Article:

McBride, BB, Sanchez-Trigueros, F, Carver, SJ et al. (2017) Participatory Geographic Information Systems as an Organizational Platform for the Integration of Traditional and Scientific Knowledge in Contemporary Fire and Fuels Management. Journal of Forestry, 115 (1). pp. 43-50. ISSN: 0022-1201

https://doi.org/10.5849/jof.14-147

Participatory Geographic Information Systems as an organizational platform for the integration of traditional and scientific knowledge in contemporary fire and fuels management

Suggested running head: Participatory GIS for knowledge integration

Abstract

Participatory Geographic Information Systems (PGIS) provide an organizational platform for the integration of traditional and scientific knowledge in contemporary fire and fuels management, while preserving linkages to broader cultural contexts. This paper summarizes the results and implications of an exploratory project that included the following objectives, to: (1) build new research partnerships, and expand upon those existing, with tribal collaborators across the Intermountain West of North America; (2) in collaboration with tribal partners and using PGIS as an integrative tool, initiate a set of case studies about the potential applications of traditional knowledge for social-ecological adaptation to changing fire regimes in a contemporary context; and (3) develop a series of new questions and hypotheses to guide future research initiatives on the incorporation of traditional knowledge in fire and fuels management.

Management and Policy Implications

Inadequate means to organize and communicate traditional fire knowledge with scientists and managers can limit its consideration in management decisions. Through this project, we have initiated several new research partnerships, and expanded upon those existing, across the Intermountain West of North America to explore the potential of knowledge integration for fire and fuels management issues, using Participatory Geographic Information Systems (PGIS). PGIS offers a powerful approach for enhancing current decision-making by allowing for the integration of traditional and scientific knowledges 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 standard spatial context in order to develop more informed management decisions. The use of a PGIS interface creates opportunities for multiple stakeholders to share their knowledge and concerns while maintaining confidentiality about culturally significant sites and resources. Knowledge integration efforts using PGIS as an organizational tool would help to bridge the communication gap that commonly exists between scientists and traditional knowledge holders as ecosystems continue to be altered through processes of land management and climate change.

Introduction

For thousands of years, indigenous peoples have used fire to manage their landscapes for a wide variety of subsistence and cultural purposes (Mason *et al*. 2012; Huffman 2013; Voggesser *et al*. 2013). In North America in particular, the frequency and extent of both human- and naturally-ignited fires were greatly reduced after European colonization. It is well-documented that "…the current American landscape reflects the historical legacy of one worldview superimposed on another- the colonial overlaying the traditional…" and that nowhere is this history more apparent than in attitudes toward fire made manifest on the landscape (Kimmerer and Lake 2001, p. 36). Euro-Americans arrived in North America with the conviction that fire was destructive and hazardous to humans, 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. Fire was used as a pragmatic tool to fill a wide variety of subsistence purposes, which were also coupled with an ethical responsibility to carefully use fire to tend the land and its inhabitants (Mason *et al*. 2012; Huffman 2013; Voggesser *et al*. 2013). Fire suppression began soon after colonization, with human-ignited fire all but disappearing from the East by the early 1700s and from the West by 1899, culminating in the fire suppression mentality of the 20th century (Kimmer and Lake 2001; Mason et al. 2012). 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). Given these profound challenges for contemporary fire and fuels management, fire scientists and managers are increasingly turning to traditional knowledge of fire and burning practices to help inform current management strategies.

Traditional Knowledge for Contemporary Management

Many have argued that the time has come to engage traditional fire practitioners in solving problems of global significance (e.g., Kimmerer and Lake 2001; Mason *et al*. 2012; Huffman 2013). Traditional knowledge of fire holds great promise for informing contemporary fire and fuels management strategies and augmenting knowledge and information derived from the western scientific model. It is suggested that this will increase social-ecological resilience of fire-adapted ecosystems in a time of rapid environmental change.

Traditional fire knowledge

A recent, extensive review of traditional fire knowledge systems from around the world identified 69 distinct elements, illuminating great depth and complexity (Huffman 2013). At local and regional scales, traditional fire knowledge entails a multifacteted understanding of how subsets of these multiple elements interact and influence one another; producing many pyrogeographies of considerable nuance and sophistication. Cultural 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 ecosystem resilience to changes in climate (Voggesser *et al*. 2013). In addition to human-ignited fire regimes, tribal cultures have adapted their subsistence strategies and socio-economic systems in response to climate and changing non-anthropogenic fire regimes for millennia. They observed and adapted to the effects of fire on ecological processes at various scales, from local habitats to landscapes encompassing diverse ecosystems (Voggesser *et al*. 2013).

Knowledge integration for social-ecological resilience

To manage the scope, complexity and uncertainty of rapidly changing environmental issues, it is imperative to take account of different types and sources of knowledge. Recognizing that modern problems cannot consistently 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). In environmental management, this is most commonly referred to as knowledge integration (Bohensky and Maru 2011). 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 knowledges and science. This attention is rapidly growing along several lines of argument, including the enhancement of biocultural diversity, promotion of social justice for indigenous peoples, supplementation for scientific studies, and provision of new prescriptions for environmental management (Bohensky and Maru 2011). While these arguments 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.

It is also argued that knowledge integration can build social-ecological resilience, the ability of a social-ecological system to withstand disturbance without changing its fundamental structure, function, feedbacks and identity, and to remain flexible in response to changing environmental and social contexts (Redman and Kenzig 2003; Walker *et al*. 2006). The resilience view holds that the management of complexity and uncertainty can benefit when diverse types of knowledge are combined, and argues that there is opportunity in complexity; that the flux of traditional and scientific worldviews that breed complexity can in fact offer a chance to revisit old problems and paradigms, and collectively construct new models of how the world works (Houde 2007; Plummer and Armitage 2007).

