Mapping Webs of Information, Conversation, and Social Connections: Evaluating the Mechanics of Collaborative Adaptive Management in the Sierra Nevada Forests

By

Shufei Lei

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Environmental Science, Policy and Management

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Maggi Kelly, Co-Chair
Professor Alastair Iles, Co-Chair
Professor Lynn Huntsinger
Professor AnnaLee Saxenian

Fall 2014

ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

Mapping Webs of Information, Conversation, and Social Connections:
Evaluating the Mechanics of Collaborative Adaptive Management in the Sierra Nevada Forests

by

Shufei Lei

Abstract

Mapping Webs of Information, Conversation, and Social Connections: Evaluating the Mechanics of Collaborative Adaptive Management in the Sierra Nevada Forests

by

Shufei Lei

Doctor of Philosophy in Environmental Science, Policy and Management

University of California, Berkeley

Professor Maggi Kelly, Co-Chair

Professor Alastair Iles, Co-Chair

Managing within social-ecological systems at the landscape scale, such as in the national forests of the Sierra Nevada of California, is challenging to natural resource managers (e.g. the U.S. Forest Service) due to the uncertainties in natural processes and the complexities in social dynamics. Collaborative adaptive management (CAM) has been recently adopted as a viable strategy to diminish uncertainties in natural processes through iterative policy experimentations and adaptations, as well as to overcome conflicting values and goals among diverse environmental stakeholders through fostering and facilitating collaborations. While many CAM studies have focused on evaluating the management impact on natural systems and processes, few have examined the social engagements and dynamics of management itself. To address this knowledge gap, I examined the various social engagements in CAM, particularly the flow of information products, dialogues in public meetings, and social connections among participants, based on my research case study—the Sierra Nevada Adaptive Management Project (SNAMP).

SNAMP began in 2005 in response to the USDA National Forest Service's 2004 Sierra Nevada Forest Plan Amendment calls for managing the forest using the best information available to protect forests and homes. The participants in the project can be sorted into three primary categories of environmental stakeholders: federal and state environmental agencies, the public and environmental advocacy groups, and university scientists. The project studies the impact of forest fuel reduction treatment on forest health, fire mitigation and prevention, wildlife, and water quality and quantity at two study sites: Last Chance in the northern region of the Sierra forests at Sugar Pine in the southern region. The primary strategies and methods for fostering partnership and facilitating collaboration among the diverse participants are producing science information and making it transparent and publicly accessible, as well as facilitating discussions about such research and management results in public meetings.

To evaluate the effectiveness of CAM in the case of SNAMP, I used a mixed-methods research approach (i.e. citation analysis, web analytics, content analysis, self-organizing maps, social network analysis), by leveraging available information technologies and tools, to characterize and analyze the flow of digital information products, the outcomes of facilitated discussions in SNAMP public meetings, and the resilience of the social networks in SNAMP. Some of the interesting findings include: 1) Scientific knowledge products, in the form of peer-reviewed journal publications, contributed to knowledge transfer between scientists and environmental managers; 2) facilitated discussions helped environmental stakeholders to stay engaged on the important administrative and research topics through time; 3) the social networks experienced turbulence but remained resilient due to the existence of a committed and consistent core group of environmental stakeholders that represent diverse backgrounds and interests. As the picture of how information, conversation, and social connections contributed to the success of CAM emerged, my dissertation provides recommendations to natural resource managers on how to improve in these areas for future implementations of CAM.

TABLE OF CONTENTS

DEDICATION

To my parents Zuojia Lei & Yueqing Mai
and my wife Karen Lei
for their unwavering support, encouragement, and prayers over the years.

ACKNOWLEDGEMENTS

My deepest gratitude goes to my co-advisers, Professor Maggi Kelly and Professor Alastair Iles, who have been guiding and supporting me throughout my graduate career. They gave me directions and inspirations for my research when I did not know where to begin. They helped me persist in my dissertation writing when I ran into emotional and intellectual roadblocks. In many occasions, they patiently listened to my struggles, empathized with me, and lifted me up with words of hope, encouragement, and helpful instructions. Words cannot adequately express my gratitude and my feelings of indebtedness toward them.

I want to thank Professor AnnaLee Saxenian, Dean of the iSchool, for giving me her valuable time and advice throughout my graduate program. I also want to thank Professor Dara O'Rouke for our collaboration in GoodGuide, which started my interest and academic pursuit in the field of environmental management. In addition, I am thankful for the opportunities to learn from and work with various professors, namely Professor Tom Gold and Professor Xiao Qiang, on many issues related to China due to my interest in China's environmental issues. Along the way, I was able to have wonderful colleagues, such as former and present Kellylab-mates, Geospatial Innovative Facility staff, and Graham Bullock who pushed me along in my graduate studies.

I want to acknowledge the Sierra Nevada Adaptive Management Project, which has funded me through the graduate program and also become the subject of my graduate research. I am thankful for the opportunities to learn from the scientists, the park rangers, as well as the public environmental stakeholders in the project. I am especially grateful to the members of the SNAMP Public Participation Team: Professor Lynn Huntsinger, Kim Rodriguez, Susan Kocher, Kim Ingram, Anne Lombardo, and Adriana Bombard. Their works in this project has laid down the indispensible and vital foundation for my research.

In my personal circles, first and foremost, I want to thank my parents (Zuojia Lei & Yueqing Mai) for all the years of selfless love, sacrifice, and support since the day that I was born. I also want to thank my beloved wife, Karen Lei, who held down a job, took care of our two young children, and still had the room in her heart to share my stress from graduate studies. The achievement of the doctoral degree is really the fruit of my parents' and my wife's labor and support. I want to thank my parents-in-law, Ken & Amy Kong, for always making sure that we have enough food to eat. I want to acknowledge Craig (brother-in-law), Mable (sister) and Sammy Murray (niece) for their wonderful presence in my life. I want to thank Uncle Yang, Aunt Amy, Aunt Ivy, and Uncle Ken for bringing my family to the United States and for taking care of my family through the years, so that I can have a chance to study and achieve in this country.

I want to thank my spiritual leaders (Pastor Ed & Kelly Kang, Pastor Manny & Sunny Kim, Tony & Michelle Sun, Chul & Sharon Kim, Patrick & Jeannie Lee, and Rick & Sue Yi, and Henry & Susan Shim), my college peers (Kenny Choi, Ben Park, Jin Kim, Henry Chen, Gary Chang, Dan Chiang, Jammy Yang, and Dennis Kang), and many, many other brothers and sisters in Christ in all the Gracepoint churches for their tireless prayers of supplication, as well as encouraging me with God's word. Through their prayers and counsels, I learned to rely on God's power and grace during the difficult times in my graduate studies.

Therefore, lastly and most importantly, I want to give all the praise and glory to my Savior and Lord, Jesus Christ, who has indeed led me all the way! My sentiment is captured by this wonderful hymn: “All the Way My Savior Leads Me”.

All the way my Savior leads me;
What have I to ask beside?
Can I doubt His tender mercy,
Who through life has been my Guide?
Heav’nly peace, divinest comfort,
Here by faith in Him to dwell!
For I know, whate’er befall me,
Jesus doeth all things well,
For I know, whate’er befall me,
Jesus doeth all things well.

All the way my Savior leads me,
Cheers each winding path I tread,
Gives me grace for every trial,
Feeds me with the living bread.
Though my weary steps may falter,
And my soul athirst may be,
Gushing from the Rock before me,
Lo! a spring of joy I see,
Gushing from the Rock before me,
Lo! a spring of joy I see.

All the way my Savior leads me;
Oh, the fullness of His grace!
Perfect rest to me is promised
In my Father’s house above.
When my spirit, clothed immortal,
Wings its flight to realms of day,
This my song through endless ages:
Jesus led me all the way,
This my song through endless ages:
Jesus led me all the way.

Soli Deo gloria!

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

Monitoring social engagements in collaborative adaptive management in the age of information

Managing complex systems

Social-ecological systems is a theoretical framework that emphasizes the inter-connectedness of humans and nature (Berkes, Folke, and Colding 1998). Recognizing that natural resource management occurs within social-ecological systems (SES) makes two major challenges apparent: ecological uncertainties and social complexities. Ecological uncertainties originate from insufficient scientific understanding of the ecological dynamics of the natural resource systems we seek to manage, in which diverse natural resources at varying scales interact with one another leading to unpredictable ecological responses (Holling 1996; Levin 1998). Social complexities also arise at multiple scales, from the processes of national policy formation to the decisions of an individual about the use of a natural resource. Complex interactions among multiple environmental stakeholders, often with conflicting goals and values (Conklin 2006), are a common feature of natural resource management on public lands like the national forests. Lack of trust, poor or obscured communication, and ineffectual collaboration can lead, in some cases, to a lack of the development and implementation of effective management practices, plans and policy.

Traditionally, natural resource management on public lands in the United States has employed "command-and-control," top-down management strategies, which fail to address ecological uncertainties and social complexities (Holling and Meffe 1996). Ecologically, command and control does not adequately diminish uncertainties in managing ecological processes because it assumes incorrectly that ecosystems are relatively stable and static. The approach also focuses on maximizing the performance of one resource; as a result, it ignores the impacts that the changes of a single resource can have on other resources in an interconnected and interdependent ecosystem. Socially, it can feed conflicts arising from social complexities because its governance structure is built on a monolithic and "closed" (not open to public, or those outside the command structure) regulatory and management body that does not involve the public in the management process, or even fully explain management decisions. It breeds mistrust from the public, such as environmental advocacy groups and local communities, because managers are not seen to understand and serve the needs of the public. As the public gains more access to scientific information and legal powers, the primary method for resolving conflicting values and goals is through costly lawsuits; this litigiousness does not foster collaborative attitudes among environmental stakeholders.

To alleviate the antagonism between environmental stakeholders and natural resource managers, the co-management framework (Armitage et al. 2009) was developed to permit managers to share decision-making power with environmental stakeholders in natural resource management. One of the goals of the co-management framework is to foster greater trust in environmental stakeholders through empowerment. However, power sharing is not always legally, politically and institutionally feasible. When power sharing is not feasible, is it still possible to foster collaboration and form partnerships among contentious environmental stakeholders without the natural resource managers sharing decision-making power? What are the appropriate and effective management structure and guiding principles?

In response to these questions, collaborative adaptive management has emerged to address the ecological and social challenges in managing components in social-ecological systems by combining an iterative adaptive management process with collaborative management techniques, without the managers sharing decision-making power with environmental stakeholders (Scarlett 2013). The adaptive management framework is made up of a structured decision-making phase and a learning-adapting phase (Fig. 1-1). The key steps include: assess management problems, synthesize possible solutions, design and implement management policies, monitor management results, evaluate and draw lessons from management results, adjust policies based on the new knowledge, and start the cycle again with the adjusted policies (C. J. Walters and Holling 1990; Allen et al. 2011). This formal, experimental process of developing management policies purportedly increases scientific knowledge about ecosystems over time, allows changes as systems change, and thus reduces uncertainties for management. The collaborative management techniques, on the other hand, seek to reduce mistrust and conflicts among multi-party environmental stakeholders by facilitating social learning, building social networks and capital, and fostering collaborations among parties in contention (Kelly et al. 2012). There is a rich literature describing the types of techniques available for the process (Wondolleck and Yaffee 2000; Greig et al. 2013; Williams and Brown 2014), but less scholarship focuses on evaluating these techniques to understand their impact on the collaborative adaptive management process.

Monitoring in collaborative adaptive management in the age of information

Monitoring the successes and failures of experimental environmental policies is needed to guide policy modifications for future iterative management cycles (Allan et al. 2008). Halbert (1993) argued that the success of adaptive management will be "predicated on clearly established goals and decision criteria that will allow for accountability and evaluation of how goals are being met." More specifically, Halbert (1993) in fishery management and Baskerville (1985) in forest management emphasized the necessity of having specific and applicable measures of performance in order to avoid reducing management to trivial academic discussions.

For example, by comparing three adaptive management case studies, McLain and Lee (1996) highlighted three specific problem areas in operationalizing adaptive management: the use of systems models hampering knowledge acquisition rates, the restricted information flow from scientists to policy makers, and the failure to provide forums for sharing knowledge among stakeholders. Some scholars have focused on how social networks and social capital affect the performance of natural resources management (Janssen et al. 2006; Bodin and Crona 2009; Ernstson et al. 2010; K. C. Nelson et al. 2013). And other scholars have focused on what specific ecological and social factors contribute to the resilience of natural resource management (Walker et al. 2006; Plummer and Armitage 2007; Goldstein 2012). Moreover, efforts at monitoring and evaluation must be able to persist through time in order to increase effectiveness (Armitage et al. 2009). In the case of long-term projects, repeated assessments provide a number of benefits: "comparisons of previous assumptions with what happened; the use of stronger, more locally specific data; and better understanding of system dynamics" (Bormann, Haynes, and Martin 2007). In contrast to the traditional natural resource management approach that concentrates on detailed single-species modeling, measuring changes over time can improve understanding of the dynamics of the whole system (Folke et al. 2005).

These examples show the importance of monitoring and evaluation to the success of an adaptive management project. In the last decade information technologies have created opportunities for new methods of digital engagement and public participation (Kelly et al. 2012). The advancement of information technologies on the Internet (Castells 1996) and the developments in eGovernance (Mol 2008) have benefited environmental management systems in at least three ways. First, the Internet routinely now serves as an effective and efficient information delivery system. Managers can use a website to easily and quickly distribute science and management information to all environmental stakeholders at low monetary and time cost. This allows project participants to obtain more timely information and better track the progress of a project. In addition to information distribution, information technologies can deliver larger and richer content, such as pictures, maps, and videos. Such media rich and visually appealing content may stimulate greater interest and attention from project participants. Second, information technologies and web 2.0 (O'Reilly 2007) open up new avenues for exogenous knowledge from diverse participants, through multi-way communication platforms, website discussion boards for asynchronous communication, and webinars for synchronous, real-time remote communication and participation.

Finally, and most importantly for this dissertation, information technologies have provided better and more extensive tools for data and information tracking (Mol 2006). Numerous useful (and often free or inexpensive) web analytics tools have emerged in the past decade that enable us to better track and analyze the use and flow of digital information (Kaushik 2010). For example, using tools like Google Analytics on a website, a website manager can learn very detailed information about who have visited the site, how long the visitors have stayed on the site or on certain pages, which pages are the most visited, and how visitors travel from one page to another. Rich insights and lessons can be gleaned from such data. In addition to web analytics, other information tools can perform analysis on different kinds of data. For example, social network analysis can analyze people's connections in order to figure out who are important figures in a social network, based on different criteria. Self-organizing maps is an unsupervised, machine learning algorithm that can visualize a body of textual data on a two-dimensional map, which can help quickly uncover key ideas in an unstructured textual dataset.

In this dissertation, I hypothesized that information technologies and tools are useful for monitoring and analyzing different aspects of the social engagements in collaborative adaptive management. I used a case study, the Sierra Nevada Adaptive Management Project, to test this hypothesis, as well as to gain empirical practices and insights into the role of monitoring in collaborative adaptive management.

Sierra Nevada Adaptive Management Project (SNAMP)

The Sierra Nevada Adaptive Management Project began in 2005 in response to the USDA National Forest Service's 2004 Sierra Nevada Forest Plan Amendment. It calls for managing the national forests using the best information available to protect forests and homes. The participants in the project can be sorted into three primary categories of environmental stakeholders: federal and state environmental agencies, the public and environmental advocacy groups, and university scientists. The participating federal and state agencies include the US Forest Service, US Fish & Wildlife Service, CalFire, California Department of Fish & Wildlife, California Natural Resources Agency, California Department of Water Resources, and California Department of Food and Agriculture. The university scientists come from UC Berkeley, UC Merced, UC Davis, UC Cooperative Extension, and the University of Minnesota. Researchers, often referred to as "the science team," have agreed to be the neutral independent party in the project, that is, they will only conduct scientific research regarding forest management without making management recommendations or taking part in the decision making process. Public stakeholders consist of environmental advocacy groups from various regions in California with diverse environmental interests and goals (e.g. Sierra Forest Legacy, Defenders of Wildlife, Sierra Club, American River Watershed Institute, and etc.), of a small group of vocal and concerned individual citizens from local communities, as well as of industry representation, such as Sierra Pacific Industries.

The study subject in the project is the impact of forest fuel reduction treatment on forest health, fire mitigation and prevention, wildlife, and water quality and quantity at two study sites: Last Chance in the northern region and Sugar Pine in the southern region in the Sierra National Forest (Fig. 1-2). Public forestlands in the US West are currently managed by the US Forest Service through complex and often contentious partnerships between public and private entities. However, to sustain the partnership and foster collaboration among contentious parties requires proactive and continuing efforts to build trust. SNAMP attempts to take advantage of the paired developments in collaborative adaptive management and information technologies to foster trust building. SNAMP has used a range of innovative outreach tools to engage stakeholders in the collaborative adaptive management process including traditional face-to-face meetings (e.g. field trips, public meetings, facilitated integration meetings) but also digital tools such as digital information products, webinars, and an interactive website. This multi-modal approach to outreach is increasingly important to public participation, as people have less time and resources to travel to face-to-face meetings, and participants' needs are often diverse. Also, SNAMP has been able to take advantage of the multitude of new evaluation techniques provided by information theory to evaluate the range, impact and effectiveness of public engagement.

Chapter overview

In this dissertation, I focus on monitoring and evaluating the public engagement techniques in SNAMP by using a broad range of evaluation techniques, including web analytics, content analysis and novel machine learning algorithms. I discuss here three research areas: 1) measurement of the use of products created by the SNAMP project for public consumption: research, outreach and web services; 2) an novel analysis of public dialogues over the duration of the project; and 3) the evolving SNAMP social network, in order to assess the effectiveness of collaborative adaptive management in a contentious setting. I provide a brief summary of subsequent chapters below.

