based disagreements over fire and fuels management be linked to the evolution of geospatial properties of the local landscape (e.g., land cover, land use, and fire regime histories), providing a multidimensional, complex, and spatially aware interpretation of public responses. Challenges to addressing these propositions include the fact that the Flathead Indian Reservation has several unique landscape units with spatially explicit meanings, some intrareservation cultural history differences (across confederated tribes), and the continuing need for outside technical consultation on PGIS module development and GIS analysis. Exploration of



**Figure 3. Visualization of Map-Me output. a.** Jocko Landscape Unit superimposed on an elevation model, depicting altitude in meters. **b.** Spray pattern from a single participant in response to “Please indicate an area that you believe has changed over the years.” **c.** Spray patterns from all respondents ( $n = 28$ ). **d.** Heat map of all spray patterns, depicting the relative frequency that each cell on the map was marked by respondents.

these complexities are underway as these propositions are being tested now.

### Santa Clara Pueblo, New Mexico

In recent years, the Jemez Mountains in northwestern New Mexico have been hit by a series of natural disasters that have seriously affected the ecosystems and socioeconomic dynamics of local settlements, consisting mainly of Pueblo communities, worsening their already difficult situations in relation to employment and economic development. From 2011 (Las Conchas Fire, 150,000 acres) to 2013 (Thompson Ridge Fire, 24,000 acres; Diego Fire, 3,500 acres), nearly 180,000 acres of forestland in the Jemez Mountains have been severely burned by wildfires, in addition to a series of drought and flooding events that have swept away the organic soils, making the process of forest and watershed recovery even more challenging. Much of Santa Clara Pueblo’s protected cultural area has been burned, along with archeological and historical cultural sites related to the Pueblo on adjacent public lands. Further, Santa Clara Creek and watershed have suffered from extreme erosion.