Knowledge integration in U.S. fire and fuels management

In the U.S., fire and fuels management has incorporated traditional knowledge on a very limited basis, despite considerable traditional knowledge of 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 potentials and challenges of knowledge integration for fire management (Alvarado *et al*. 2011; Mason *et al*. 2012), while others are conducting research as to benefits and feasibility of such integration (Ray *et al*. 2012). However, little integration work has actually been performed and assessed. Ray *et al*. (2012) identified numerous 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.

Project Objectives

This project has sought to build upon the gathering momentum in support of knowledge integration for fire and fuels management in the United States. Much traditional knowledge has been lost to time and forced assimilation, but much persists in the oral tradition and practices of contemporary native communities (Kimmerer and Lake 2001). In practice, however, inadequate means to organize and communicate traditional knowledge with scientists and managers can limit its consideration in management decisions. Many argue that traditional and scientific knowledges are radically asymmetrical, and in the extreme, incommensurable, in addition to numerous other place-specific environmental, social, and political issues surrounding knowledge integration (e.g., Nadasdy 1999; Dickison 2009). Such challenges require novel approaches to cross-cultural communication and collaboration.

We propose that Participatory Geographic Information Systems (PGIS) is one such means of providing an organizational platform for the assemblage, archiving, and communication of traditional knowledge vital to fire and fuels management, while preserving linkages to its broader cultural contexts. PGIS has the capacity to assemble and integrate such knowledge by providing a mechanism for the involvement of multiple stakeholders in the description of and decision-making about processes related to space. 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 datasets, and enable data sharing amongst 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 to environmental management issues by including a range of stakeholders in the planning process, with the goals of including diverse perspectives on the problem and promoting shared knowledge, understanding and trust between all parties to avoid conflict and/or facilitate conflict resolution.

With PGIS as our primary method, we contend that facilitating the combination of experiential with experimental knowledge and fostering complementarity of different knowledge systems can contribute to more resilient social-ecological outcomes in fire and fuels management. In this paper, we summarize and discuss the results and implications of an exploratory project that has included the following primary objectives, to:

(1) build new research partnerships, and expand upon those existing, with tribal collaborators across the Intermountain West;

(2) in collaboration with tribal partners, initiate a set of case studies of the potential application of traditional knowledge for social-ecological adaptation to changing fire regimes using PGIS; and

(3) propose a series of new questions and hypotheses to guide future research initiatives on the incorporation of traditional knowledge into contemporary fire and fuels management.

Methods

The project began with a series of outreach initiatives to prospective tribal collaborators across the Intermountain West to discuss the problems and potentials of integrating traditional and scientific knowledge in fire and fuels management, with the intent of forming new research partnerships. Objectives were to: (1) meet individuals in person and form a personal and professional rapport; (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 as a means of assembling traditional and scientific fire knowledge to inform management strategies; and (4) invite their collaboration on future joint research proposals.

We worked specifically with a PGIS tool called Mapping Meanings (Map-Me), developed cooperatively by the Aldo Leopold Wilderness Research Institute and the Universities of Leeds and Lancaster. Earlier versions of Map-Me have already been applied for examining and resolving contentious issues surrounding fire and fuels management, to support restoration of fire and in assessing community attitudes toward impacts of climate change on benefits from protected areas (Carver *et al*. 2009; Watson *et al*. 2009). Map-Me (http://map-me.org) 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, critically providing comments about the places they have sprayed (Figure 1). The spraycan tool enables participants to locate phenomena on a map in a fuzzy manner (Huck *et al*. 2014). Data collected using Map-Me can also be statistically compared to other datasets and GIS layers, such as land cover, land use, fire regime history, etc., to look for patterns and correlates suggesting reasons for and rationale behind participants' responses and their relationships with the landscape.

Our introductions to Map-Me for project collaborators ranged from informal discussions to full-day workshops on PGIS fundamentals and applications, with a focus on relevant previous case studies as examples. 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 surveys that could be used to explore their respective research 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. In Montana and New Mexico, tribal liaisons identified and interviewed key tribal informants using indigenous research methodologies (Smith, 2012). We then worked to communicate participants' ideas in the form of new questions and hypotheses/propositions to help guide future research initiatives in these places.

Results

Existing partnerships were enhanced, and new partnerships were formed in the states of Montana, New Mexico, and Washington (Figure 2). We helped to facilitate research planning for the incorporation of traditional fire knowledge in a broad range of fire and fuels management objectives, using PGIS as an integrative tool. On the Flathead Reservation in northwestern Montana, we examined residents' perceptions of where prescribed fire should be implemented in response to climate change impacts, and the importance of traditional knowledge to these efforts. In the Jemez Mountains of northern New Mexico, we focused on issues related to post-fire restoration and hazardous fuels reduction in and around Santa Clara and Jemez Puebloan lands. In collaboration with the Confederated Colville Tribes in northeastern Washington, we considered the role of traditional knowledge in determining appropriate locations and strategies for fuels treatments to enhance conditions for culturally important plant species while reducing risk of large fire events.

A case study on climate change impacts to tribal resources (water, vegetation, and fire regimes) in the Jocko Landscape on the 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 negative effects of climate change on tribal forest lands, particularly with respect to changing fire regimes. The objective of this project was to determine climate change impacts to tribal resources in the Jocko Landscape Unit as outlined in the management plan. The Map-Me tool was employed by the CSKT Forestry Department to gather perceptions from tribal and non-tribal residents and natural resource managers about how the landscape has changed over time, the causes of those changes, and desired future conditions (Figure 1). Participants were also asked how traditional knowledge might be applied to help address these challenges. Map-Me output was analyzed to illustrate both cultural and biophysical attributes of the landscape (Figures 3a-d). Tribal and non-tribal residents identified different areas as being overgrown and/or having hazardous fuels accumulations, and held different perceptions of where prescribed fire should be implemented (Figures 4a-d). With respect to areas that were identified as overgrown, tribal members identified the southern section of the Mission Mountains Wilderness area on the eastern side of the Jocko landscape unit as well the Middle Jocko Valley, whereas non-tribal members identified the Middle Jocko Valley (Figures 4a, b). With respect to where prescribed fire should be reintroduced to the landscape, tribal members identified the wilderness area, whereas non-tribal members identified the valley floor (Figures 4c, d). Interestingly, tribal members focused on the implementation of prescribed fire only in the wilderness area, even though they identified both the river valley and wilderness as being overgrown (Figures a, c). Whereas tribal and non-tribal residents different in their perceptions of where the most change has occurred and where prescribed fire should be implemented, both groups suggested that traditional burning practices should be reintroduced into the landscape. Yet, both groups expressed uncertainty as to how this knowledge might be incorporated into management plans.