Chapter Two tracks the flow of digital information products in SNAMP according to the four-stage (i.e. *production*, *transport*, *use* and *monitoring*) information cycle framework in order to characterize and evaluate the effectiveness of information sharing and social learning that are important to the success of collaboration among multiparty environmental stakeholders in collaborative adaptive management. I use a number of information analysis tools, such as web analytics, citation analysis, and content analysis, to monitor and characterize the use of various science and management information products in SNAMP. The results from this research show that information technologies and systems greatly facilitate the flow and use of digital information, leading to multiparty collaborations such as knowledge transfer and public participation in science research. I conclude with recommendations for how to increase information exchange in collaborative adaptive management.

In Chapter Three I use self-organizing maps (SOM)—a relatively new unsupervised machine learning algorithm that can perform textual analysis—to visualize and analyze meeting notes recorded in SNAMP public meetings. The goal of this study is to understand whether and how collaborative adaptive management has facilitated collaborative discussion in a contentious environmental management setting. Input textual data consisted of the questions and responses from public meetings (2005 to 2012) in which scientific results, project progress, and other issues were discussed. I found that public discussion remained focused on the project content, yet the more contentious and critical issues dominated the discussions through time. Integration across topics could be improved. I conclude that SOM is an effective and efficient unsupervised machine-learning tool for organizing, distilling and making sense of unstructured and unorganized meeting notes, and can be explored more often for this kind of analysis. I also conclude that collaborative adaptive management in SNAMP has been successful in sustaining engagement and facilitating focused discussions among the contentious participants in the project.

Chapter Four explores the social dynamics among the SNAMP participants by applying affiliation network analysis to the attendance data from SNAMP public meetings. The objectives are: 1) to quantitatively characterize aspects of social resiliency of collaborative adaptive management for a social-ecological system; and 2) to understand which factors in SNAMP contributed to its social resilience. I examined 7 years of attendance data at all public meetings associated with SNAMP and constructed an affiliation social network that allowed me to ask questions about project cohesiveness, participation, and overall social resilience. Various patterns among the SNAMP participants and meetings emerged through the analysis: the geographic and core-periphery patterns for the participants, the importance of individuals and particular public meetings, and the variation of cohesiveness of the SNAMP network over time. These patterns suggest that SNAMP showed aspects of social resiliency in the face of exogenous stressors. Important to the success of the SNAMP network were: 1) the ability of members of the management and public groups to become leaders; 2) the project norms of transparency and science integration; and 3) a flexible governance structure.

Chapter Five summarizes the key findings from this dissertation and highlights directions for future research. Collectively, these chapters help us understand that collaborative adaptive management for public lands must involve a variety of engagement techniques, including public meetings and workshops, scientific publications, as well as media outreach in order to facilitate collaboration among multiparty environmental stakeholders, who often have conflicting management values and goals. The performance of these engagement strategies and techniques can be measured and evaluated by information monitoring tools throughout the collaborative adaptive management process to better ensure management success.

This dissertation demonstrates innovative adoption and deployment of freely available and easy-to-use information tools for monitoring collaborative adaptive management. I believe that these monitoring theories and methods may be applied in other participatory natural resource management contexts; therefore, they would be helpful assets to project coordinators for enhancing collaboration and partnership in future participatory management projects. The lessons learned from the case study are transferrable to future collaborative adaptive management projects; therefore, they are valuable knowledge for natural resource managements to reflect upon.

CHAPTER ONE – FIGURES

Fig. 1-1. Adaptive management framework, taken from Allen et al. 2011.

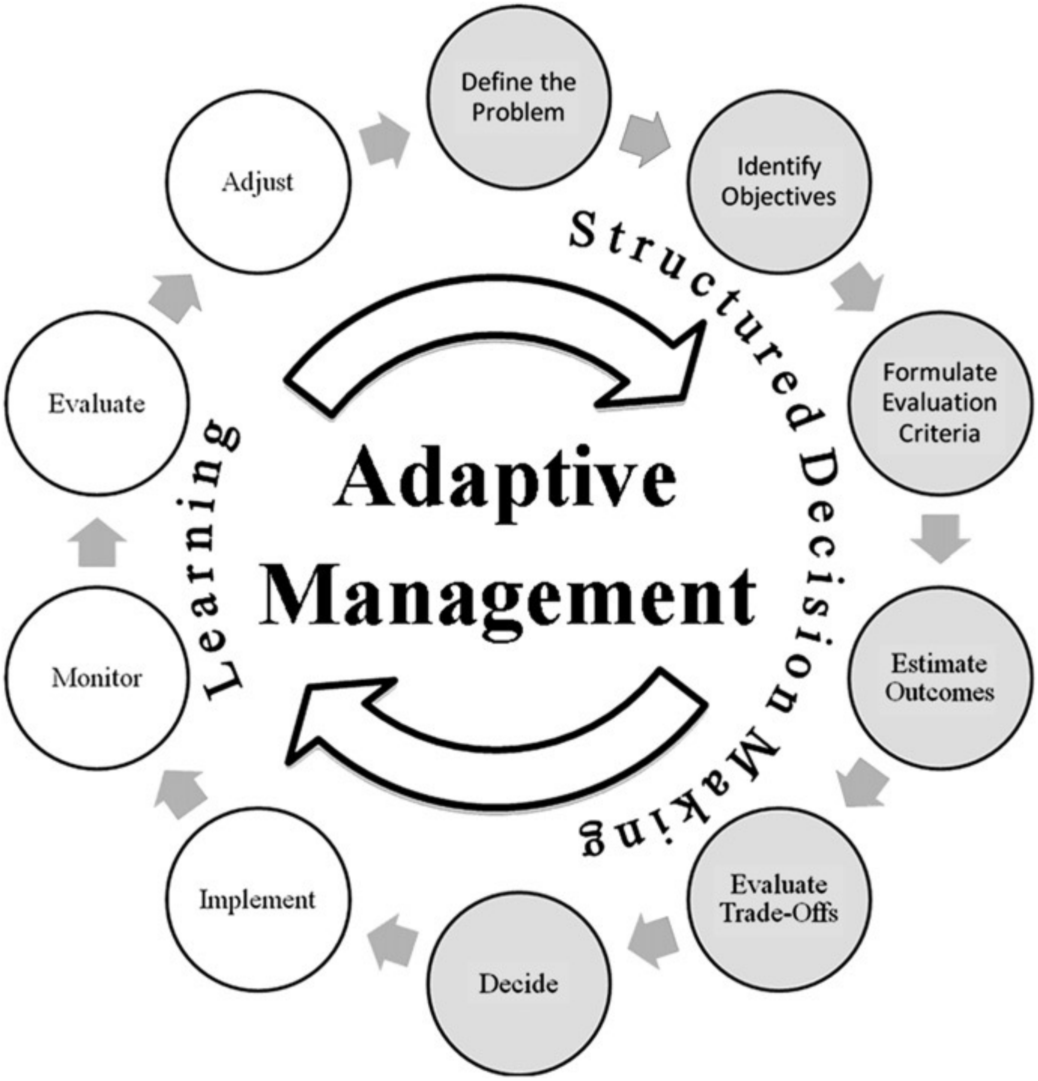
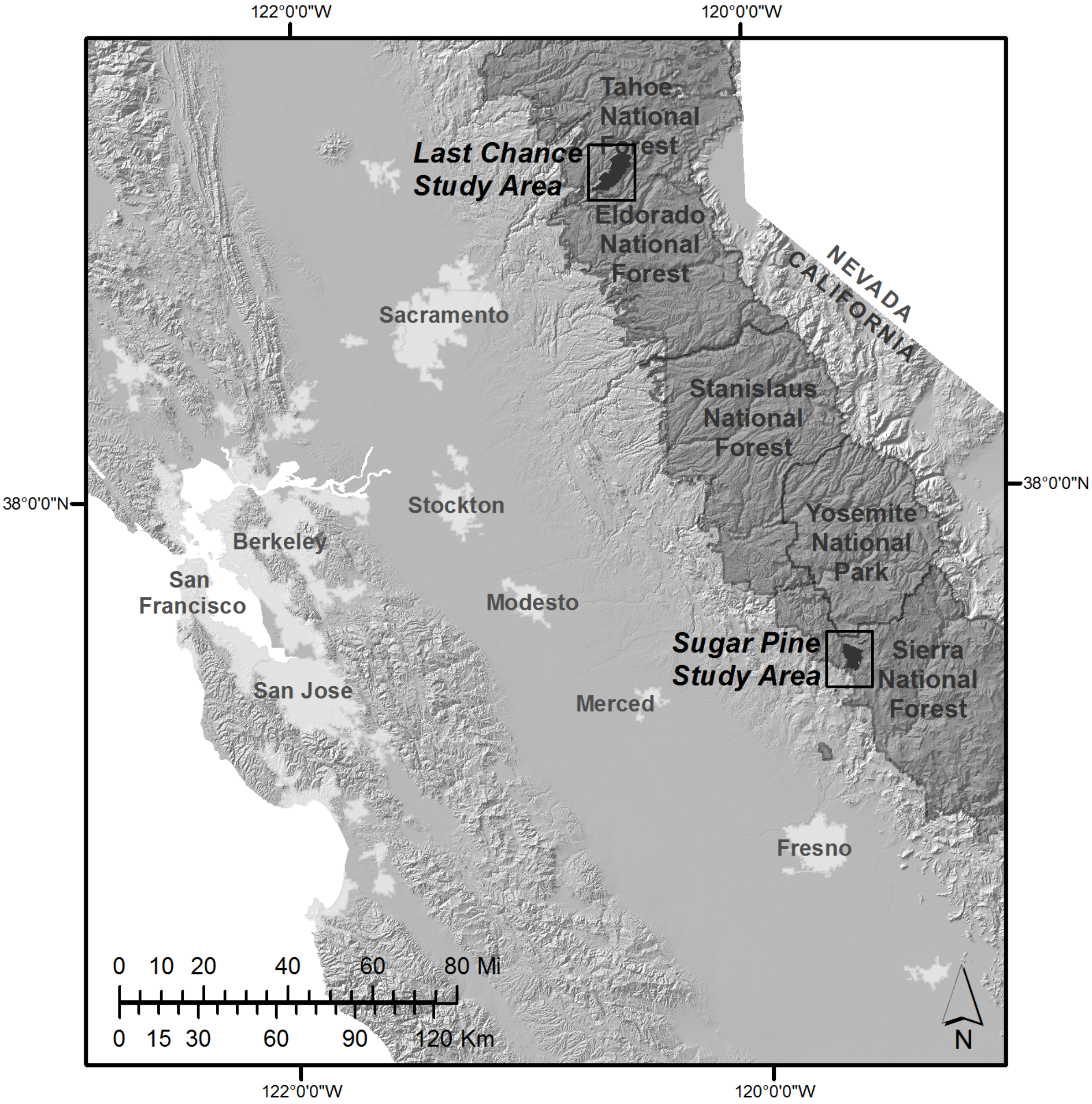


Fig. 1-2. Two SNAMP study areas: Last Chance in the Tahoe National Forest and Sugar Pine in the Sierra National Forest.



CHAPTER TWO

Characterizing the networks of digital information that support collaborative adaptive forest management in Sierra Nevada forests

Some of the factors that can contribute to the success of collaborative adaptive management – such as social learning, open communication, and trust - are built upon a foundation of the open exchange of information about science and management between participants and the public. Despite the importance of information transparency, the use and flow of information in collaborative adaptive management has not been characterized in detail in the literature, and currently there exist opportunities to develop strategies for increasing the exchange of information, as well as to track information flow in such contexts. As digital information channels and networks have increased over the last decade, powerful new information monitoring tools have also evolved allowing for the complete characterization of information products through their production, transport, use, and monitoring. This study uses these tools to investigate the use of various science and management information products in a case study - the Sierra Nevada Adaptive Management Project (SNAMP) - using a mixed methods (citation analysis, web analytics, and content analysis) research approach borrowed from the information processing and management field. The results from our case study show that information technologies greatly facilitate the flow and use of digital information, leading to multiparty collaborations such as knowledge transfer and public participation in science research. I conclude with recommendations for expanding information exchange in collaborative adaptive management by taking advantage of available information technologies and networks.

Introduction

Public forestlands in the US West are currently managed by the US Forest Service through complex and often contentious partnerships between public and private entities. The success (and failure) of such management is often related to the ways in which information is controlled, accessed, and moved between parties (Kelly et al. 2012). This study attempts to provide a quantitative characterization of knowledge transfer in a case study of collaborative adaptive management in publically managed forests in California by tracking the flow of digital information products.

Managing components of social-ecological systems such as forests is challenging due to the ecological uncertainties and social complexities inherent in these systems (Berkes, Folke, and Colding 1998). To effectively address uncertainties in natural systems, Holling (1978) formalized the adaptive management process. Adaptive management aims to reduce uncertainties by learning from science-based, management experimentation (C. J. Walters and Holling 1990). As with adaptive approaches to natural processes, management experimentation follows an iterative, structured decision-making process that: defines the problem; identifies and prioritizes objectives; identifies and implements management; monitors and evaluates outcomes; and adapts management based on implementation results (Allen et al. 2011). There is growing recognition that the social complexities in natural resource management can act as forces of fragmentation that prevent management success (Conklin 2006). Natural resource managers have looked to adaptive co-management (Plummer and FitzGibbon 2007; Armitage, Marschke, and Plummer 2008)—management by sharing power among participating environmental stakeholders—to diminish the forces of fragmentation and, hence, to produce better partnerships and to improve management outcomes because co-management is good for linking different types and levels of organizations and individuals together, facilitating exchange of resources, and providing conflict resolution mechanisms (Carlsson and Berkes 2005). However, since power sharing is not always politically or legally feasible, an alternative management scheme called collaborative adaptive management (CAM henceforth) has been adopted to create a partnership among diverse environmental stakeholders based on co-management strategies and techniques without full sharing of management power.

One of the key building blocks for collaboration is social learning, defined as "the collective action and reflection that occurs among different individuals and groups as they work to improve the management of human and environment interrelations" (Keen, Brown, and Dyball 2005). Pickerton (1994) claimed that collaboration would be more likely to succeed if a social learning process occurred among different stakeholders. To understand how social learning helped collaboration succeed, Schusler et al. (2003) showed that social learning, by means of deliberation, contributed to identifying common purpose and developing collaborative relationships in their study of the Lake Ontario Islands Search Conference. Extending those findings, Plummer and FitzGibbon (2007, 56) argued that "deliberation that enables social learning may produce social capital," which would in turn lead to more collective action and social learning (Berkes 2009). Berkes (2009) further argued that social learning was "one of these tasks, essential both for the cooperation of partners and an *outcome* of the co-operation of partners" when he examined the role of knowledge generation, bridging organizations and social learning in the evolution of co-management. In sum, social learning can increase the chances for collaboration by identifying common purposes, developing collaborative relationships, producing social capital, and fostering cooperation among partners.

Central to studies of social learning in the environmental management context is the production, transfer, and use of knowledge, as Weber and Khademian (2008) argued that knowledge sending, receiving, and integrating were critical tasks for achieving network effectiveness in dealing with "wicked" problems (Rittel and Webber 1973), such as managing within social-ecological systems. In his review of the co-management literature, Berkes (2009) focused on knowledge generation and social learning because these two elements were key to "moving co-management forward." One of Berkes' central points was that knowledge ought to be co-produced and shared among multiple parties at different scales in order to bridge different levels of organizations. In discussing scale dynamics in linked human-environmental systems, Cash et al. (2006) went beyond the conventional scales (i.e. spatial, temporal and jurisdictional scales) and portrayed knowledge as a scale in itself, highlighting the importance of facilitating knowledge scale-crossing and level-crossing to overcome scale challenges in managing such systems.
Despite its importance to dealing with "wicked problems," some scholars have found that studies on learning in the context of adaptive management and co-management remain poorly formulated and vague. Armitage et al. (2008) argued that there exists a "paradox of learning" in collaborative environmental management, that is, while the importance of learning is emphasized, managers still struggle to learn from experience and adapt. Fabricius and Cundill (2014) argued that learning had not been critically analyzed in a practical context; as a result, "researchers and practitioners are no clearer about who learns during the process, what they learn about, and the processes that support the kind of learning outcomes observed or recorded." The

lack of clarity is attributable to the very real difficulties in following the movement of information, as physical forms of information (e.g. a printed environmental report) do not readily produce an information trail, that is, who has read it and how many times it has been read. The advancement of information technologies on the Internet (Castells 1996) has dramatically changed this situation, and environmental governance and management are increasingly facilitated by information systems that perform data and information tracking (Mol 2006). Numerous useful (and often free or inexpensive) web analytics tools have emerged in the past decade that enable us to better track and analyze the use and flow of digital information (Kaushik 2010). Environmental management systems such as CAM have benefited from these developments (Mol 2008). There have been numerous recent studies on the flow of information through social networks (Bodin and Norberg 2005; Knoot and Rickenbach 2011) and information collection and distribution via information systems and technologies on the Internet (Helly et al. 2001; Kearns, Kelly, and Tuxen 2003; Pedersen, Kearns, and Kelly 2007; C. T. Moore et al. 2011; Kelly et al. 2012), but less has been done using these tools to focus on CAM. Thus, there is a great need for a thorough and rigorous characterization of the use and flow of digital information on the Internet for CAM.

This study attempts to provide a quantitative characterization of knowledge transfer by tracking the flow of digital information products in the Sierra Nevada Adaptive Management Project (SNAMP). Tracking the flow of digital information products is used here as a surrogate measure of knowledge transfer processes because information acquisition generally takes place before knowledge formation (Ackoff 1989; Bellinger, Castro, and Mills 2004). The tracking process follows a devised information flow framework inspired by Timmerman et al. (2000) who devised an information cycle framework for water quality monitoring. While the old Timmerman framework focused more on the production and monitoring of information, this study examines four important stages in the information cycle: *production*, *transport*, *use* and *monitoring*. At the *production* stage, the key aspects of information products are: when information is produced; and where and how it is distributed. In the *transport* stage, information is characterized by: travel rate, distance and movement pattern. At the *use* stage, the consumption and impact of information are investigated. And in the *monitoring* stage, the importance and methods for monitoring information is discussed. In this framework, the production, transport, and use stages proceed sequentially while the monitoring stage intervenes throughout the information flow cycle. This systematic tracking and analysis of information flow will enable a more accurate study of the influence of information.