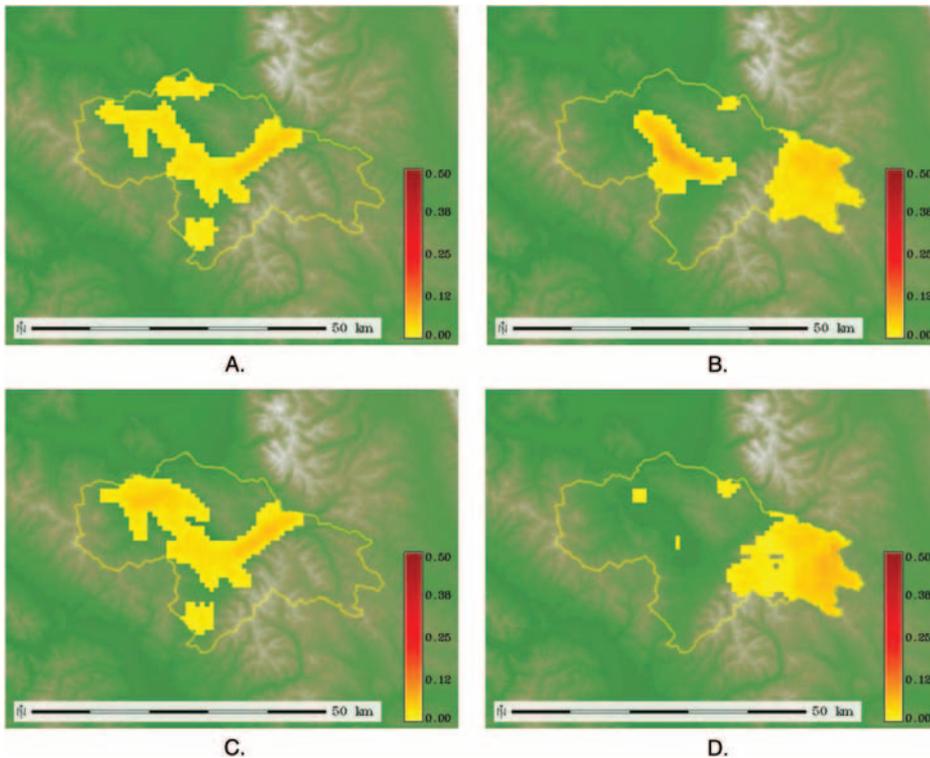
The people of Santa Clara Pueblo hold

a rich store of traditional knowledge about its ecosystem that can make significant contributions to landscape and streambed restoration efforts (Stumpff 2015). For instance, Stumpff (2015) described the upper reaches of Santa Clara Creek as a shrine, the middle section holds knowledge of ancestral dwellings and ways of existence, and the lower section provides a homeland for sustainable agriculture. Restoration in each section should be done within both an ecosystem and a cultural context. In order for the community and lands to recover from these recent fires, there is a tremendous need to incorporate traditional knowledge and cultural concerns at all levels of planning, future fire response, and postfire restoration. However, there are many barriers to such incorporation. These include limited coordination between state, federal, tribal, and local governments that prevents traditional knowledge from being incorporated in recovery initiatives; and a tendency toward “one-size-fits-all” prescriptions and practices that exclude traditional knowledge and often present environmentally and culturally inappropriate approaches to postfire flood control (Stumpff 2015).

In consultation with natural resource managers at Santa Clara Pueblo, we have posed the question: How can traditional knowledge be integrated with best postfire restoration science practices to contribute to the recovery of Santa Clara Pueblo? We developed several propositions, including the following: PGIS will improve coordination between governments by fostering the assembly of traditional and scientific knowledge systems for postfire rehabilitation; traditionally constructed water catchment systems will provide a more effective, environmentally sound, and culturally appropriate means of postfire flood control than uniform prescriptions, with PGIS helping to determine where such catchments should be located and construction materials; and PGIS will enable traditional knowledge to inform rehabilitation efforts by helping to identify plant species that are best suited to current climatic conditions on a local scale. These propositions, although aimed to increase efficiency in protecting cultural aspects of the landscape, may be perceived as in conflict with one-size-fits-all efficiency efforts using culturally insensitive technological solutions. Building trust among parties to explore alternative solutions that could prove more resistant to future impacts and increase efficiency over the long run will be challenging.

### Jemez Pueblo Lands, New Mexico

The catastrophic wildfires that have devastated Santa Clara Pueblo and wildlands now are highly likely to impact Jemez Pueblo, located only 67 miles west of Santa Clara Pueblo, across Valles Caldera Natural Preserve. Public bodies that manage land in this immediate region include Puebloan governments, the National Park Service, the USDA Forest Service, and the Valles Caldera Trust. In a meeting including representatives from Jemez Pueblo and Valles Caldera Trust, we asked: How can traditional knowledge be integrated with contemporary hazardous fuels reduction practices to contribute to the protection of Jemez Pueblo? We proposed the following: (1) a PGIS framework will enhance collaboration between the Jemez community and management agencies, enabling the adoption of more locally and culturally appropriate fire and fuels management actions; geovisualization of the cultural impacts of fire can inform managers of areas of cultural sensitivity and concern that require special treatment; and traditional phenological knowledge about the timing and effects of prescribed



**Figure 4.** Tribal ( $n = 15$ ) and nontribal ( $n = 10$ ) respondents' perceptions of areas of overgrowth and where prescribed fire should be implemented (note: 3 respondents did not specify their tribal membership). A. Areas linked to comments about vegetation overgrowth by tribal respondents. B. Areas linked to comments about vegetation overgrowth by nontribal respondents. C. Areas linked to comments about implementing prescribed fire by tribal respondents. D. Areas linked to comments about implementing prescribed fire by nontribal respondents. Heat maps depict the relative frequency with which each cell on the map was marked by respondents.

fires of the past will improve efforts to reduce hazardous fuels by identifying the most suitable locations and environmental conditions under which to implement low-intensity burns. Agency efforts to incorporate traditional knowledge to increase resistance to future fire impacts on cultural landscapes are poorly informed. Once the knowledge is more readily available, building trust through commitment to incorporate that knowledge into practical guidelines will be the challenge. Funding for and implementation of scientific studies that document resistance effectiveness are also needed and are crucial to this knowledge integration effort.