We inquired: How can traditional knowledge be integrated into the CSKT Forest Management Plan? Hypotheses included: (1) PGIS is a means to organize and compare features of traditional fire knowledge about the landscape with local fire management plans implemented by 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 (2) from an historical perspective, demography-based disagreements over fire and fuels management can be linked to the evolution of geospatial properties of the local landscape (e.g., land use, land use, fire regime histories), providing a multidimensional, complex, and spatially-aware interpretation of public responses.

Traditional knowledge for the post-fire rehabilitation of 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 socio-economic 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 Rige Fire, 24,000 acres; Diego Fire, 3,500 acres) nearly

180,000 acres of forest land in the Jemez 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. In order for the community and lands to recover, there is a tremendous need to incorporate traditional knowledge and cultural concerns at all levels of planning, fire response, and post-fire 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 uniform prescriptions and "one-size-fits-all" practices that exclude traditional knowledge and often present environmentally and culturally inappropriate approaches to post-fire flood control. We posed the question: How can traditional knowledge be integrated with best post-fire restoration science practices to contribute to the recovery of Santa Clara Pueblo? We developed several hypotheses, including: (1) PGIS will improve coordination between governments by fostering the assembly of traditional and scientific knowledges for post-fire rehabilitation; (2) traditional water catchment systems will provide a more effective, environmentally sound and culturally appropriate means of post-fire flood control than uniform prescriptions, with PGIS helping to determine where such catchments should be located; and (3) 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.

Traditional knowledge for the reduction of hazardous fuels on and around Jemez Pueblo lands, New Mexico. The high likelihood of catastrophic wildfires that have devastated Santa Clara Pueblo and wildlands now threatens to impact Jemez Pueblo, located only 67 miles (108 kilometers) 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, Forest Service and the 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 hypothesized that, (1) PGIS will enhance collaboration between the Jemez community and management agencies, enabling the adoption of more locally and culturally appropriate fire and fuels management actions; (2) geovisualization of the cultural impacts of fire can inform managers of areas of cultural sensitivity and concern that require special treatment; and (3) traditional knowledge about prescribed fire will improve efforts to reduce hazardous fuels by identifying the most suitable locations and conditions under which to implement low-intensity burns.

Developing a strategy for monitoring the effects of fire management activities on culturally important plant species on Colville National Forest lands bordering the Colville Indian Reservation, Washington. In 2012, the *Northeast Washington Forest Vision 2020* project (*NWFV 2020* 2011) was selected for funding under the Forest Service High Priority Restoration Program. In 2013, Vision 2020 was assimilated into the Collaborative Forest Landscape

Restoration Program (CFLRP) to ensure continued funding. The 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 to the Confederated Colville Tribes (CCT) and the likelihood 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 of interest to the CCT while reducing the likelihood of a large fire event damaging the CCT's identified values at risk? We proposed: (1) PGIS is a means of organizing CCT members' knowledge of past, present, and desired future distributions of culturally important plant species and their perceptions of highest-risk areas on Colville lands; (2) PGIS provides a mechanism for comparing this knowledge with the effects of fuels treatments over time as part of the monitoring strategy.

Discussion

Through this project, we have built upon the gathering momentum in favor of knowledge integration for fire and fuels management in the U.S. Using PGIS as an organizational framework and an integrative tool, we have laid foundations for several new research collaborations across the Intermountain West. We now consider our work in light of other fire knowledge integration efforts in the U.S., the implications of fire knowledge integration via PGIS, and the notion of fire knowledge integration for social-ecological resilience.

Knowledge integration for more holistic fire management

A growing number of governmental, academic and other institutions in the U.S. are convening to discuss the challenges, potentials, and feasibility of knowledge integration in fire management, but little integration work has been performed and assessed.

There are some exceptions to the current sparseness of on-the-ground implementation in the U.S. Active efforts are underway to recover, 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; Voggesser *et al*. 2013). Several landscapes in the U.S. Fire Learning Network (USFLN) have begun to rejuvenate their traditional fire knowledge systems. The USFLN, a cooperative program of the U.S. Forest Service, the four fire agencies of the Department of the Interior, and The Nature Conservancy, supports multi-stakeholder, multi-scalar efforts to restore fire-adapted social-ecological systems (Butler and Goldstein 2010). Over the past decade, thirteen 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, Esselen, Ho-Chunk, Karuk, Klamath, Paiute, Pueblo, Shoshone, Warm Springs, Washoe, and Yakima Tribes (USFLN 2014; Huffman 2013). Other interagency-tribal partnerships are also expanding. While 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 power dynamics that in the past led to the exclusion of indigenous groups from fire management decisions that have 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 (reviewed by Voggesser *et al*. 2013).

With respect to applied traditional fire knowledge integration research in the U.S., perhaps the most notable and relevant work includes ongoing efforts at the U.S. Forest Service Pacific Southwest Research Station in collaboration with the Department of Natural Resources of the Karuk Tribe in California. The Karuk Tribe is currently developing 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).

Fire knowledge integration and PGIS

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, while a recent, extensive review of traditional fire knowledge systems around the world has been conducted (Huffman 2013), and fire knowledge integration practices are expanding as discussed, we are unaware of examples of applied spatial knowledge integration research from traditional and scientific knowledge sources to inform decision-making in fire and fuels management.