I had three objectives in characterizing the flow cycle of digital information on the Internet in the SNAMP project. The primary objective was to evaluate whether and how online digital information had improved collaboration in CAM. The second objective was to examine how much information technologies and systems facilitated digital information use and flow. Finally, I sought to verify the effectiveness of using a mixed methods approach to measure and evaluate online digital information in CAM.

Case Study: Digital information in SNAMP

Responding to the call from the 2004 Sierra Nevada Forest Plan Amendment (U.S. Forest Service 2004) to manage the forest "using the best available scientific information," the Sierra Nevada Adaptive Management Project (SNAMP) began in 2005 to study the impact of forest fuel treatment strategy - Strategically Placed Landscape Area Treatments (Collins et al. 2010) on forest health, fire mitigation and prevention, Pacific fishers (*Martes pennanti*) and California Spotted Owls (*Strix occidentalis*), and water quality and quantity in two study areas (called Last Chance and Sugar Pine) in the mixed conifer Sierra Nevada forests of northern California. The US Forest Service initiated the creation of a partnership among three broad groups of participants: federal and state natural resource agencies (e.g. U.S. Forest Service, US Fish & Wildlife Service, CalFire, California Department of Fish & Wildlife California Natural Resource Agency, California Department of Water Resources, and California Department of Food and Agriculture); environmental advocacy groups (e.g. Sierra Forest Legacy, Sierra Club, Defenders of Wildlife, and etc.) and local communities; and university scientists from UC Berkeley, UC Merced, UC Davis, University of Minnesota, and UC Cooperative Extension, collectively serving as an independent third-party (Bales et al. 2010). To foster collaboration among the diverse participants in SNAMP, the Public Participation Team (PPT), consisted of University of California Cooperative Extension Specialists, university scientists, information technology experts, and experienced researchers in the field of natural resource management, was tasked to facilitate dialogues in public meetings (e.g. field trip, all stakeholders annual meetings, workshops, and others) (Lei and Kelly 2014 in review) and to make the SNAMP information transparent and accessible to all participants.

Given the diversity of participants, the PPT employed a number of digital information systems and networks to achieve information transparency and accessibility. The online information distribution backbone for SNAMP was its official website, which aimed to provide comprehensive information about the project to the public and all parties involved (Kelly et al. 2012). Visitors to the website could find information about what groups were involved in the project, updates on the latest research activities and findings, a list of upcoming events, and archives of past events and documents. Among these archived documents were founding documents, meeting notes and presentations, maps, and news articles from public news media. To increase the appeal of the content, the website also hosted photos of fishers, owls, research sites, and interaction among participants in public meetings, as well as videos that explained the SNAMP process, forest treatments activities, fisher research, and others. As an attempt to reach more people with the SNAMP information, the PPT also utilized a number of community driven web applications, such as Flickr, YouTube, and Facebook. For a more detailed discussion of the development and maintenance of the website, see Kelly et al. (2012).

In addition to using web technologies, SNAMP also made information transparent by publishing research results in peer-reviewed scientific journals and posting short summaries of research goals, methods and results on the SNAMP website. The primary target audiences for the scientific information were research scientists and forest managers. Another way to digitally publicize the SNAMP information was promoting the SNAMP outreach and research activities to online newspapers and weblogs. The main goal of publicizing the SNAMP information to online media was to inform and engage local communities and environmental advocacy groups. The full spectrum of digital information produced and tracked is found in Table 2-1.

Methods

I analyzed the flow of digital information in a wide variety of digital information products and distribution channels in SNAMP (Table 2-2) through a mixed research methods including citation analysis (Garfield 1972; Bar-Ilan 2006), web analytics (Kaushik 2010; Clifton 2012), and content analysis (Neuendorf 2002).

Citation analysis

Citation analysis was used to track the use of SNAMP peer-reviewed publications. Despite long-running debate over the validity of the citation analysis method (Garfield 1972; MacRoberts and MacRoberts 1989), citation analysis remains an effective quantitative method for analyzing connections among scientific publications and scholars by taking advantage of the structured citation information (Small 1999; Rorissa and Yuan 2012). Our citation analysis began with collecting publicly accessible articles that had cited SNAMP publications[1] by searching their titles on Google Scholar, a citation search engine. Using only Google Scholar was sufficient for this study because it returned more citation search results than other citation search engines, such as Web of Knowledge and CiteSeerX (W. H. Walters 2007). It also sourced citations from both academic and non-academic publications, which could depict more accurately the movement of information among participants and the public. These search results were entered into a spatially enabled, relational database, modeled by the Unified Modeling Language (UML) to represent entities (i.e. articles, authors, search engines, affiliated organizations, and sources of the articles) and their relationships. A web interface for inputting the collected citation articles was built on Django, an open-source, rapid web development framework.

Once the citation results were entered into the structured database via the web interface, pieces of the citation data could be queried from the dataset to evaluate the impact of SNAMP publications in terms of time, relative knowledge domain, and geographic location. In particular, to calculate the rate of formal knowledge adoption, the time lapses between SNAMP publications and their first citations published by authors unaffiliated with SNAMP were measured. Document types were examined to check whether these academic publications were cited only within academic circles. Similarly, the primary knowledge domains of the SNAMP publications were compared with those of their citations in order to see how much SNAMP-produced knowledge was adopted and/or extended by other researchers. Lastly, the locations of the citations articles, according to the institutions of their first authors, were visualized on a map in order to gauge how far in geographic terms knowledge could travel.

Web analytics

While peer-reviewed journal publications from SNAMP were studied by citation analysis, other SNAMP information products, such as its website, photos on Flickr, social network on Facebook, and its videos on YouTube, were measured by their respective web analytics. The technique of "multiplicity" (Kaushik 2010), or using multiple web analytics tools to synthesize and analyze interaction and consumption of web contents, was applied to SNAMP information portals and channels on the Internet. Thus, the official SNAMP website was measured by Google Analytics, Facebook page by Facebook Insights, YouTube videos by YouTube Analytics, and Flickr photos by Flickr stats. The evaluation metrics for these four web analytics tools included: the number of pageviews of the content, location of visitors, information consumption patterns, and the statistics for visitors' social engagement (i.e. sharing information with others).

---

[1] The full list of SNAMP publications is available on the SNAMP website at http://snamp.cnr.berkeley.edu/publications/.

Content analysis

Content analysis, "the systematic, objective, quantitative analysis of message characteristics" (Neuendorf 2002), was performed on online newspaper and weblog articles that have mentioned SNAMP. Most of the traditional paper-based newspapers now offer digital version of their content on the Internet to increase their readership. Many of the news articles had already been collected and stored in the *News* and *Other Media* sections of the SNAMP website over the course of the project. Additional newspaper articles about SNAMP were collected from searching the keyword phrases "Sierra Nevada Adaptive Management Project" and "SNAMP" on the LexisNexis database, which contained archived digital news content from newspapers. The newspapers that covered SNAMP were primarily local newspapers near the SNAMP study sites, such as Sierra Star, Sacramento Bee, Modesto Bee, Merced Sun-Star, and others. Besides traditional news sources, journalism is extended by the popularization of weblogs, a grassroots journalism platform (Gillmor 2004). To search the blogosphere, the Google Blog Search was a more suitable search engine than the standard Google Web Search because it returned more relevant results based on their content, as well as more articles from the past.

The weblogs that cited SNAMP came mostly from non-profit environmental organizations. The content of the newspaper and weblog articles typically fell into three categories: reposting upcoming SNAMP events and activities, publicizing new research findings from SNAMP, and linking SNAMP findings with current issues (e.g. linking the use of rodenticide in marijuana growth on federal lands to the death of fishers). The collected newspaper and blog articles were coded in two dimensions—according to the authorship of the articles, i.e. SNAMP team members (Self), bloggers (Blog), and news outlets (News), and according to the theme of the articles, i.e. General, Fisher, FFEH (Fire & Forest Ecosystem Health), PPT (Public Participation Team), Spatial, Water, and Owl. The coded articles were then plotted on a timeline for visualization and analysis.

Results

Scientific knowledge networks

As of December 31, 2013, the SNAMP Science Team had produced twenty-five peer-reviewed journal papers: twenty-three papers were published while two were accepted or in press. Among the 23 published papers, nineteen were cited at least once, with a total of 190 citations (see Table 2-2). The five most cited SNAMP publications were Pub#4 (43 times), Pub#1 (40), Pub#2 (22), Pub#6 (20), Pub#7 (12). Pub#1 and Pub#4 were the first two publications from SNAMP (on 1/1/10 and 6/1/10, respectively), and Pub#2, #6, #7 were also among the earlier publications. In terms of content, Pub#1 and Pub#2 studied the impact of fuel treatments on fire in forested landscape, while Pub#4, Pub#6, and Pub#7 discussed the methodology of using the emerging LiDAR technology. The affiliated organizations of the first authors on papers citing SNAMP were categorized as academic institutions (Academic, 110 citations), federal organizations (Federal, 53), foreign research institutes (Foreign, 14)[2], research institutes (Research, 8), Non-Government Organizations (NGO, 4), and industry or companies (Industry, 1). Among the 53

---

[2] A foreign educational institution is classified under Academic not Foreign.

Federal citations, twenty-four of them were citing publication #1, ten citing publication #2, and six citing publication #17.

The publications citing SNAMP research came in a variety of types including book sections (2), conference papers (7), journal articles (138), petitions (2), professional paper (1), environmental reports (19), theses (16), a user guide (1), white papers (2), and workshop documents (2). While the majority of the citations (86%) belonged in the academic and scientific sectors, eighteen out of the 19 citations were found in environmental management reports that were produced by research scientists in the U.S. Forest Service. The notable examples among these reports are the General Technical Reports (Mclver et al. 2010; Calkin et al. 2011) and Science Synthesis Reports (Long et al. 2013). The goals of these reports are to synthesize and deliver the latest scientific research findings to land managers, so that they can make better management decisions. As the citations in these environmental reports indicate a transfer of information from the SNAMP to the U.S. Forest Service, they may mark the completion of one of the SNAMP goals, which is to increase environmental managers' scientific knowledge for managing social-ecological systems.

The knowledge domains (or areas of research focus) of the SNAMP publications and their citation articles are illustrated in Fig. 2-1. The knowledge domains of the citation articles generally matched those of the SNAMP publications (more than 50% matching for 7 of 8 publications), implying that SNAMP publications have led to greater depth of knowledge in the same knowledge domains. Nevertheless, some of the SNAMP publications were cited by studies in other knowledge domains. For example, Publication #2, which focused on forest, fire, and models, was cited by research projects that studied other aspects of the forest, such as greenhouse gas, biomass, carbon, fisher, and water. By other scholars applying research methods and knowledge developed in SNAMP to their own research, the SNAMP process was able to expand knowledge beyond the scope of the project. The finding validates the efficacy of information transparency and accessibility for knowledge production and expansion.

The SNAMP publications and their citations are plotted on a timeline according to their publication dates[3] in Fig. 2-2. By highlighting the time lapse between SNAMP publications and their respective first citation articles that were authored by scientists unaffiliated with SNAMP, the rates of information adoption were calculated to range from 2 to 19 months, with the majority of them (17 out of 19) under a year. Mapping the citations according to the locations of their first authors' institutions—found in the author information section of the journal articles—on the Google Map interface rendered a visual representation of where SNAMP publications were produced and where they were cited (see Fig. 2-3). The flight lines aim to provide a sense of approximate "travel distances" for SNAMP publication information transfer. The spatial distribution patterns varied among SNAMP publications, but generally speaking, publications were cited far outside of their originating institution. Publications focusing on forest landscapes (i.e. Publication# 1, 2, and 13) and wildlife (Publication# 3, 8, 9, 10, 16, 17, 19, and 21) in the Sierra Nevada forests were primarily cited within the United States while publications focusing on LiDAR technologies (Publication# 4, 5, 6, 7, 14, 18, and 24) and website development (Publication #12) were more globally cited. This suggests that methods- and techniques-based

---

[3] The first day of the month is chosen for publications that have only the month and year.

information is more transferrable and less restricted by the context in which the information is produced.

Web applications and services networks

Google Analytics

The SNAMP website went online in January 2006. The Web statistics collected by Google Analytics reports that the SNAMP website received 42,661 sessions of visits between October 1, 2007 (the start of the website traffic data collection) and January 31, 2014, which averages to 569 sessions per month. On average, website visitors stayed for 3 minutes and clicked on 4 pages per visit. The majority (83.65%) of the visitors came from the United States, and more than two thirds (67.42%) of them from California. The top 8 cities that generated the most number of sessions were Sacramento (2,661), San Francisco (1,649), Berkeley (1,332), O Neals (1,276), Merced (1,235), Fresno (1,058), Oakhurst (777), and Davis (726). The overall traffic pattern highly correlated with the SNAMP public meetings in that the website traffic spiked for the few days surrounding the public meetings, suggesting that SNAMP participants were interested in finding out more information about upcoming activities through the website. The top 5 most visited sections of the SNAMP website were the photos (23.13%), documents (18.82%), home page (17.19%), teams (12.13%), and news/newsletters (11.55%). The traffic pattern suggests that visitors to the SNAMP website were either seeking or attracted to the SNAMP content in the form of photos and documents.

Flickr stats

SNAMP uploaded 707 photos and 6 videos to its Flickr account. Every photo/video was titled with the name of the public meeting at which the photo/video was taken and captioned by a detailed description. The photos/videos were placed in one of the ten photo sets: public meetings (291 photos), field visits (228), water (80), fisher (71), northern site (64), spatial (61 photos, 6 videos), southern site (53), owl (28), fire and forest health (19), and logos (7). The lifetime total number of views for photos, videos, photostream pages, and photo sets was 30,673. Among the top 20 most viewed photos, 6 photos featured owls while 7 depicted fishers. Regarding viewers' interaction with the SNAMP Flickr content, 709 items were viewed at least once, but only 3 items (1 forest picture, 1 LiDAR video, and 1 fisher picture) were commented and 2 pictures (1 owl and 1 fisher) were marked with "Favorite." The way people have interacted with SNAMP photos indicate that they were most interested in the wildlife studies.

YouTube analytics

SNAMP has published 13 videos to YouTube since July 12, 2010. The first 8 videos were about various science research components of SNAMP. Three videos were shot at the cable logging field trip on October 16, 2012; and, two were shot at the fisher field trip on May 1, 2012. The top three most viewed videos were "California Spotted Owl research in the Sierra Nevada" [4:02] (1,626 views), "Close up of yoder yarding logs to the landing at the Last Chance project 10 16 2012" [1:19] (1,020 views), and "Pacific Fisher Kits in Den" [1:12] (566 views). The statistics for the most popular playback location and the highest traffic source show that individual watch page on YouTube received the most views (2,917 views – 60%) while the embedded player on the SNAMP website and other websites came in second (1,214 views – 25%). The top three traffic sources were YouTube search (1,392 views – 29%), embedded player (1,205 views – 25%), and direct access to individual watch page (1,163 views – 24%). For social engagement, the SNAMP video channel gained 3 subscribers, 2 Likes / 1 Dislike, 6 Shares, 2 Favorites and 1 Comment.

Facebook Insights

SNAMP started a Facebook page on January 22, 2009 as an additional information channel for distributing events information, documents, photos, and videos. User traffics and activities on the SNAMP Facebook page were measured by Insights, Facebook's native web analytic tools. However, because Insights did not begin until July 19, 2011, the web analytics dataset was limited to the period between that date and January 3, 2014. The SNAMP Facebook page audience was composed of the fans of the page—people who had "liked" any content of the page. The number of Likes grew from 170 to 182 over this period of time, implying that the SNAMP social network on Facebook has not grown much after an initial surge. SNAMP produced 5 different types of posts: link (17 posts), photo (23 posts), share (3 posts), status update (11 posts), and video (6 posts). The top three most consumed content types were photo (271 clicks), link (18 clicks), and video (14 clicks). The consumption of the SNAMP Facebook page, defined by the number of clicks anywhere in a post, generally spiked when new content was posted to the page. The amount of SNAMP content posted on Facebook largely depended on when such content was produced and posted by the Public Participation team. For instance, a spike in consumption took place on March 28, 2012 because 8 posts of varying content types including Updates, Links, Photos and Videos were posted to the SNAMP page. The traffic pattern suggests that the amount of content and the timing of the posting matters more significantly for online social networking sites, such as Facebook.

Online media networks

Seventy-one news articles were collected from the SNAMP *News* and *Other Media* archive (34 articles), the Google Blog Search results (32 articles), and the LexisNexis search results (5 articles). Grouping these articles by their authorship types, 12 articles were classified as Self, 32 as Blog, and 27 as News. The content of the news stories were coded into seven different categories: SNAMP (9 articles), Public Participation (2 articles), Owl (1 article), Water (2 articles), Fisher (45 articles), Spatial (3 articles), and Fire & Forest Ecosystem Health (9 articles). The coded news articles were plotted on a timeline in Fig. 2-4.

The timeline of the news stories showed that media coverage and self-promotion of SNAMP were sparse prior to the fall of 2010. Starting at the end of 2010, the SNAMP Public Participation Team started to increase self-promotion of the different aspects of SNAMP. One possible catalyst might have been the publications (#1, #3, and #4) of SNAMP research findings. As more SNAMP information was publicized, local groups and individuals also seemed to have started to repost more about SNAMP on their blogs. The Pacific Fishers drew the most media attention from bloggers and news outlets. The first wave of media attention came in May 2011 when the first fisher denning site was identified in Yosemite. Two news articles and six blog posts reported this story. The second and bigger wave of media attention was generated by the sock drive in December 2011. The sock drive called for the donation from the public of unused socks, which would be used to hold chicken as bait to lure fisher individuals to the tree where a monitoring camera would be activated by their presence. Eleven news articles and nine blog posts were written about the SNAMP "sock drive."

Discussion

The mixed methods approach to the information products, channels, and networks in SNAMP generated many useful results that better characterized the digital information flow cycle in a CAM project. The following discussion focuses on the four stages of the devised information flow framework: production, transport, use and monitoring.