### Colville Indian Reservation, Washington

In 2012, the Northeast Washington Forest Vision 2020 project (Northeast Washington Forest Vision 2020 2011) was selected for funding under the USDA Forest Service High Priority Restoration Program. In 2013, Forest Vision 2020 was assimilated into the Northeast Washington Collaborative Forest Landscape Restoration Program (CFLRP) to ensure continued funding. The

Forest Vision 2020 proposal makes a compelling case for restoring the landscape to more traditional fire regimes by increasing the forest's resilience to natural disturbance, breaking up the homogeneity of the landscape mosaic, thinning overcrowded, suppressed stands, and enhancing the development of fire-resistant late/old forest structure. Questions that the monitoring plan seeks to address include: How have the past and present fuels treatments implemented by Colville National Forest influenced cultural plants of interest or other cultural uses to the Confederated Colville Tribes (CCT) and what is the likelihood and likely effects of a large fire event traveling from Forest Service lands onto the Colville Reservation and Colville tribal allotments within the CFLRP boundary? How can Colville National Forest use fuel treatments to maintain and enhance cultural plants and other values of interest to the CCT while reducing the likelihood of a large fire event damaging the CCT's identified values at risk? In discussions with representatives

from the CCT and Colville National Forest, we proposed the following: PGIS can be a means of organizing CCT members' geographic knowledge of past, present, and desired future distributions of cultural uses on the Colville National Forest and their perceptions of conservation risk related to prescribed burning, mechanical treatments, and wildfire on Colville lands; and PGIS can provide a mechanism for periodically comparing this knowledge with the effects of fuels treatments over time as part of the monitoring strategy. Data collection for this case study has been implemented, and challenges emerged related to needs to adjust the PGIS tool to accommodate inclinations of participants to impart large volumes of information over a lengthy data collection interview, pushing the limits on data storage and access time allocations in online applications. This type of knowledge is not easily or automatically reduced to nominal or binomial data forms, so PGIS devices and data collection methods must be adapted to cultural inclinations for sharing information in a story manner.

### Conclusion

In a time of rapid environmental and social change, barriers to fire and fuel management activities will continue to threaten the integrity and resilience of social-ecological systems. As in other kinds of natural resource management, cross-cultural problem solving about fire is complex, but it is possible. Our ability to adapt will require reciprocal knowledge exchange, collaboration, and proactive approaches toward bringing together insights from multiple knowledge sources and worldviews.

We sought to build on the gathering momentum in favor of knowledge integration for fire and fuels management in the United States. Using PGIS as an organizational framework and an integrative tool, we have laid foundations for several new, active collaborations in the Intermountain West. We hope to continue to increase dialogue and discussion among traditional knowledge holders, fire and fuels managers, scientists, and governing agencies, fostering mutual respect and knowledge sharing that will be sustained into the future through increased collaboration.

Challenges associated with the previously relatively untested technological capacity of PGIS to capture voluminous traditional or place-specific knowledge emerged and have been addressed. There remains a need for development of frameworks for ap-

plication of acquired integrated knowledge, and there is a need to counter motivations to achieve efficiency in postfire restoration through culturally insensitive technological solutions. In all cases, when one is working with tribes and potentially sensitive information, there is a need for specific guarantees to protect gathered place or culture-specific knowledge but still allow integration with other sources of knowledge for information sharing. This challenge can be overcome through demonstration of commitment to better decisionmaking and building trust but can also be addressed through memorandums of understanding, letter agreements, and specific wording in study plans and contracts.

## Endnote

1. For more information, see map-me.org.

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