To demonstrate how fire knowledge integration may be used to enhance current decision-making processes, future efforts should focus on collaborative GIS methods for integrating traditional and scientific knowledges with spatial environmental data in an interactive participatory process for establishing fire management priorities and enhancing current decision-making processes. This would allow traditional and scientific knowledge experts to share, explore, manage, analyze, and interpret multidimensional data in a standard spatial context in order 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. Such research would represent an innovative effort to merge diverse spatial, biophysical, and traditional knowledges about fire into a format suitable for informing current fire decision-support processes at a resolution suitable for localized decision making. 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 ecological change than is currently utilized in decision making that includes effects on local resource utility value and areas of cultural significance.

By seeking collaborative partnerships for assessing impacts and uses, state 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 dialog 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, ultimately helping to inform fire decision-making 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, as well as start to bridge the communication gap that typically exists between scientists and traditional knowledge holders as ecosystems continue to be altered through processes of fire management and climate change.

Fire knowledge integration for social-ecological resilience

Given the tremendous interest in and support for the argument that knowledge integration builds social-ecological resilience, there is still little empirical evidence to support this claim. Based on a recent, extensive review of a decade of international discussion on knowledge integration, Bohensky and Maru (2011) found that little of the literature engages substantively with resilience theory, and where it does, the relationship between traditional knowledge, integration and resilience is not particularly clear. While there has been a strong theoretical basis and a few empirical studies supporting this argument, their analysis points to the need to further confront this claim with real-world evidence. This represents a key research frontier for the theory and practice of knowledge integration, in fire and fuels management and beyond.

Conclusion

In a time of rapid environmental and social change, disruptions to fire activity will continue to threaten the integrity and resilience of social-ecological systems. Our ability to adapt will require reciprocal knowledge exchange, collaboration, and proactive approaches toward bringing together insights from multiple knowledge sources and worldviews. As in other kinds of natural resource management, cross-cultural problem solving about fire is complex, but it is possible. We hope to continue to increase dialog and discussion between traditional knowledge holders, fire and fuels managers, scientists and governing agencies, fostering mutual respect and knowledge sharing that will be sustained beyond the term of this study.

References

Alvarado, E., L. Mason, A. Leighton, G. White, G. Morishima, J. Durglo, C. Hardy, J. Erickson, L. James, and E. Isaac. 2011. Integration and application of traditional ecological knowledge for contemporary for contemporary wildland fire management in tribal lands of North America. Fifth International Wildland Fire Conference, South Africa. Available online at http://www.wildfire2011.org/material/papers/Ernesto_Alvarado.pdf; last accessed Oct. 9, 2014.

Bethel, M.B., L.F. Brien, E.J. Danielson, S.B. Laska, J.P. Troutman, W.M Boshart, M.J. Giardino, and M.A. Phillips. 2011. Blending geospatial technology and traditional ecological knowledge to enhance restoration decision-support processes in coastal Louisiana. *Journal of Coastal Research* 27: 555-571.

Bohensky, E.L., and Y. Maru. 2011. Indigenous knowledge, science, and resilience: what have we learned from a decade of international literature on "integration"? *Ecology and Society* 16:6.

Butler, W.H., and B.E. Goldstein. 2010. The US Fire Learning Network: springing a rigidity trap through multiscalar collaborative networks. *Ecology and Society* 15: 21.

Carroll, M.S., P.J. Cohn, T.B. Paveglio, D.R. Drader, and P.J. Jakes. 2010. Fire burners to firefighters: the Nez Perce and fire. *Journal of Forestry* 108: 71-76.

Carver, S., A. Evans, R. Kingston, and I. Turton. 2001. Public participation, GIS and cyberdemocracy: evaluating on-line spatial decision support systems. *Environment and Planning B* 28: 907-921.

Carver, S., A. Watson, T. Waters, R. Matt, K. Gunderson, and B. Davis. 2009. Developing computer-based participatory approaches to mapping landscape values for landscape and resource management. P. 431-448 in *Planning support systems: best practice and new methods*, Geertman, S., and J. Stillwell (eds.). Springer, NY.

Chevalier, J.M., and D.J. Buckles. 2013. *Participatory action research: theory and methods for engaged inquiry*. Routledge, Taylor & Francis Group, NY, 469 p.

Dickison, M. 2009. The asymmetry between science and traditional knowledge. *Journal of the Royal Society of New Zealand* 39: 171-172.

Elwood, S. 2006. Critical issues in participatory GIS: deconstructions, reconstructions, and new research directions. *Transactions in GIS* 10: 693–708.

Houde, N. 2007. The six faces of traditional ecological knowledge: challenges and opportunities for Canadian co-management arrangements. *Ecology and Society* 12: 34.

Huck, J., D. Whyatt and P. Coulton. 2014. Spraycan: a PPGIS for capturing imprecise notions of place. *Applied Geography* 55: 229-237.

Huffman, M.R. 2013. The many elements of traditional fire knowledge: synthesis, classification, and aids to cross-cultural problem solving in fire-dependent systems around the world. *Ecology and Society* 18: 3.

Karuk Tribe Department of Natural Resources. 2014. Official Tribal Website. Available online at http://karuk.us/index.php/departments/natural-resources/dnr; last accessed Oct. 9, 2014.

Kimmerer, R., and F.K. Lake. 2001. The role of indigenous burning in land management. *Journal of Forestry* 99: 36-41.

Lake, F.K. 2007. *Traditional ecological knowledge to develop and maintain fire regimes in northwestern California, Klamath-Siskiyou bioregion: management and restoration of culturally significant habitats*. Ph.D. dissertation, Oregon State University, Corvallis, OR, 732 p.

Lake, F.K., W. Tripp, and R. Reid. 2010. The Karuk tribe, planetary stewardship, and world renewal on the middle Klamath River, California. *Bulletin of the Ecological Society of America* 91: 147-149.