Information production

Timing of information production and distribution

Public involvement and engagement are key features in CAM, which makes timely information production and distribution very critical, for with timely information dissemination the faster and more effective public feedback and reaction may be, and thus the more reactive (or adaptive) the system is able to be. This was made evident in SNAMP when I found that various types of information about SNAMP, when made available on its website, were re-published in blog posts and news articles. This follows the information rule that "information is costly to *produce* but cheap to *reproduce*" (Shapiro and Varian 1999, 3). Because information technologies have made reproducing information cheaper and easier, information can be made available in digital formats quickly and has a higher chance of re-distribution. The growing number of blog posts and newspaper articles reporting about SNAMP over the years also indicated that the public found the project increasingly interesting and relevant because bloggers were more inclined to repost new and helpful knowledge (Hsu and Lin 2008; Yu, Lu, and Liu 2010).

To produce and distribute information in a timely manner requires the understanding of information needs, a plan and process for generating new information, commitment to make information transparent, an information distribution infrastructure, as well as an active effort of information dissemination. In the case of SNAMP, the commitment to information transparency was made at the outset of the project (Bales et al. 2007), which translated to making meeting notes, participant discussions, and science findings accessible on the SNAMP website in a timely manner. Even the research process was transparent to the public, so that the public could understand the scientific processes and results and provide feedback to the scientists and managers about the science in the project. Perhaps, due to freshness and timeliness of the SNAMP content, weblogs and news outlets found the information valuable enough to re-publish.

Directions and channels of information distribution

The direction of information distribution can also affect information sharing and participation in a CAM project. In a traditional adaptive management setup, the knowledge and information produced is targeted at primary participants such as resource managers and environmental stakeholders (Holling 1978; C. J. Walters 1986). However, the flow of information and communication must be "multi-directional" in CAM projects in order to increase learning and to foster understanding and trust among multiparty stakeholders.

Having multiple information channels can significantly increase information sharing because it can lower the time-cost and effort for seeking information (Hardy 1982). To make SNAMP information more accessible to the public via multiple channels, the PPT published events information, photos and videos to various web services and online weblogs and newspapers. A particularly important and effective channel of information was peer-reviewed journals, which allowed researchers in various research institutions and government agencies to access and utilize the scientific knowledge produced by SNAMP for their own work. Another effective channel of information was the USDA Digital Collections. Although publishing to the USDA Digital Collections was only available to U.S. Forest Service staff, it held two SNAMP publications (Publication #1 and #2), which were cited by researchers in the U.S. Forest Service. It effectively facilitated knowledge transfer between academic and government researchers.

Information transport

The movement and behavior of digital information flow through various online information networks can be characterized by the rate, distance and pattern of travel.

Rate

Information transport rate refers to how fast a piece of information is used after it is made available to the public. I used a broad definition for the use of information in this study: it could be a visit to a web page, a click to a post to the Facebook page, or a citation of a publication; and thus the information transport rate varied based on information channels. For instance, a post to the SNAMP Facebook page could be viewed within minutes, while it might take between two months to more than one year for a peer-reviewed journal publication to be cited. Information transport rate has a double-edge: while some channels are much faster in reaching people, the value of their information can decay much quicker. For instance, information became obsolete much faster on Facebook (i.e. on the order of minutes) than on peer-reviewed journals (i.e. on the order of years) (Nicholas et al. 2005). Understanding information transport time, as well as the persistence length of information value, for different information channels could help environmental management project managers decide what information channels would be more appropriate for which kinds of information. For a multi-year CAM project like SNAMP, the time lag in the peer-reviewed journal system would be acceptable to project participants who were committed to the duration of the project. For other environmental management projects with shorter project timelines, different information channels for knowledge validation and transfer should be considered.

Distance

Digital information can travel long distances in a short time (Fig. 2-2), yet barriers to access can hinder information transport distance. One type of barrier is content accessibility. For instance, most citations of SNAMP articles were found in academic institutions that had access to peer-reviewed research journals available online. This pattern suggests two things: scientific journals can be too expensive for individuals to subscribe to, but they are often provided by university libraries; and scientific information travels more easily within the academic community because the social networks among scientists can be small, with only one or two connections away from one another (M. E. J. Newman 2001). One potential solution to these barriers might be open access publishing (Antelman 2004), which would allow the public to access a scientific publication without paying for journal subscription. Another barrier to the transport of digital information is the digital divide leading to differential access to information technologies (Chakraborty and Bosman 2005). As indicated by the website traffic pattern in the results section, much of the SNAMP website traffic came from large cities or university towns, such as Sacramento, San Francisco, Berkeley, and Merced, which might had better Internet coverage. Another information transport barrier might be related to lack of familiarity of the some of the information channels used by the project, namely, Facebook, Flickr, and YouTube. As a result, these web applications and services generated very little engagement from SNAMP participants and did not achieve the goal of further propagation of information by SNAMP participants.

Pattern

The transport of information can also be a function of how information travels through various information products and channels. The ability to easily link information in various channels via hyperlinks and mashup is a distinguishing feature of web technologies. Web mashups can enhance user interface and experience, add value to information by aggregation, improve user interaction with the information, and increase credibility of the information (Murugesan 2007; Robins and Holmes 2008). SNAMP took advantage of the mashable feature of the web technology by embedding SNAMP videos hosted on YouTube and SNAMP photos hosted on Flickr on the SNAMP website. The result was a better user interface and a better way of organizing information for the SNAMP event pages, and opened up multiple pathways to access a piece of information.

Another travel pattern that facilitated information flow was to take advantage of the people-people connections in online social networks and communities provided by Facebook, Flickr and YouTube. For example, besides serving as an online photo repository, Flickr enables photographers to easily share their photos with other Flickr members (Shirky 2009). Motivations for sharing information include increasing reputations (Wasko and Faraj 2005), enjoying one’s ability to provide valuable information/knowledge (Lu and Hsiao 2007), and remaining in a conversation (Boyd, Golder, and Lotan 2010). Such motivations and actions enable information to reach more people as well as validate the value of the information.

Information use

After information passes through various information channels, information recipients may use it or interact with it in different ways: through consumption, information sharing, information extension, and participation.

Basic consumption

Basic consumption of information refers to visiting a web page, viewing/reading, clicking the “like” button, or submitting a very simple comment. This type of information use generally requires very little time and investment from users. Although the form of interacting with information may eventually lead to knowledge production, it often does not result in knowledge production and participatory actions. Much of the information use in SNAMP fell into this category because most of the information was created for the purpose of informing SNAMP participants. For example, meeting agenda and notes informed SNAMP participants about public meetings; science briefs provided latest research findings; photos showed pictures of wildlife as well as human interactions at public meetings; and, video documented some of the SNAMP processes. This type of use usually ends the flow of information and does not generate participation or collaboration (Kelly et al. 2012).

Generating new knowledge

New knowledge can be generated from existing information through synthesis, analysis, applications, or other methods of information processing. The process to generate new knowledge from existing information requires greater intellectual involvement as well as time and resource investment by information users. It also requires the information to be in a synthesizable and analyzable form. An example of generating new knowledge in SNAMP was when SNAMP publications were cited in scientific publications—a process in which researchers obtained SNAMP publications, acquired the scientific knowledge in them, and synthesized the SNAMP information with other information to generate new scientific publications. This process took place primarily in the larger scientific community, but it also happened among scientists within SNAMP (e.g. Publication #2 produced by the Fire and Forest Ecosystem Health team was cited by Publication #16 produced by the Fisher team).

Participation

Participation entails responding to information that explicitly calls for an action or actions. This type of "actionable" information provides clear goals and instructions for participation and collaboration. The SNAMP sock drive was a good example of mobilized public participation. It began with a simple poster that asked for the donation of single socks, which would be used to hold the bait to entice Pacific fishers to come before a monitoring camera. The sock drive drew much attention in SNAMP's online social media networks, and drove much traffic to the website's Fisher Team pages. More significantly, it mobilized the public to contribute to the fisher monitoring and research effort through socks donation (Kocher, Lombardo, and Sweitzer 2013). In return, the public benefitted from increasing knowledge about fishers, which was not a well-known animal species, by having more direct communication and interaction with fisher research scientists. And there was an increase of public interests for the animal, as the Fisher Team page, two fisher photos and a fisher news post on the SNAMP website were among the most visited pages during the period of sock drive.

Information monitoring

The fourth phase of the information cycle is information monitoring, which played a critical role in the CAM information cycle. Project monitoring involves observing and evaluating the impact of management policies and implementation on natural resources, and is a "cornerstone to effective decision making amid uncertainty in natural resource management" (Cundill and Fabricius 2009). Participatory ecological monitoring leads to shared understanding of the ecosystem, social learning and community building, greater trust and credibility within and outside management organizations, communication of findings to the public, and increasing the impact of monitoring information (Fernandez-Gimenez, Ballard, and Sturtevant 2008).

Information monitoring has the potential to directly improve collaboration and learning in a CAM project.

Information monitoring can also ensure information systems performance (Wang, Abraham, and Smith 2005, 200), and alert managers to system failures or malicious attacks. A monitoring plan should be in place to detect unexpected system problems, to resolve them quickly. For example, a sudden drop in website traffic would alert project managers, that there might be bugs in the information system, or that information is mistakenly sent through the wrong information channels and will not be reaching the appropriate audiences, or simply that the information is not interesting to these audiences.

Finally, monitoring information use could identify whether information supplies met information demands. While the concept of information needs has not yet been fully defined (Shenton and Dixon 2004), one recently proposed method for measuring information needs was to examine content user, usage and feature (Shih et al. 2012), which could be found in web analytics data. Since what is interesting to the public and stakeholders may not be apparent at the beginning, information monitoring is a crucial step in sending signals upstream to project managers to evaluate and adjust information production. Monitoring digital information should take place throughout a collaborative adaptive management project. Many digital information monitoring tools (e.g., Google Analytics) have become mature and sophisticated, and can be built upon for in depth analysis of CAM information flow with minimal cost.

Conclusions

By tracking and analyzing the flow of digital information in a collaborative adaptive management project (SNAMP) using mixed research methods, I was able to characterize information use and flow across numerous online information channels, systems and technologies. As a result, I gained three broad insights into the value and contributions of tracking information. First, I found that increasing the flow of information could positively contribute to collaboration in CAM. The increase of information flow was accomplished by delivering project information to specific audiences via different information channels including scientific knowledge networks (peer-reviewed journals and USDA Digital Collections), web services and applications (the SNAMP website, Flickr, YouTube and Facebook), and online media networks (blogs, newspapers, and SNAMP news). These created many more channels for distribution, thereby increasing information availability, accessibility and discoverability.

Second, I learned that information flow takes particular patterns that can affect CAM, depending on which channels are used and in what combinations. In general, information technologies dramatically increased the speed and the distance that information could travel. Information traveled at different rates depending on the information channel. For example, SNAMP peer-reviewed publications had, on average, a time lapse of around 7 months before their first citations, but they persisted much longer in scientific knowledge networks than, say a status update on the Facebook page, thus supporting future learning and collaboration. Some channels, such as peer-reviewed journals, seemed to lend credibility and provide validation to SNAMP scientific results. Significantly, networks of information systems – not just networks of people – could help sustain collaborative learning by enabling certain SNAMP participants to transfer knowledge across multiple organizations. This happened in SNAMP when academic journal articles were published also in the USDA Digital Collections. Critically, as information was transformed into an actionable form (e.g., knowledge transfer between scientists and resource managers; and making requests to the public for assistance), greater collaboration and increased public participation in contributing to science research took place.

Finally, I found that using mixed research methods (citation analysis, web analytics and content analysis) to measure and evaluate digital information in CAM was an effective way of monitoring and analyzing information use and flow in real time, not just after a project has ended. These methods provided quantitative measurements for information use, unearthed the relationships between different information networks, and even identified knowledge brokers important to the project. They could also inform project managers whether information supplies had met information demands, which could contribute to maintaining trust and collaboration over the course of CAM.

Recommendations based on lessons learned

Here I present a list of recommendations on how to facilitate the flow of digital information in a CAM or other collaborative project.

- *Identify information channels*. Information channels are growing as hardware and software technologies advance. Information flow can increase greatly if information can flow through multiple channels. Traditional channels such as newspapers, electronic library databases of peer-reviewed literature, and institutional websites (all of which emphasize delivering information to audiences) can be augmented with Web 2.0 web services include micro-blogging sites (e.g. Twitter), online social networks (e.g. Facebook and Google+), and online media sharing sites (e.g. Flickr, YouTube, and Vimeo), which empower audiences to participate much more actively in deciding what information matters. If location information is available, social mapping services (e.g. WikiMapia) can add to the mix of information channels. Publishing to open access journals (Harnad and Brody 2004; Antelman 2004) can make information more available to the academic and scientific community as well as the public.
- *Design information architecture for web tools and channels*. Given the variety of web tools today, the configuration and integration of these web tools should be carefully planned based on the audience of the information, the modes of interaction, and the speed, distance and persistency of the information (Lazar 2001). For example, a traditional website might not be the best information portal because a Facebook page could provide many of the website features and other interactive community features. However, it is advisable to have a centralized location that holds all the information produced in a project because it can reduce the uncertainty in information seeking for project participants (Chowdhury, Gibb, and Landoni 2011).
- *Publish information early*. Communication to the public about the project should take place as soon as a CAM project begins (Schindler and Cheek 1999). While there may not be any meaningful research results to share early on, preliminary findings, research plans, and similar previous research works by other scientists should be made transparent and accessible in order to foster public interest, engagement, and trust. In addition, general project information should be communicated repeatedly and frequently to the public via press releases or online media channels, so that people become more informed and prepared for future participation.

- *Automate publishing workflow*. While publishing information to multiple channels may seem time, labor and resource intensive, a publishing workflow should be planned at the beginning of the project in order to guide this process. The workflow should provide instructions on what information is published to which channel at what time. It is advisable to invest more resources up-front on building a system that can integrate web services (Hansen, Madnick, and Siegel 2003; Peltz 2003) and automate the publishing workflow. Such a system can reduce most of the publishing work, especially for publishing to web services, to a few simple publishing steps.
- *Identify knowledge brokers*. Tracking the production, transport and use of information enables the identification of critical knowledge brokers in a CAM environment. Knowledge brokers play a crucial role in facilitating information flow across different social networks and knowledge networks because they can traverse different scales and organizations (Ernstson et al. 2010). Adding to the list of brokering strategies proposed by Michaels (2009) is the information/knowledge channeling strategy. Intentionally seeking and instituting knowledge brokers in CAM, particularly those with access to highly influential organizational resources, can pay dividends for information flow, resulting in effective knowledge transfer between different organizations and parties.
- *Create opportunities for participation*. Ideas that can allow the public to partake and contribute to the research effort can increase information flow. This starts with a paradigm shift for the researchers to value educating and incorporating the public. It might help to learn from Citizen Science projects on how to involve the general public in conducting scientific research (Pandya 2012; Zoellick, Nelson, and Schauffler 2012).
- *Build social networks*. Information, if made valuable and interesting, may serve to attract more visitors and viewers, and thus increasing the size of online social networks. This may result in greater information reach and flow, leading to fostering further collaborations, trust, transparency, and public support for CAM projects. Therefore, it is worthwhile to strategically invest resources in building more robust and dynamic online social networks, e.g. adding contacts, inviting friends, sharing content, and finding similar projects.
- *Monitor information regularly*. Information monitoring needs to be incorporated into the information flow cycle so that successes and failures of the above actions can be evaluated throughout a CAM project. Training on how to analyze different web analytics should be provided to project managers. Summary reports of information use should be generated and discussed at a quarterly interval. If the amount of data is too large and complicated, a third-party data analysis tool should be purchased to aid the analysis, so that information delivery methods can be better honed to reach desired project goals.

CHAPTER TWO – FIGURES

Fig. 2-1. The matching percentage of knowledge domains between SNAMP publications and their citation articles.

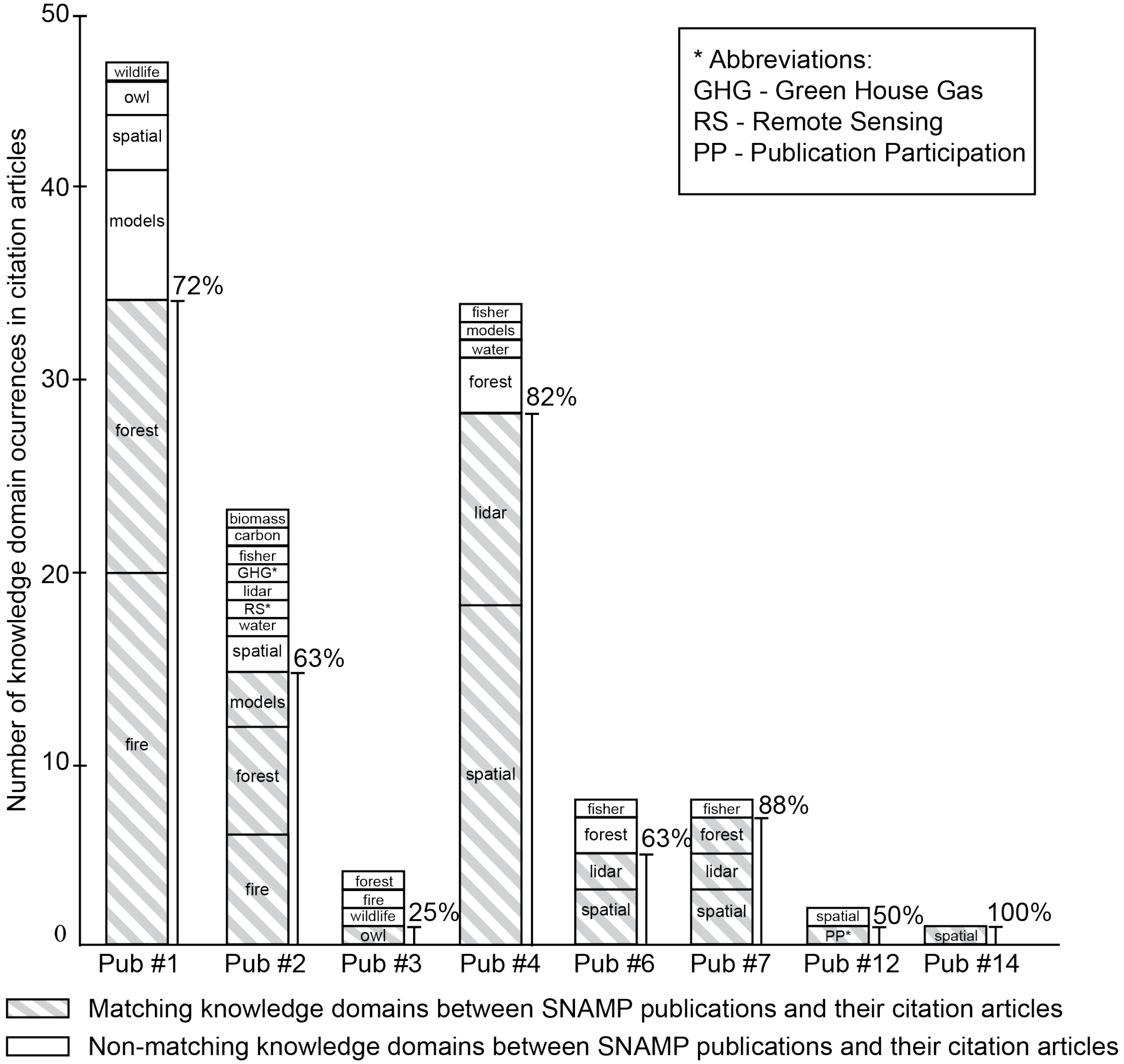


Fig. 2-2. Time to first citation by authors not affiliated with SNAMP.

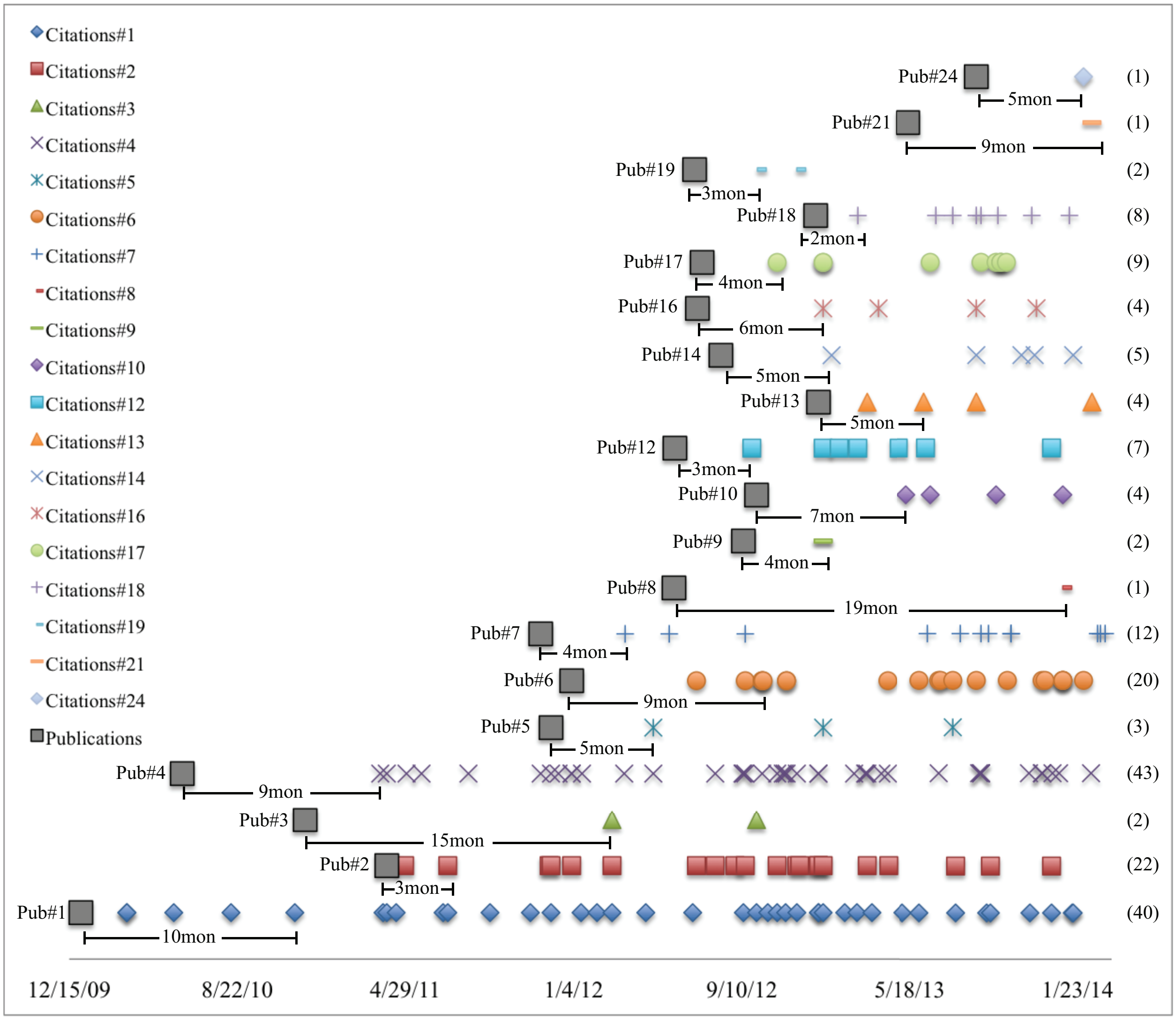


Fig. 2-3. Map of SNAMP publications and citation articles, located by their first authors' affiliated organizations.

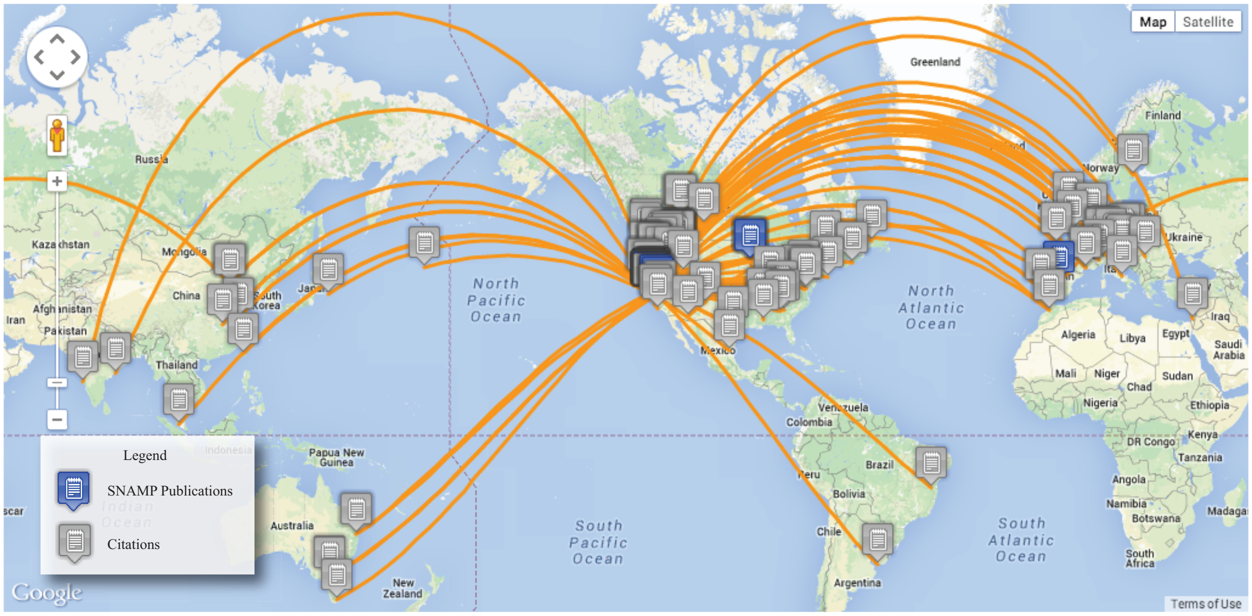
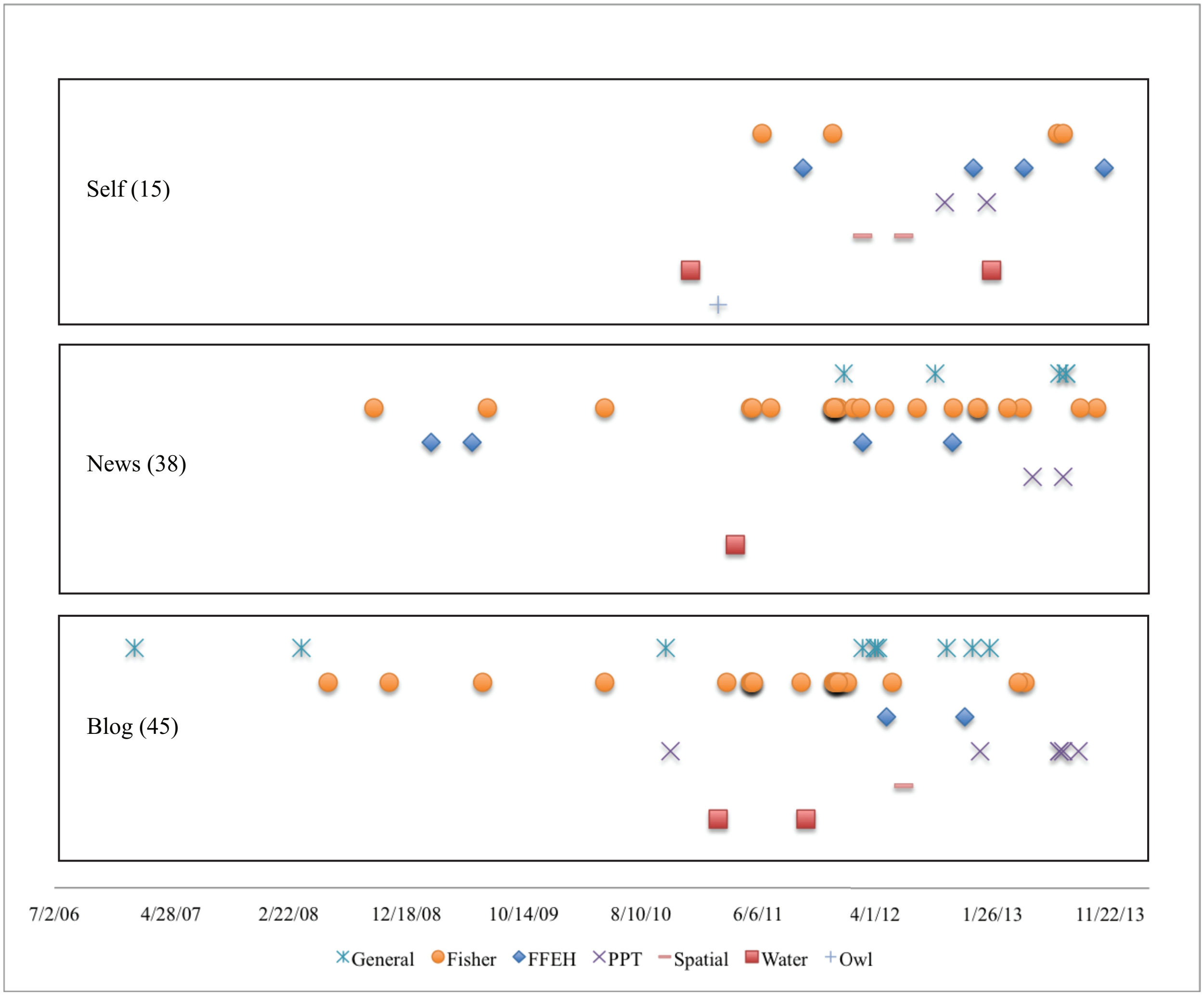


Fig. 2-4. Timeline of weblog posts (Blog), news articles (News), and self-promotional articles (Self) about SNAMP.



CHAPTER TWO – TABLES

Table 2-1. Public engagement techniques and quantitative evaluation methods evaluated in this work.

Target	***Dataset used***	***Evaluation Method***
SNAMP website	Website content, use	Google analytics
SNAMP Science products	Peer-reviewed journal articles; Newsletters	Content analysis; citation analysis
SNAMP digital products	Media articles	Content analysis; citation analysis
SNAMP web services	Facebook, Flickr, YouTube	Web analytics

Table 2-2: Citations' first authors' affiliated organization type and their counts (as of February 19, 2014).

Publications	***Academic***	***Federal***	***Foreign***	***Industry***	***NGO***	***Research***	***Total***
Pub#4	37	2	2			2	43
Pub#1	13	24	2		1		40
Pub#2	9	10	1	1		1	22
Pub#6	17		2			1	20
Pub#7	11	1					12
Pub#17	1	6			1	1	9
Pub#18	5		3				8
Pub#12	4		3				7
Pub#14	3	1				1	5
Pub#10	2	1			1		4
Pub#13	2	2					4
Pub#16	2	2					4
Pub#5	2	1					3
Pub#3		1				1	2
Pub#9		2					2
Pub#19			1		1		2
Pub#8						1	1
Pub#21	1						1
Pub#24	1						1
Total	**110**	**53**	**14**	**1**	**4**	**8**	**190**

CHAPTER THREE

Evaluating collaborative adaptive management in Sierra Nevada forests by exploring public meeting dialogues using self-organizing maps

Collaborative adaptive management (CAM) is an appropriate management regime for social-ecological systems because it aims to reduce management uncertainties and fosters collaboration among diverse stakeholders. I evaluate the effectiveness of CAM in fostering collaboration among contentious multiparty environmental stakeholders based on the Sierra Nevada Adaptive Management Project (SNAMP). Our evaluation focuses on facilitated public multiparty discussions (2005-2012). Self-organizing maps (SOM), an unsupervised machine-learning method, were used to process, organize, and visualize the public meeting notes. I found that public discussion remained focused on the project content, yet the more contentious and critical issues dominated the discussions through time. Integration across topics could be improved. These results suggest that SNAMP collaborative adaptive management seems to have helped participants focus on the key issues as well as to advance their discussions over time. Given the effectiveness of SOMs in analyzing text, I provide suggestions on how natural resource managers might use SOM.

Introduction

Managers of American national forests face increasing challenges in managing complex ecosystems across heterogeneous geographical regions and changing environmental conditions, while involving a greater number of environmental stakeholders with sometimes competing interests and expectations (Tear et al. 2005; Lawler et al. 2010). Forests are examples of these types of socio-ecological systems, in which environmental and social processes are interconnected across spatial, temporal and socio-political scales (Berkes, Folke, and Colding 1998; Folke 2007). The implementation of large-scale, science-driven forest treatments is often complicated in these settings due to scientific uncertainties in the understanding of interacting ecological elements such as fire, forest health, water, and wildlife (C. J. Walters 1997); and further complicated by environmental stakeholders' conflicting views and values regarding how to use and manage the forests around them (G. Brown, Kelly, and Whitall 2013a; Ferranto et al. 2013).

Indeed, in the last two decades there has been an increase in the frequency of administrative appeals on and lawsuits about forest plans and projects (Wondolleck 1988; Portuese et al. 2009). In the United States, forest management is no longer the sole sovereign domain of managers from federal or state agencies (Baskerville 1988), but has come to encompass a much broader set of actors. Regulations for the USDA Forest Service (hereafter "Forest Service") state that the agency "must use a collaborative and participatory approach to land management planning ... by engaging ... Forest Service staff, consultants, contractors, other Federal agencies, federally recognized Indian Tribes, State or local governments, or other interested or affected communities, groups, or persons'' (Federal Register 2012). In providing opportunities for participation, the agency must take "... into account the discrete and diverse roles, jurisdictions, and responsibilities of interested and affected parties" (G. Brown, Kelly, and Whitall 2013a). To facilitate the management of on public lands in the US, in which pre-existing and longstanding disagreements between management agencies and diverse stakeholder groups exist (Allen et al.

2011), collaborative adaptive management (CAM) has been applied as a management framework (Greig et al. 2013).

How does CAM mitigate the uncertainties that come from ecological complexities and social conflicts in a social-ecological system? Theoretically, CAM builds on the foundations of adaptive management (Holling 1978) and collaborative management (Wondolleck and Yaffee 2000). CAM is distinguished from adaptive co-management (Plummer and FitzGibbon 2007) by the fact that the Forest Service is not sharing management power with other environmental stakeholders. The adaptive management approach primarily focuses on tackling the ecological uncertainties while the collaborative management framework concentrates on resolving social uncertainties in managing within a social-ecological system. Adaptive management requires that natural resource management be conducted as "experiments," a formal process of "learning-by-doing" (C. J. Walters and Holling 1990), in order to increase the production of scientific knowledge about the natural processes and diminish management uncertainties. Adaptive management experimentation follows an iterative, structured decision-making process beginning with problem definition, setting objectives, designing policies, implementation, monitoring and evaluating results, and lastly modifying policies based on results from the previous iteration (Allen et al. 2011).

However, successful adaptive management is difficult to implement due to various collaboration barriers, ranging from lack of stakeholder engagements (Allen and Gunderson 2011; Williams and Brown 2014), to conflicts and disagreements among stakeholders (Lee 1999), as well as insufficient institutional design for stakeholder engagements in the adaptive management process (Susskind, Camacho, and Schenk 2010). To overcome the challenges facing stakeholder collaboration, the collaborative management approach focuses on building understanding among social actors, making wiser decisions, providing support for the decision-making process, increasing capacity, and achieving management goals (Wondolleck and Yaffee 2000). Collaborative management increases social capital and learning opportunities that can reduce conflicts among environmental stakeholders (Weber and Khademian 2008). Diverse participation in collaboration contributes to building trust and advancing social learning, leading to more effective community monitoring of forests (Fernandez-Gimenez, Ballard, and Sturtevant 2008). Moreover, even conflicts when "bounded" (i.e. not leading to anarchy) in management can be viewed as a useful accountability instrument for social learning important to collaboration, like a gyroscope that corrects erroneous directions in the course of sailing (Lee 1993, 113–114).