Mason, L., G. White, G. Morishima, E. Alvarado, L. Andrew, F. Clark, M. Durglo, et al. 2012. Listening and learning from traditional knowledge and western science: a dialogue on contemporary challenges of forest health and wildfire. *Journal of Forestry* 110: 187-193.

Moller, H., F. Berkes, P.O. Lyver, and M. Kislalioglu. 2004. Combining science and traditional knowledge: monitoring populations for co-management. *Ecology and Society* 9: 2.

Nadasdy, P. 1999. The politics of TEK: power and the "integration" of knowledge. *Arctic Anthropology* 36: 1-18.

Northeast Washington Forest Vision (NWFV) 2020. 2011. Collaborative forest landscape restoration: proposal for funding. Available online at http://www.fs.fed.us/restoration/documents/cflrp/2011Proposals/Region6/Colville/NEWForestVisionCFLRP2020ver2.pdf; last accessed Oct. 9, 2014.

Plummer, R., and D. Armitage. 2007. A resilience-based framework for evaluating adaptive co-management: linking ecology, economics and society in a complex world. *Ecological Economics* 61: 62-74.

Ray, L.A., C.A. Kolden, and F.S. Chapin III. 2012. A case for developing place-based fire management strategies from traditional ecological knowledge. *Ecology* 17: 37.

Redman, C.L., and A.P. Kinzig. 2003. Resilience of past landscapes: resilience theory, society and the *longue duree*. *Conservation Ecology* 7: 14.

Smith, L.T. 2012. *Decolonizing methodologies: research and indigenous peoples, 2nd edition*. Zed Books, New York, NY. 240 p.

United States of America Fire Learning Network (USFLN). 2014. Fire learning network. Available online at https://www.conservationgateway.org/ConservationPractices/FireLandscapes/FireLearningNetwork/Pages/fire-learning-network.aspx; last accessed Oct. 9, 2014.

Voggesser, G., K. Lynn, J. Daigle, F.K. Lake, and D. Ranco. 2013. Cultural impacts to tribes from climate change influences on forests. *Climatic Change* 120: 615-626.

Walker, B., L.H. Gunderson, A.P. Kinzig, C. Folke, S.R. Carpenter, and L. Schultz. 2006. A handful of heuristics and some propositions for understanding resilience is social-ecological systems. *Ecology and Society* 11: 13.

Watson, A., R. Matt, T. Waters, K. Gunderson, S. Carver, and B. Davis. 2009. Mapping trade-offs in values at risk at the interface between wilderness and nonwilderness lands. P. 375-387 in *Proceedings of the Third International Symposium on Fire Economics, Planning, and Policy: Common Problems and Approaches*, Gozalez-Caban, A. (tech. coord.). USDA Forest Service, Pacific Southwest Research Station Gen. Tech. Rep. PSW-GTR-227.

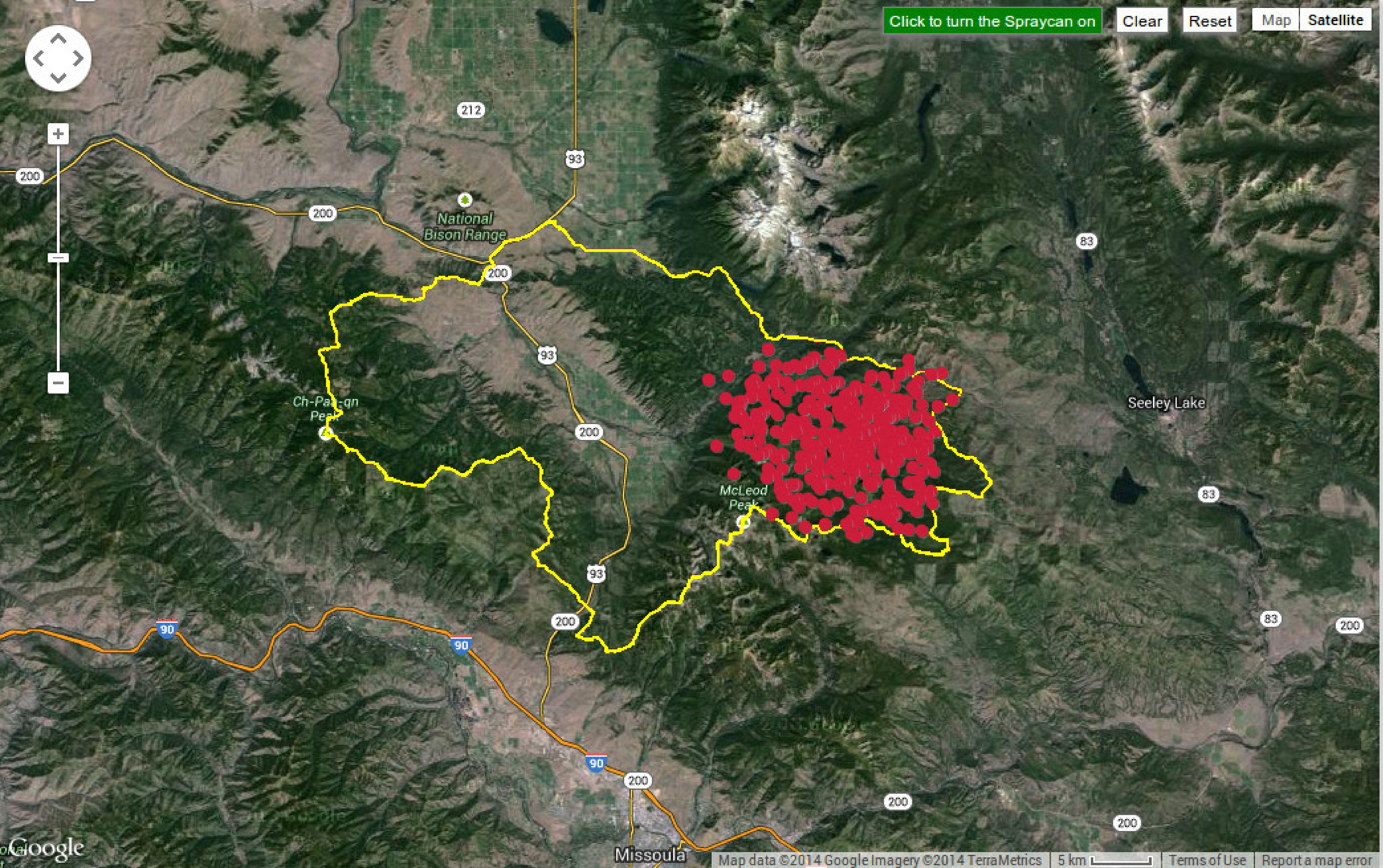
Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313: 940-943.

Figure 1. Map-Me user interface. Map data from Google Imagery and Terrametrics.

Figure 2. Locations of tribal collaborators in the Intermountain West of North America.

Figures 3a-d. 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 reponse to “Please indicate an area that you believed has changed over the years;” c. Spray patterns from all respondents (n = 28); d. Heat map of all spray patterns, depicting the relative frequency with which each cell on the map was marked by a respondent.

Figures 4a-d. Tribal (n = 15) and non-tribal (n = 10) respondents’ perceptions of areas of overgrowth and where prescribed fire should be implemented (Note: 3 respondents did not specify their tribal affiliation). a. Areas linked to comments about vegetation overgrowth, by tribal respondents; b. Areas linked to comments about vegetation overgrowth, by non-tribal respondents; c. Areas linked to comments about implementing prescribed fire, by tribal respondents; d. Areas linked to comments about implementing prescribed fire, by non-tribal respondents. Heat maps depict the relative frequency with which each cell on the map was marked by a respondent.



The area outlined in red is the Jocko Landscape. Please indicate an area that you believe has changed over the years.

What did this area used to be like and what is the source of your knowledge?

Woodlands used to be much more open. I've been gone to this place since the 1960's. Also from Elders

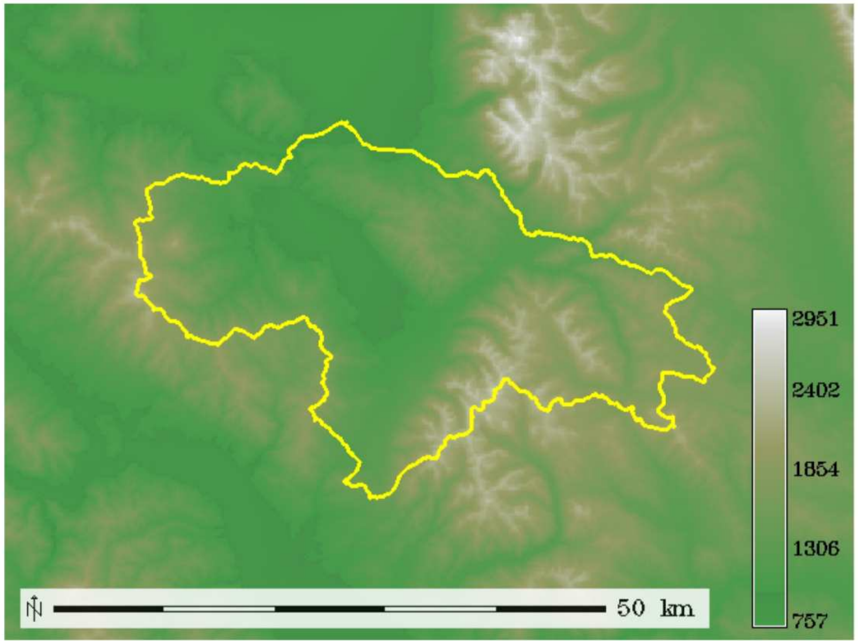
What is the area like now and what do you believe has caused the change from what it used to be like?

Oversized forest. Closed canopy. Unhealthy. They have to thin.

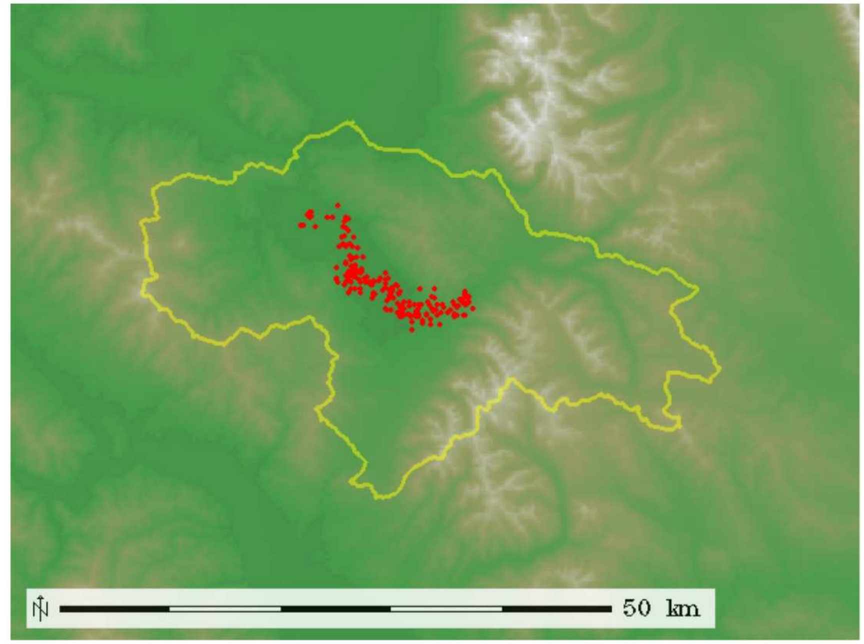
What would you like this area to be like in the future and why?