The primary mechanisms for fostering collaboration among multi-party participants in environmental management include discussions, negotiations, and deliberations (Wondolleck and Yaffee 2000). The effectiveness of the collaborative process within an adaptive management project is often approached through qualitative means, by examining the outcome of such interactions (van Wilgen and Biggs 2011) or by employing a qualitative mixed-methods approach to obtain participants' post-project evaluation (Davies and White 2012). A direct and quantitative investigation and analysis of the collaborative discussions within adaptive management projects is not very well represented in the adaptive management literature. There is thus a need to develop means to quantitatively evaluate the role of discussions, negotiations, and deliberations in adaptive management and, hence, to learn how to improve these tools for future collaborations.

In this paper I ask: what are the important characteristics through time of a participatory process that are revealed through discussions at public meetings? I want to observe the influence of collaborative adaptive management on the discussions among contentious stakeholders in natural resource management. I use textural analysis of meeting notes and a relatively new method for exploring textual data called the "self-organizing map," to explore the interplay between public discussion and public participation. I sought to reveal the general landscape of discussion topics at public meetings, popular topics, how these topics change over time, and the relationships among topics.

Analyzing discussions: content analysis versus self-organizing maps

Content analysis (Neuendorf 2002) is a commonly used social science research method for studying and analyzing textual data. Content analysis includes: 1) establishing research questions, hypotheses and predictions, 2) defining data units and samples, 3) building a code book, guide and a team of coders, 4) coding data while ensuring data reliability, and 5) analyzing and reporting results. Content analysis has been used to study a wide range of issues in the context of contentious environmental management. For example, it has been used to track the forest values of forestry professionals, mainstream environmentalists, and the general public (Xu and Bengston 1997), and to track and identify expressions of conflict about forest management in the US from news media stories (Bengston and Fan 1999). It has also been used to understand the effect of public participation on government decision-making, conflict resolution among stakeholders, and trust building among environmental agencies (Beierle and Konisky 2000). The method has been utilized to analyze organization newsletters that were published during community conflict resolution processes in order to track participants' attitudes toward opposing organizations (Gwartney, Fessenden, and Landt 2002). Content analysis is an effective research method for analyzing textual data according to a particular research theme; however, it does not provide researchers with the ability to explore textual data without *a priori* hypotheses. In addition, the coding process for content analysis can be time-consuming and costly, as it requires the creation of a coding guide, a team of trained content coders, and the purchase of expensive software licenses. The coding guide needs to be carefully designed and tested because it cannot be easily modified and repeated afterward. The difficulty multiplies if the collection of documents is large or needs to grow over time.

Against these challenges facing content analysis, the self-organizing map (SOM), developed by Teuvo Kohonen (1998), has recently been employed as an alternative method for analyzing textual data. SOM is an unsupervised artificial neural network that can represent a complex set of data on a two-dimensional (or sometimes three-dimensional) "map." SOM has been used previously with large high dimensional biological and environmental datasets to reveal patterns in genomes (Dick et al. 2009), to target environmental remediation (Tran et al. 2003), to extract information from complex ecological data (Chon 2011), and as a tool for scientific visualization (Skupin 2008). The method is also increasingly being used with textual or document data (Rutherford, Buller, and McMullen 2003) to understand concealed dimensions of social interaction. When SOMs are used to analyze texts, documents full of words are converted to high dimensional vectors with components of weights, which are numerical values that represent the importance of the words in the documents, and are, then, projected onto a two-dimensional "feature map" based on the original locations and importance of the words from the input documents. At the end of the process, a SOM can help researchers visually explore the importance of and relationships among the input documents.

The SOM has several advantages over conventional content analysis. Because the algorithm is unsupervised, it does not require pre-existing theoretical hypotheses, which can eliminate human biases in coding and organizing textual data. Using SOM computer software can save cost because many programs, such as the Java SOMToolbox (Mayer and Rauber 2011b) used in this study, were developed as open-source and free software. Operating SOM programs requires only one person with basic programming knowledge. And the process for creating a SOM is repeatable, which makes it a suitable method to analyze a collection of documents that can grow over time.

SOM provides an accuracy measurement called mean quantization error, which is a mathematical algorithm that quantifies the difference between the original set of input documents and their final representation in a SOM. The accuracy and reliability of content analysis is measured by comparing a single coder's coding results on repeated trials (Carmines and Zeller 1979, 11) or coding results from multiple coders—*intercoder reliability* (Neuendorf 2002, 141). The quantization error in a SOM is more precise and easier to calculate than checking the consistency of the coding work in content analysis. In addition to accuracy measurement, the SOM takes advantage of clustering algorithms to group similar content on the map; whereas, for content analysis, additional steps of textual clustering and categorization are needed to achieve the result. With the different levels of textual clustering, the SOM also provides users the ability to "zoom" in and out of data at different levels of grouping, whereas content analysis does not provide such capabilities.

Moreover, the SOM is capable of handling a large collection of documents as input data. Kohonen (2000) demonstrated the capacity of the SOM to handle massive documents when he used it to map over 6.8 million patent abstracts. As its creation coincided with the development of the Internet, early applications of the SOM for textual analysis focused on Internet content. For example, a conceptual search framework was developed with the SOM at its core to tackle the nascent browse-and-search challenge facing the burgeoning number of documents on the Internet (Chen, Schuffels, and Orwig 1996). This idea was later formalized by another research group into a system called WEBSOM, which organizes documents harvested from Usenet newsgroup from the World Wide Web onto a two-dimensional web page to facilitate effective and interactive browsing (Kaski et al. 1998).

As the SOM preserves the value and topological relationship (i.e. connectedness and context) between words in documents, it is useful in knowledge discovery. SOM was used in linguistic analysis to group words by their contextual relations from corpuses of texts, such as the Grimm's Tales (Honkela, Pulkki, and Kohonen 1995). SOM was used to discover connections among scholars by "plotting" the disciplinary and intellectual areas of scholars like Eugene Garfield and Michael Goodchild on a continuous space of science disciplines (Skupin 2009). SOM was also used to explore key topics and their topical relationships in WikiLeaks documents (Mayer and Rauber 2011a), further highlighting its efficacy for knowledge discovery. Recent advances in SOM were in the visualization arena: combining the visual layer provided by the SOM textual analysis have been mapped to GIS cartographic layers (Skupin 2008; Yan and Thill 2008).

In this paper I take advantage of the SOM's abilities for knowledge discovery, handling large textual dataset, and data organization and visualization in order to study a cross-section of collaborative interaction - public meeting notes - from our case study, the Sierra Nevada Adaptive Management Project.

Case Study: Discussions in the Sierra Nevada Adaptive Management Project (SNAMP)

The Sierra Nevada Adaptive Management Project (SNAMP) is a multi-year forest management project which began in 2005 in response to the 2004 Sierra Nevada Forest Plan Amendment (U.S. Forest Service 2004). SNAMP was developed to study the efficacy of Strategically Placed Landscape Area Treatments (SPLATs) (Mark A. Finney 2004; Collins et al. 2010) – one type of forest fuel reduction treatments – on forest health, fire mitigation and prevention, wildlife, and water quality and quantity. To test these treatments, SNAMP employs CAM to understand forest ecosystem behavior, incorporate stakeholder participation, and inform management of public lands in the Sierra Nevada mountains of California (Kelly et al. 2012).

SPLATs were implemented by the Forest Service in two study areas in the mixed-conifer forests of the Sierra Nevada: "Last Chance" in the Tahoe National Forest and the "Sugar Pine" in the Sierra National Forest. These two areas contain dense mixed-conifer forests at risk of fire, with fuel loads that have increased over the last century as a likely result of fire suppression policies and warmer and moister climactic conditions in California (Collins et al. 2010). The proposed fuel reduction treatments have had a mixed reception from some environmental advocacy groups and others (Kelly et al. 2012), and so in 2005 the Forest Service asked the University of California to serve as a neutral third party (Bales et al. 2010) in the CAM process, carrying out research studying the efficacy of these treatments and conducting outreach activities (via University of California Cooperative Extension program) through six specialized science teams (Table 3-1). The SNAMP project explicitly recognizes the scientific uncertainty and controversy surrounding the efficacy of forest treatments (Martin, Bender, and Shields 2000), and the project's framing document highlights a commitment to transparent decision-making and calls for ongoing analysis of stakeholder and researcher information in the Forest Service adaptive management process (Bales et al. 2007). In SNAMP this public engagement is promoted through the Public Participation team that is involved in all phases of a project (Kelly et al. 2012).

SNAMP Stakeholders

SNAMP stakeholders include three broad groups: managers, scientists and the public. Managers are individuals from participating federal and state agencies (e.g. Forest Service, US Fish & Wildlife Service, CalFire, California Department of Fish & Wildlife, California Natural Resources Agency, California Department of Water Resources, and California Department of Food and Agriculture). The scientists come from UC Berkeley, UC Merced, UC Davis, UC Cooperative Extension, and the University of Minnesota. Public stakeholders are consisted of a number of environmental advocacy groups, such as the Sierra Club, Sierra Forest Legacy, Defenders of Wildlife, and of a small group of vocal and concerned individual citizens from local communities, as well as of industry representation, such as Sierra Pacific Industries. A key role of the Public Participation team is to facilitate open discussions in public meetings that are attended by participants from all three groups, who bring to the table diverse, and at times contentious, viewpoints and interests regarding the progress and process of the project.

These public meetings usually begin with a project overview, reminding the participants of the goal and agenda of this multi-year project, reiterating the commitment to practice and produce good and open science information, and emphasizing the importance of trust, discussions and collaboration in achieving success in this project. Research updates from the UC Science Teams as well as updates on the progress of the strategic forest fuel treatments from Forest Service managers are presented. The remainder of the time is devoted to public discussions usually in the form of questions and answers in the large group as well as in theme-specific smaller groups. The discussions that take place in these meetings are extensively recorded in notes, which are published on the SNAMP website (http://snamp.cnr.berkeley.edu/documents/meeting-notes).

Public Meeting Notes

This paper uses meeting notes recorded at 38 SNAMP public meetings in 2005-2012. While these meetings notes did not record the meeting dialogues verbatim, they aimed to capture, with high fidelity, the presentations and dialogues among the participants. To achieve this goal, the meeting discussions were written up during the public meetings by multiple UC Cooperative Extension personnel. These notes were then crosschecked, combined, and edited. They were also checked against audio recordings if a meeting was recorded. In the earlier phase the project, the meeting notes were sent out to all stakeholders for review and comments; however, given the lack of response from most of the stakeholders, now the notes were sent only to the UC Scientists for verification. Upon approval by the scientists, they were then posted to the SNAMP website for everyone to read or download. The whole process would usually take two to three weeks in order to ensure that the meetings accurately represented the conversations at the meetings. Because the notes mirrored the structure of the meetings, they generally started with individual presentations and followed by questions and answers among the participants. Given the content and the format of these meeting notes, they became suitable for data mining and analysis using the SOM approach.

Method

Dataset

As mentioned, the public meeting notes (2005-2012) recorded participant discussions in the questions and answers ("Q&A pairs") format, so I chose a Q&A pair as the data unit for analysis. I considered a Q&A pair to be a better data unit for this study because each pair focused on one discussion topic; and, collectively, all the Q&A pairs captured most of the discussions from SNAMP participants in the public meetings. A breakdown of the number of Q&A pairs by the year is shown in Table 3-2. The identity of the questioners and responders were not included in the notes in order to protect speakers' confidentiality. The lengths of these questions and answers ranged from a few words to hundreds of words.

Data Preprocessing

Before creating SOMs for textual analysis, the input documents need to be converted to suitable document formats in order to increase processing speed and to produce SOMs with optimal quality. I used a suite of textual processing software on an Ubuntu Linux operating system to preprocess the meeting notes in Portable Document Format (PDF). First, the files were converted from PDF format to ASCII format using the “pdf2text” program. Second, they were parsed into 714 Q&A pairs by using “csplit,” a program that can split up a document by context. Third, the Linux stream editor, called “sed,” was used to remove auxiliary verbs, such as would, should, could, etc. Lastly, to handle the inflections of English vocabulary, all the words were converted to their stem words (e.g. “manag” is the stem word for manage, management, managed, etc.) using the Perl stemming script “porterstem.pl.”

Converting Q&A Pairs to Vectors

After obtaining these input Q&A pairs from the preprocessing phase, they were converted to vectors by the SOMLib parser script that was included in the Java SOMToolbox (Mayer and Rauber 2011b). The components of these vectors were numerical values that signified the importance of the words in the input Q&A pairs. The weights of the words were calculated by the frequency of each term appearing in a document divided by the number of documents they appeared in. In other words, a word was important to a particular document when it showed up multiple times in the document; however, it became less important to that document when it showed up frequently in all documents. This conversion process also removed stop words, such as “a,” “the,” “be,” and others and normalized the weights of the words (range of values between 0 and 1) at the end. These input vectors were used to train the feature map in the next step.

Training the feature map with vectors

Building the final SOM began with the initialization of a feature map, populated by randomized weight vectors that had the same dimensionality as the input vectors. I obtained 714 input vectors from the previous step, and each vector had 681 weights. I initialized a 40×50 rectangular space, a total of 2,000 nodes, which was larger than the number of input vectors for the purpose of spacing out the vectors in the final SOM.

The training of the feature map was an iterative process that involved two key steps: competitive learning and cooperative learning (Kohonen 2001). The first step was to place an input vector at the most similar node, also known as the Best Matching Unit (BMU), on the randomized feature map. The mathematical formula for choosing the BMU was to calculate the shortest distance between the input vector and the weight vector on the feature map:

$$Dist = \sqrt{\sum_{i=0}^{i=n} (V_i - W_i)^2},$$

where V_i = Input vector, W_i = Weight vector on feature map, and n = vector dimension. A formal treatise on this subject was provided by Kohonen (2001). Once the BMU was selected, the cooperative learning phase took place—the neighborhood vectors around the BMU were adjusted according to the BMU vector. Nodes that were closer to the BMU required greater adjustment while nodes farther away from the BMU required less adjustment. Through cooperative learning, similar input vectors, or Q&A pairs, were placed near one another in the feature map. After a sufficient number of training iterations, the representational difference between the input vectors and the feature map, calculated by quantization error, reached a minimum, signaling the completion of the training process.

Input data and required training parameters for Java SOMToolbox included a random seed of 7, a learning rate of 0.75, and 10,000 learning iterations. I set a torroidal configuration, so that the resulting maps would wrap edge-to-edge. The complete set of training parameters and guide is located at the URL: http://ifs.tuwien.ac.at/dm/somtoolbox/somtoolbox-guide.html.

Visualizations

Different SOM visualizations were created in the Java SOMToolbox. The Q&A pairs in the SOM were grouped by the Ward's clustering algorithm (Ward 1963)—a hierarchical agglomerative clustering procedure that began by treating every node in the SOM as a cluster and then reduced the number of clusters one at a time until all the nodes became one cluster. The SOM is divided into 30 clusters, each labeled by the two most prominent words drawn from the Q&A pairs in each cluster based on the clustering algorithm. The larger label is the most representative word for the cluster while the smaller label provides addition description. After that, I visualized the SOM using a smoothed data histogram (Pampalk, Rauber, and Merkl 2002)—estimating the probability density of the Q&A pairs on the SOM. I also classified the Q&A pairs by the year the notes were taken and then visualized the SOM using the thematic class map (Mayer, Aziz, and Rauber 2007). Lastly, I used a U-matrix (Ultsch 1993)—distance between a node and its neighbors—to show the degree of closeness among discussion topics.

Results

Four different visualizations of the SOM revealed a general landscape of discussion topics at SNAMP public meetings, the popular topics among them, how these topics have changed over time, and the relationships among these topics (Fig. 3-1 to 3-4).

Discussion Landscape

The general landscape of prominent discussion topics at SNAMP public meetings is shown as a clustering map (Fig. 3-1). The topics that emerge from these Q&A pairs have three main groupings: 1) *scientific* - on wildlife (e.g. "fisher/private," "bobcat/predation,"), water ("water/snow"), fire and fire modeling (e.g. "splat/model," "fire/treatment,"), forest health (e.g. "tree/growth," "species/tree,") and analysis (e.g. "lidar/return," "product/accuracy"); 2) *administrative* – with focus on funding (e.g. "funding/john," "scale/overall") and planning (e.g. "definition/monitoring," "focus/adaptive"); and they concern the *adaptive management process* itself - on treatments (e.g. "fire/treatment," "management/peer,") and participation (e.g. "participation/demographics," "members/ongoing").

Consistent Discussion Topics

While the clustering map provides a general landscape of the prominent discussion topics in the project, some of these topics have been discussed more regularly than others. The smoothed data diagram (Fig. 3-2) reveals which topics have been discussed consistently across the entire 8-year project. In Figure 1b, red indicates more consistent topics and blue indicates more intermittently discussed topics. The most consistently discussed topics relate to the impact of forest treatments on fire and water conditions ("fire/treatment" and "water/snow"), on the funding and process of the project ("funding/john" and "process/report"), on the use of remote sensing technology called light detection and ranging (“lidar/return”), and on issues surrounding the Pacific fisher (“bobcat/predation,” “fisher/private,” and “squirrel/female”).

Discussion Through Time

The evolution of discussion topics through time is mapped in the thematic class map (Fig. 3-3) by coloring Q&A pairs from earlier years with less saturated green and later years with more saturated green. In the early years of the project, discussion focused on planning and bounding the science: topics such as “definition/monitoring,” “process/report,” and “moup/ucst,” dominated the discussions in the earlier years of the project. In later years, topics related to wildlife science (e.g. “bobcat/predation,” “road/animal,” and “predation/camera”) and to the treatments (e.g. “fire/treatment,” and “management/peer”) begin to dominate discussion.

Relationships among Discussion Topics

Lastly, the relationship among the clusters based on the connectedness of the underlying Q&A pairs is presented in the U-matrix map (Fig. 3-4), with darker blues indicating connectedness between topics and brighter red indicating disjointedness. In Figure 1d, groups of topics in blue are clusters, and red areas function as borders around the clusters. Topics that were usually discussed in isolation (i.e. blue clusters surrounded by red boundaries) belonged to the six science research categories: “lidar/return,” “water/snow,” “species/tree,” and “bobcat/predation.” In contrast, there were topics commonly discussed together (i.e. blue clusters), such as planning and participation (“plan/resilience,” “moup/ucst,” and “participation/demographics”).