Thinned forest, for fauna and flora to be in equilibrium. That's how it used to be.

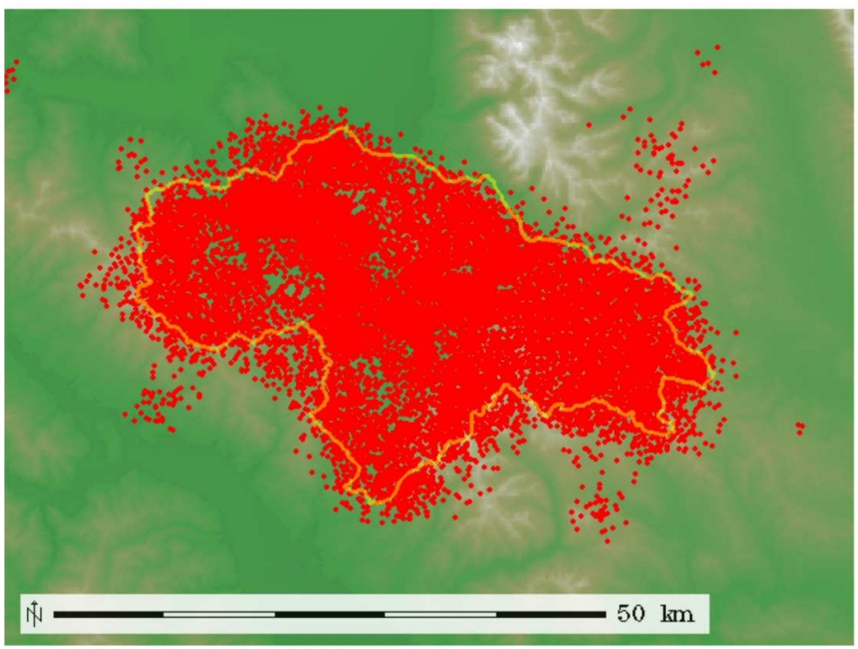

PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico
1
2
3
4
Legend
Tribal Collaborators:
1) Confederated Tribes of the Colville Reservation
2) Confederated Salish and Kootenai Tribes
3) Jemez Pueblo
4) Santa Clara Pueblo


2951
2402
1854
1306
757
50 km

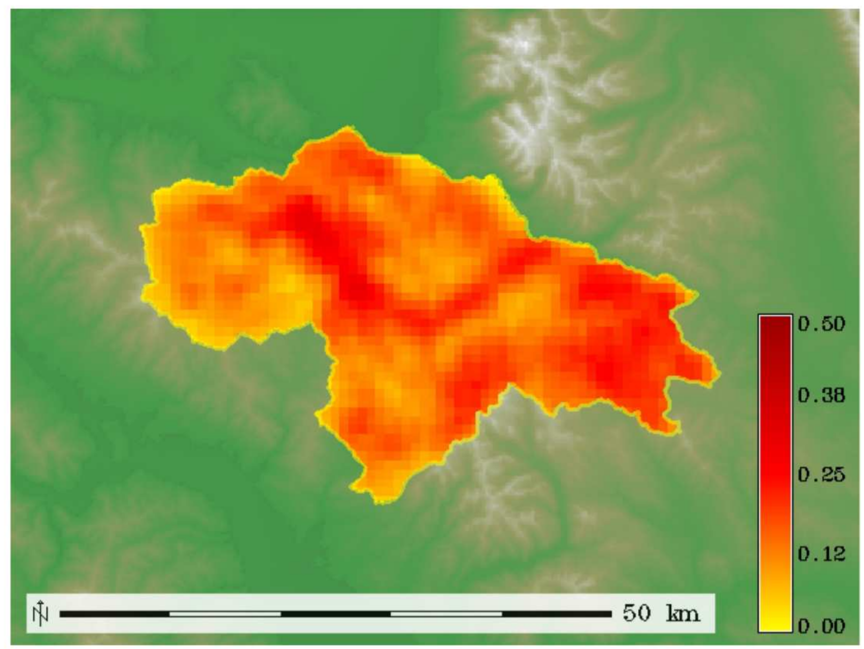
a.


50 km

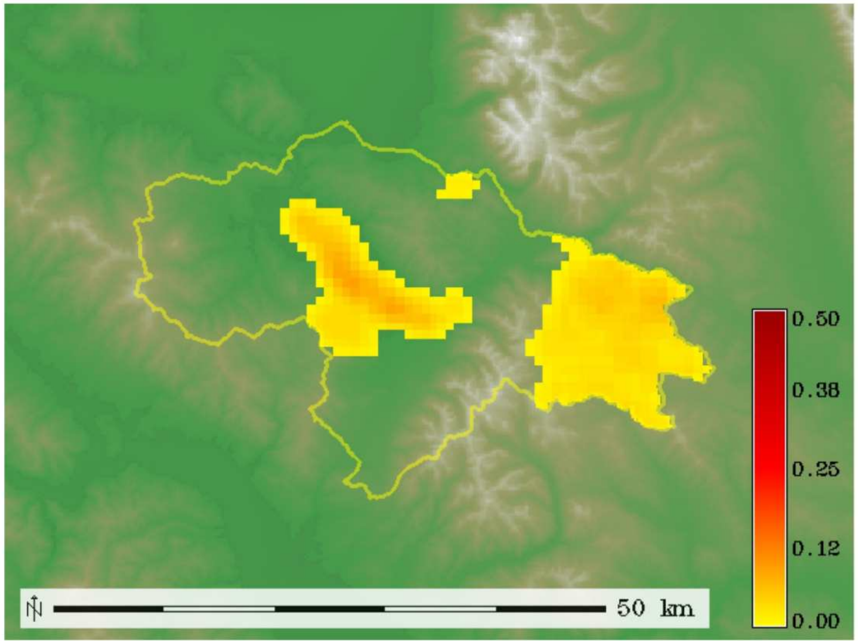
b.


50 km

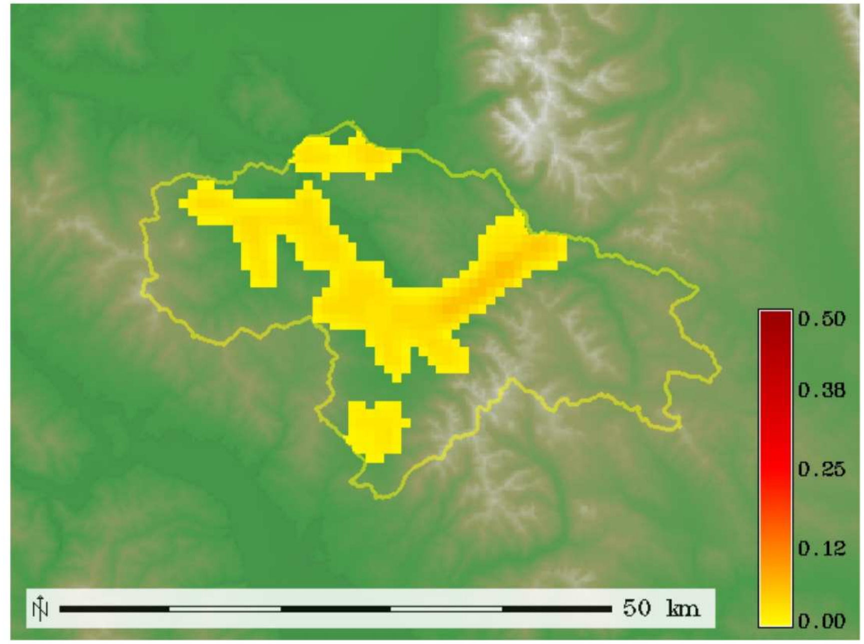
c.


0.50
0.38
0.25
0.12
0.00
50 km

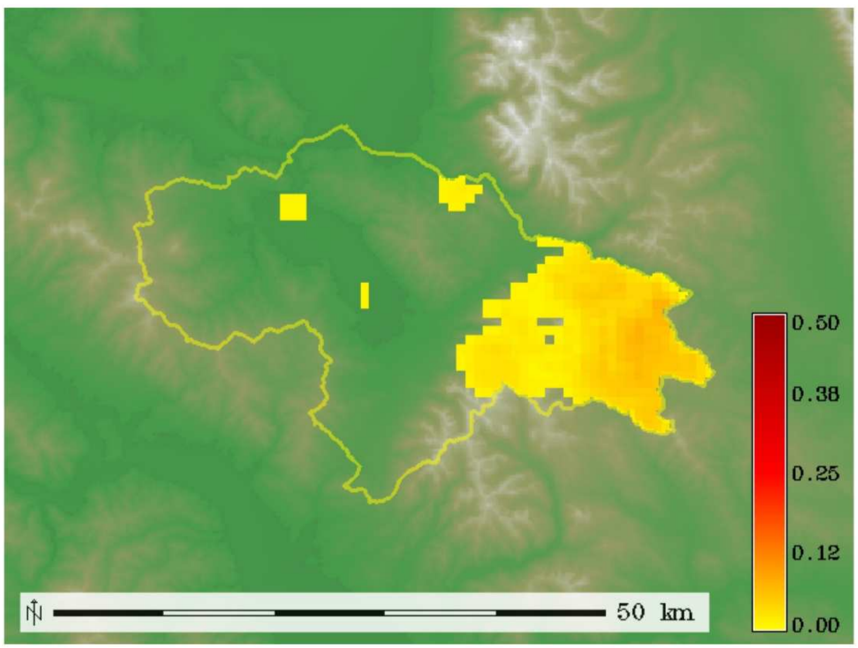
d.


50 km
0.50
0.38
0.25
0.12
0.00

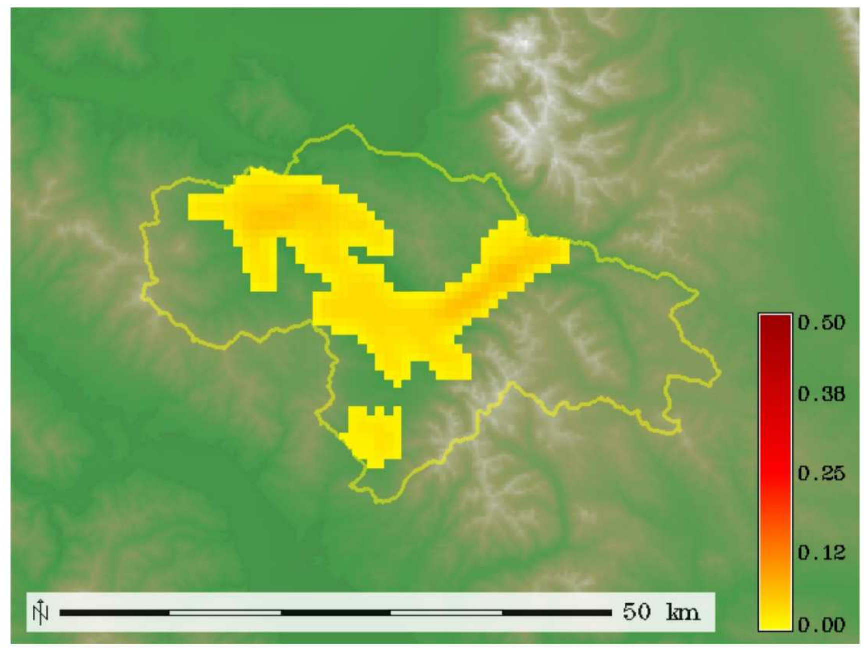
a.


50 km
0.50
0.38
0.25
0.12
0.00

b.


50 km
0.50
0.38
0.25
0.12
0.00

c.


50 km
0.50
0.38
0.25
0.12
0.00

d.