Discussion

Discussions focused on the project: science and management.

The topics displayed by the SOM clustering map (Fig. 3-1) correspond well with the primary science research areas and other important administrative aspects of the project. This suggests that participants have focused on the primary research agenda and goals in the public meeting discussions. The success in guiding participants’ conversations in public meetings and helping them stay focused on the key research and management questions is likely the result of the continual scientific knowledge production (Lei, Iles, and Kelly 2014), the consistent facilitated discussions among participating parties, and the commitment to transparent information and processes made by the Science Team at the start of the project (Bales et al. 2007; Bales et al. 2010). These are positive results in light of literature suggesting that scientists need to improve their performance in civic science information delivery (Bormann, Haynes, and Martin 2007).

There is an evolution of discussion topics.

Another way to show that the SNAMP participants have stayed the focus on key research topics is by examining the meeting notes through time. The thematic class map (Fig. 3-3) shows the change of topics over time, with less saturated green showing discussion topics at an earlier time and darker green at a later time. Corroborating the findings from the clustering map, SNAMP research areas such as water, fisher, tree, and lidar have consistently showed up in the discussions over time. However, the thematic class map not only shows the consistent discussion topics over time, but it also shows the advancements of the discussion topics. For example, topics on defining the process, scale and participants in the project show up as lighter green, denoting that they are discussed more often before 2007. These topics have faded in participants' discussions after 2007, likely because these issues have been resolved. As anther example, in 2012, scientists start to produce more research results, which are presented and discussed at the public meetings. The research progress in SNAMP is reflected on the map as the darker green patches tend to fall on the main SNAMP research topics.

Some contentious issues may dominate discussion.

While project participants generally focus on the key science research topics in the project, these topics do not receive the same amount of attention during the discussions. Certain topics will dominate discussion. In our case, discussion on the Pacific Fisher, forest treatments, fire and lidar, have been discussed more frequently through time than other research topics. This variation in the frequencies of discussion topics indicates that while all science teams are considered equally important in the project and have been given equal amount of time during discussions, participants largely drive the discussions in these public meetings toward topics that are more important and relevant to them. The frequency of discussion around fire is not surprising as it is at the heart of the project, and the focus on lidar suggests that the technology is critical to all aspects of the project that remains of high interest to the participants. The most popular discussion topics involve wildlife, and in particular the Pacific Fisher and California Spotted Owl, which are the most contentious issues in the project. This focus on wildlife is also reflected in on-line discussion and website interaction (Kelly et al. 2012).

Integration of discussion topics is not always present.

SNAMP's commitment to integrated science and outreach shows up in several areas of discussion. Topics related to management, participation, and science process are well connected, as are topics relating to wildlife. Yet, there is a lack of integration among some of the discussions around science research topics. This is revealed by the U-matrix in Figure 1d, which shows significant "barriers" between some of the six science research categories. An interesting example is lidar, which is mostly discussed in isolation from the other science topics even though the technology is used in the work of all the science teams. And interestingly, there is a stronger connection between the topic of forest treatments (SPLATs) and topics related to owls than there is between SPLATs and fire. This lack of integration between some topics is explained in a number of ways. First, these data include both public meetings and specialized public meetings ("Integration Team Meetings"), led by scientists from each research team. The purpose of the specialized Integration Team meetings for each research topic is to provide more detailed science information and research updates specific to the topic to the project participants, but this focus may deter or exclude those who are not interested in this technical level of detail, hence, lessening the potential for a more integrated discussion. Second, the format of the Annual Meetings, in which each team discusses its findings in sequence, might have prohibited a more natural integration between topics. Finally, the project has as its final task of integrating science research results in the final year (2014) of the project; thus, more active integration might still be revealed. Visualizing the "barriers" among some of the discussion topics may provide valuable feedback to project coordinators, so that they may devise strategies to achieve more balanced and integrated discussions.

Evaluating the SOM for Analysis of Meeting Notes

The SOM is an effective and efficient unsupervised machine-learning procedure for textual data analysis and exploration when applied to meeting notes, such as the SNAMP public meeting notes. Its effectiveness derives from the variety of convenient visual representations of the input data – the "maps" - on two-dimensional space that revealed concealed information about public discussions: topic consistency, evolution of importance of topics, and integration between topics. Another feature, not used in this study, is that the two-dimensional SOM can be explored at different scales, similar to the zooming in-and-out capability on a digital map. The Java SOMToolbox provides such functionality by growing a hierarchical SOM (Rauber, Merkl, and Dittenbach 2002). Although this feature is not necessary for answering the research questions in this study, it might be helpful for project coordinators to explore individual Q&A pair at a finer scale of resolution to draw more insights from the data.

While SOM affords a number of advantages for textual exploration and analysis, a few shortcomings are noted. Although flexible and powerful text processing tools are available, depending on the content and condition of the input data, the preprocessing steps can require considerable amount of time and effort—something to budget for in the research planning stage. And despite the unsupervised nature of the SOM, a level of familiarity with the input data is still required from its user to properly interpret the SOM results and visualizations. I did not identify the individuals who ask or answer questions, and focused our analysis only on ideas in the Q&A pairs. This choice severed the connection between the ideas and their sources and prevented us from seeing social dynamics in the discussions. For example, the SOM may reveal that a particular scientist consistently received and responded to questions from a particular group of participants. It would be advisable to include participants' names in the raw meeting notes but remove them before public posting, so that the raw notes, after coding for anonymity, can be used to draw insights for social dynamics using the SOM method.

Conclusions

In this paper I used the self-organizing map (SOM), a relatively new method for exploring textual data, to explore the multi-year public discussions associated with a forest management case study in the Sierra Nevada mountains in order to understand whether and how the CAM process has facilitated discussion among various stakeholders in a contentious environmental management setting. I analyzed the questions and responses from public meetings (2005-2012) in which scientific results, project progress, and other issues were discussed. Our results are fourfold. First, the discussion in the annual meetings remained largely focused on the project: on science, on administration and on the adaptive management process itself. Second, there was a natural evolution of discussion topics. Some topics ran their course earlier in the process – those focused on planning and logistics – and some remained a topic of interest with the public. Third, some of the more contentious and critical issues dominated the discussions through time. Finally, integrated discussion across topics was rarely present. Collectively, these results suggest that CAM in SNAMP has been successful in some regards but not in others: in particular, it sustained engagement and facilitated focused discussions among the contentious participants in the project, but it did not foster an integrated science approach for collaborative management.

The SOM method was effective and efficient for organizing, distilling and making sense of unstructured and unorganized meeting notes. The four visualizations of the SOM provided the overall landscape of the discussion topics through time; they highlighted the most popular topics, produced a longitudinal view for these topics, and revealed how the topics were connected. The SOM technology is freely available to natural resource managers. The main challenge to using SOM might be in preparing the meeting notes before running it through the SOM software; however, this challenge can be easily overcome with a commitment to transcribe meeting discussions accurately.

Besides using SOM to visualize and analyze meeting notes from public meetings, it can be added to the battery of methods in stakeholder analysis (Reed et al. 2009). Performing stakeholder analysis is critical to collaborative natural resource management because it helps bring the right people to the management table. The SOM can facilitate this process by identifying environmental stakeholders' concerns and values through collecting their publicly available mission statements and documents on their websites, processing these documents with the SOM algorithm, and then visualizing and interpreting their issues/values. After producing and comparing value maps for all relevant stakeholders, natural resource managers can identify common or conflicting issues/values and develop collaboration structures and strategies accordingly.

In conclusion, I think that natural resource managers might take advantage of the SOM in management in a number of ways. First, the representations of large sets of unstructured meeting notes can provide indicators about the state of management and collaboration in natural resource management. By generating SOM maps of meeting notes at a regular interval, resource managers can monitor ongoing discussions in public meetings involving multiparty stakeholders. This might be especially useful for projects with contentious parties because the method can provide managers early detection of critical issues that may halt collaboration and management. Second, the visualizations of discussion topics can also quickly inform mangers about what issues concern environmental stakeholders the most and how these issues relate to one another. Such understanding might improve communication with environmental stakeholders. Third, by seeing a map of issues, including their dynamics over time, managers might develop a more holistic management scheme for prioritizing and tackling the myriad of issues they are confronted with. These maps might serve as justification for their management decisions. Finally, managers might also use these maps as an education tool to show environmental stakeholders the issues that they have been discussing, the progress they are making in the discussions, and how much their issues may be related to one another. This may give stakeholders a sense of progress in collaboration. These and other possible uses make SOM a potentially important tool for use in collaborative adaptive management.

CHAPTER THREE – FIGURES

Fig. 3-1. Clustering Map visualization showing 30 clusters of Q&A pairs from SNAMP public meetings (2005-2012), each labeled by 2 most prominent words in the clusters.

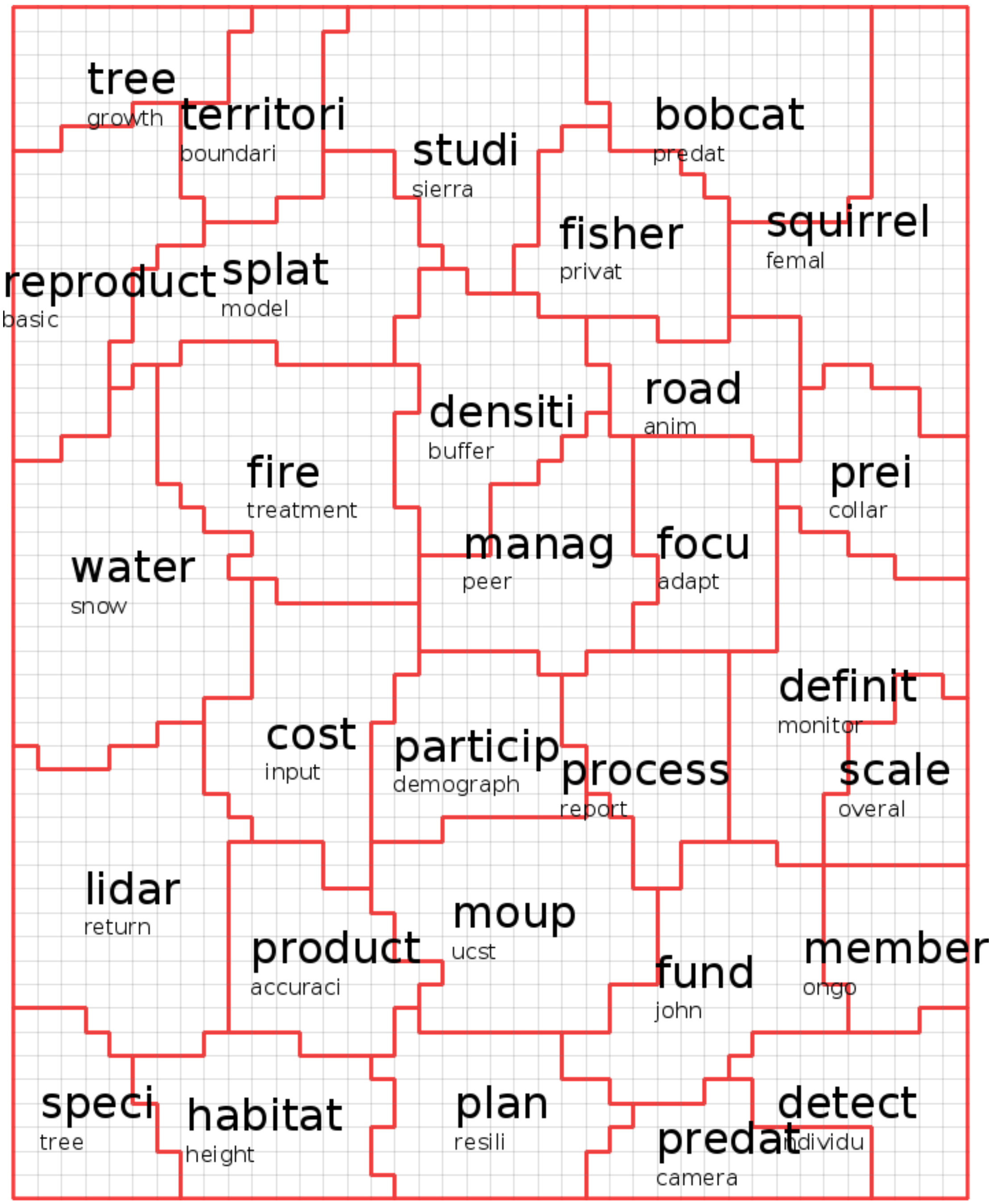


Fig. 3-2. Smoothed Data Histogram visualization showing the frequency of discussion topics in SNAMP public meetings (2005-2012).

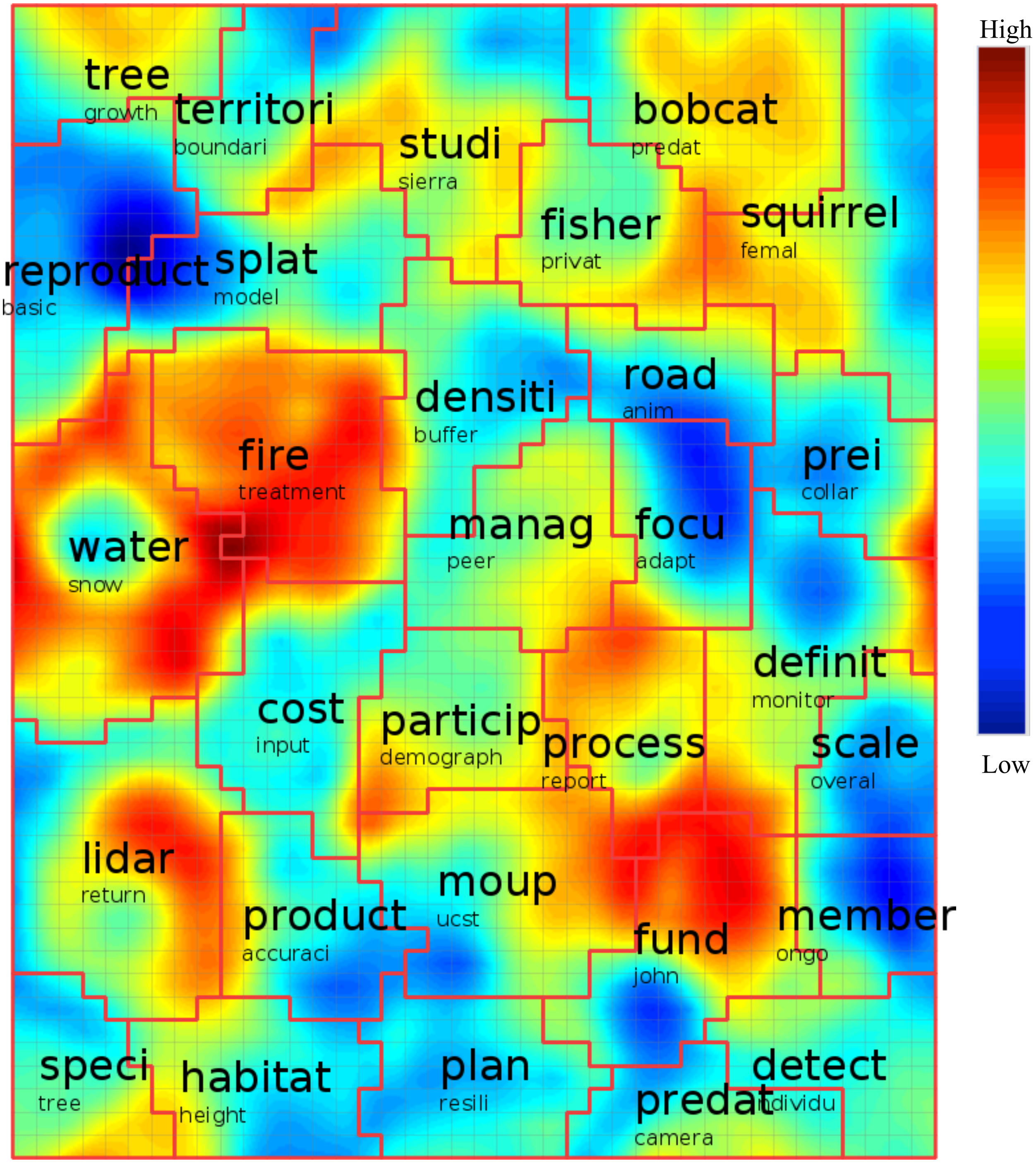


Fig. 3-3. Thematic Class Map visualization showing the timing of the discussion topics in SNAMP public meetings (2005-2012).

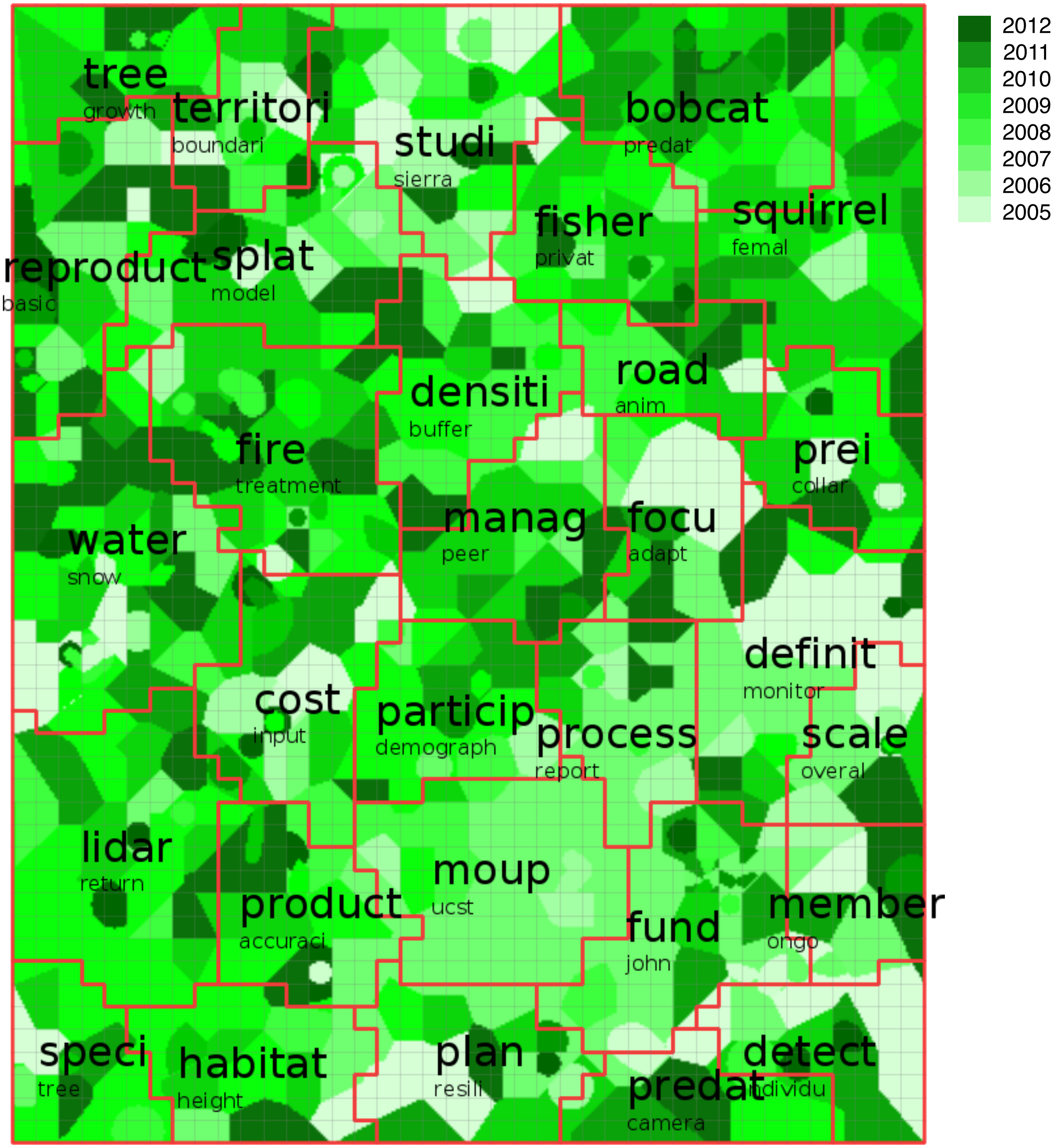
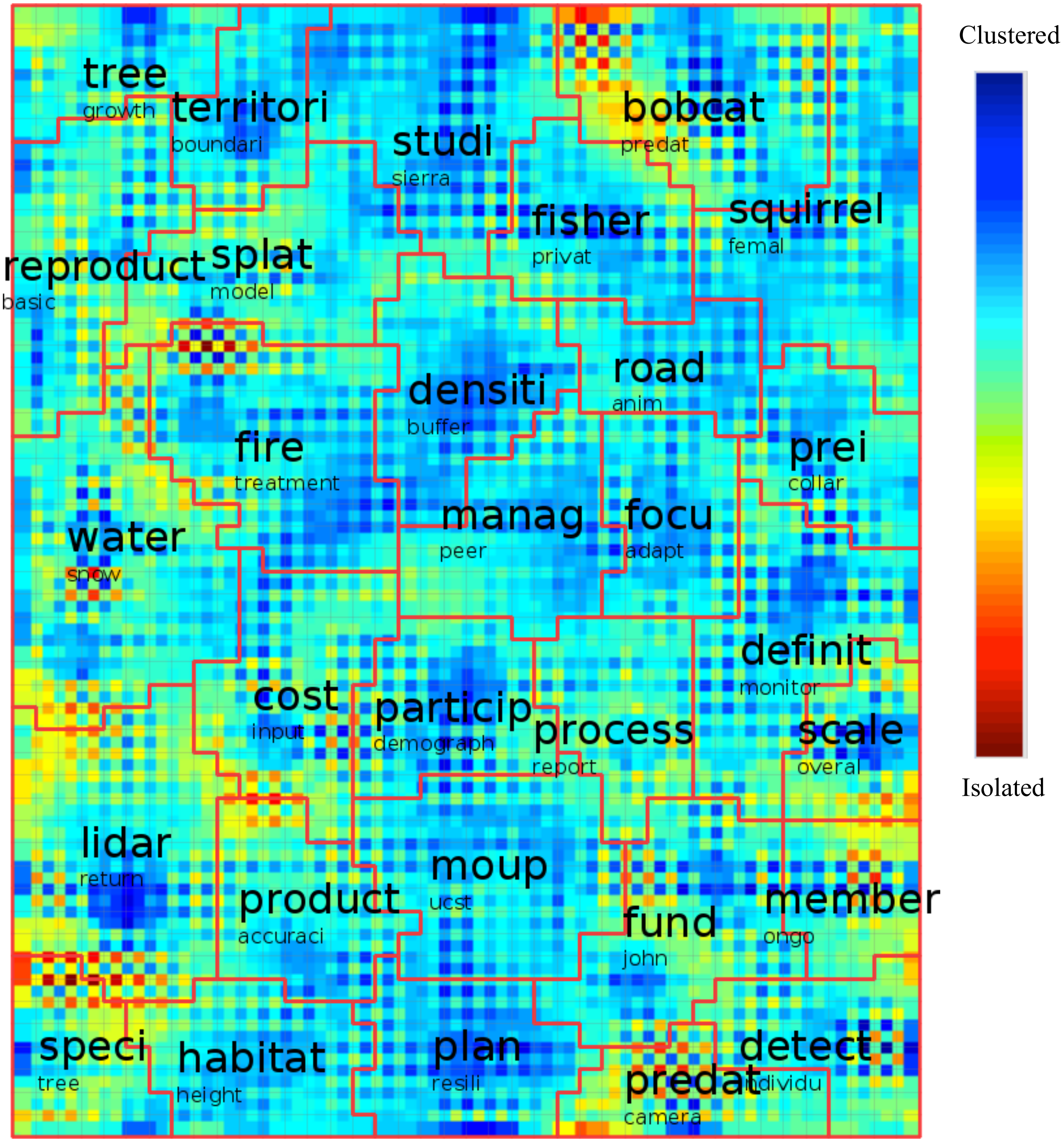


Fig. 3-4. U-Matrix visualization showing which discussion topics are more integrated with one another in SNAMP public meetings (2005-2012).



CHAPTER THREE - TABLES

Table 3-1: SNAMP Science research teams and their responsibilities.

SNAMP Science Teams	*Responsibilities*
Fire and Forest Ecosystem Health	Investigate effects of strategic fuel treatments on fire behavior, tree morbidity and mortality, and forest health.
Water	Research water quality and quantity across treatment and control catchments prior to, and after, fuel treatments.
Fisher	Determine the limiting factors for the Pacific Fisher (*Martes pennanti*) population in the southern site.
Owl	Determine if forest fuel treatments have an effect on spotted owl (*Strix occidentalis*) territory occupancy and reproductive success in the northern site.
Spatial	Lead the GIS, remote sensing, and spatial analysis required by teams.
Public Participation	Research the Forest Service public participation process and increase stakeholder involvement through regular public meetings, public outreach, and an interactive website.

Table 3-2: The number of Q&A pairs by the year.

Year	*Number of pairs*	*Word count range*
2005	68	3-57
2006	30	10-502
2007	104	6-576
2008	64	19-406
2009	129	11-560
2010	137	14-287
2011	69	15-462
2012	110	13-442

CHAPTER FOUR

Mapping the dynamics of social resilience in a forest management setting: Use of affiliation network analysis of public meetings and participants in the Sierra Nevada Adaptive Management Project

Collaborative adaptive management is widely seen as the appropriate management regime for dealing with complex social-ecological systems, and to ensure ecological and social resiliency in these systems. More research has been devoted to understanding the ecological resilience of social-ecological systems; in this paper, our objectives were: 1) to characterize patterns of social resilience of collaborative adaptive management for a social-ecological system using affiliation network analysis; and 2) to analyze how leadership, norms of engagement, and governance contributed to sustaining collaboration networks. I constructed an affiliation social network from 7 years of attendance data at all public meetings associated with the Sierra Nevada Adaptive Management Project (SNAMP). The affiliation network allowed us to examine management cohesiveness over time, the effects of the project's guiding principles, and the roles of core participants, which included managers from federal and state natural resource agencies and the public. The Sierra Nevada Adaptive Management Project demonstrated social resiliency in the face of exogenous stressors. Important to the success of the social networks in the case study were: 1) the formation of a core group with consistent participation and balanced representation; 2) the project norms of transparency and science integration; and 3) flexible governance structure.

Introduction

The social-ecological systems framework (Berkes, Folke, and Colding 1998) can be used to analyze the complexities of management of Sierra Nevada national forests in the United States. Public forests are difficult to manage because they are fraught with uncertainties in natural processes as well as social complexities (Conklin 2006). Scholars have characterized the uncertainties in natural processes as diverse, cross-scale, and nonlinear or "surprising" behaviors (Holling 1996; Levin 1998). For example, large-scale, science-driven forest treatments are difficult to implement due to insufficient scientific understanding of the interactions among various ecological processes, such as fire, forest health, water, and wildlife (C. J. Walters 1997). Recognizing their need for more scientific knowledge to handle such uncertainties, resource managers turned to adaptive management (Holling 1978; C. J. Walters 1986), or management by policy experimentation with an emphasis on systematic and scientific learning (C. J. Walters and Holling 1990). Learning is critical to diminishing uncertainties for management as new knowledge guides management policies and decisions in the iterative adaptive management cycle (Schusler, Decker, and Pfeffer 2003; Williams and Brown 2014).

Yet as important as this framework is to contemporary policy, adaptive management has often concentrated on natural processes, rather than integrating the social complexities that inevitably arise when managing natural resources. Social complexity, which manifests in contentions and conflicts over environmental values and goals among environmental stakeholders (G. Brown, Kelly, and Whitall 2013b; Ferranto et al. 2013), can undermine the learning process needed to improve management. Lee (1999) argued that adaptive management has been more influential as an idea than practice because conflicts and disagreements among stakeholders have largely inhibited the capacity to learn and to manage effectively. Similarly, McLain (1996) investigated three adaptive management cases—spruce budworm management effort in New Brunswick, Canada, fisheries management in British Columbia, Canada, and hydro-electric power and fisheries management in the Columbia River Basin, United States—and found that adaptive management was ineffective in resolving conflicts among stakeholders. Consequently, researchers and policy-makers have developed a collaborative management approach that emphasizes fostering collaboration among multiparty environmental stakeholders in dealing with conflicts and unexpected dynamics in management (Wondolleck and Yaffee 2000).

While collaboration can build understanding among diverse environmental stakeholders, support for decision-making processes, and capacity for implementing management decisions and policies (Wondolleck and Yaffee 2000, 23), it faces three categories of challenges and barriers. These are 1) *institutional and structural barriers*—fragmentation of interests, power and authority, conflicting missions and goals, inflexible policy and procedures, and constrained resources; 2) *barriers due to attitude and perceptions*—mistrust and negative group attitudes and the informal organizational norms and cultures that resist cooperation; 3) *problems with the process of collaboration*—stakeholders' unfamiliarity with the process, lack of facilitation skills, and tensions with their real-world political orientation outside of the collaboration process (Wondolleck and Yaffee 2000, 47–66). To address these barriers and problems, this paper focuses on three facets of social capital that are important to enhancing resilience in networks of collaboration: leadership, norms of engagement, and governance (Folke et al. 2005). Leadership provides innovation and helps achieve the flexibility needed to handle ecosystem dynamics and uncertainties. Norms of engagement provide common rules that can foster trust, social learning, and integration of knowledge and effort among collaborators. And flexible governance enables collaboration networks to "cope with changing conditions" (Nelson et al. 2007).

In this paper, I evaluate the effects of leadership, norms of engagement, and governance on collaboration according to their effects on the *resilience* of collaborative adaptive management during crisis moments (see also Goldstein 2012). The concept of resilience was originally developed to describe the ability of an ecosystem to maintain its structure and functions in the event of an unexpected disturbance (Holling 1973). An ecosystem can transition through four different phases—from exploitation, to conservation, to creative destruction, to renewal, and back to exploitation (Holling 1986)—across spatial, temporal, ecological, and social scales (Gunderson 2002; Holling 2001). While resilience has been extensively applied to the ecological dimension of SES research (Gunderson and Pritchard 2002; Gunderson 2000), it can also be applied to its social counterpart (Adger 2000; K. Brown 2013). Folke (2006) noted the growing number of studies in integrating resilience with other social theories. For examples, resilience has been integrated with the discipline of health and developmental psychology to form community-level resilience (Berkes and Ross 2012), with the well-being concept in development economics to gain deeper insights into the social side of social-ecological systems (Armitage et al. 2012), and with vulnerability research in the theoretical traditions of hazard studies (Miller et al. 2010). Of particular interest to this paper is the application of the concept of resilience to *social management processes* within a social-ecological system in analogy to ecological resilience,(Walker et al. 2002) and analyzing the resilience of social relationships in management based on relational change (Nkhata, Breen, and Freimund 2008).

In this paper, I propose the use of affiliation network analysis as an appropriate analytical tool to characterize and evaluate the social resilience of management because the structural properties and dynamics of the social network influence system adaptability (Walker et al. 2006), as well as the outcomes and processes of management (Bodin and Crona 2009). Also, examining participant affiliation is especially fitting for this study because participant relationships are not established based on power sharing, which is typically found in co-management literature (Plummer and FitzGibbon 2007), but through their participation and interaction in the public meetings in the case study. Affiliation network analysis applies conventional social network analysis methods and techniques (Scott 1988) to affiliation data, a network of "relationships between members of two sets of items" (Borgatti and Halgin 2011). A classic example of affiliation network analysis is Davis, Gardner and Gardner's (1941) study that identifies social cliques among a group of women in Natchez, Mississippi by their attendance at social events.

Many researchers have suggested that social network analysis is relevant and useful for studying the resilience of social-ecological systems (Abel, Cumming, and Anderies 2006; Olsson et al. 2006; Booher and Innes 2010; M.-L. Moore and Westley 2011). Janssen (2006) linked social network properties to the resilience of management in social-ecological systems. The advantages of such linkage included quantitative measurements of resilience in management that allowed for comparison of performance between different social-ecological systems, flexibility in representing study subjects and their relationships with nodes and ties, and visualization of resilience using social network graphs. Among suggested future research directions, Janssen (2006) repeatedly called for more explicit inclusion of the dynamics and heterogeneity of a network structure to understand resilience in SES.

Building on and responding to Jansen's work, I use affiliation network analysis to generate insights into how and why social resilience can manifest a cyclical pattern similar to ecological change. This is accomplished by analyzing the *network cohesion* (i.e. the connectedness of the people in the network) over time. Among the cohesion metrics, I use *density* (the ratio between actual number of ties and its theoretical maximum in a network) to indicate the density of connections; I use *average degree* (average number of ties among network nodes) to understand overall participation rate; and, I use *centralization* (how much a network is gravitated toward particular network nodes) to identify key participants or events.

Affiliation network analysis is also used to reveal how leadership, norms of engagement, and governance affect the social resilience of management. Leadership and norms of engagement are characterized by the *centrality* measures (i.e. the importance of an entity based on its connections and position in a network) of people and events, respectively. There are four types of centralities: *degree centrality* (how many ties an entity has), *closeness centrality* (how close an entity is to other entities in the proximity), *betweenness centrality* (how much an entity is between other entities), and *eigenvector centrality* (how close an entity is to other entities in the entire network). Governance is characterized through the visualization of the affiliation network and the attendance rates of the people with high centrality measures.

The basic building blocks in affiliation network are *nodes* (i.e. a generic term that include all entities in the network, e.g. people and events in SNAMP), *ties* (i.e. the connections among nodes), and *modes* (i.e. the different types of nodes). An affiliation network is also called a two-mode network because it is made up of relationships between two modes, namely people and events in the case of SNAMP. A full treatment of social network analysis and network metrics and measurements is beyond the scope of this paper, but they can be found in a number of social network analysis publications (Prell 2012; Borgatti, Everett, and Johnson 2013).

The objectives of this paper are three-fold. First, I seek to understand and characterize how leadership, norms of engagement, and governance contribute to social resilience in management. Second, it is becoming evident that leadership, norms of engagement, and governance are not stable over time but may go through a similar pattern of resilient behavior as I observe in the ecological realm (Holling 1973). If so, it is important to understand this process and why a management network might decay before reviving. Third, the affiliation network analysis methodology is developed to map the affiliations among participants in our case study, the Sierra Nevada Adaptive Management Project, in order to shed light on the resilience pattern in a way that adds further insight into leadership, norms of engagement, and governance.

Case study: SNAMP affiliation network

Sierra Nevada Adaptive Management Project (SNAMP)

The Sierra Nevada Adaptive Management Project is a multi-disciplinary, multi-stakeholder project focused on governing fire in the Sierra Nevada forests of northern California. Fuel loads in Sierra Nevada forests have increased due to fire suppression policies as well as warmer and moister climactic conditions in California in the last century (Collins et al. 2010). The increase in fuel loads has heightened the risk of catastrophic fire for millions of hectares of dense forest (van Wagtendonk 1996). Strategic fuel management at the landscape level, including thinning trees and removing underbrush, was recommended by the 2004 Sierra Nevada Forest Plan Amendment (U.S. Forest Service 2004), which called for managing national forests using the best scientific information available in order to protect forests and homes from wildfire. In response to the Amendment, the U.S. Forest Service implemented strategically placed treatments (SPLATs) in two study sites in the mixed conifer forests of the Sierra Nevada, “Sugar Pine” in the Sierra National Forest, and “Last Chance” in the Tahoe National Forest. The experimental design uses a before-after-control-implementation (BACI) (Stewart-Oaten, Murdoch, and Parker 1986) approach explicitly designed to obtain quality scientific information about the impact of forest fuel reduction treatments.

These fuel management strategies have been vetted in a modeled environment (M. A. Finney 2007), and have been supported by homeowners in forest-urban interface areas, yet such management is fraught with uncertainty as a result of insufficient scientific information about complex ecosystem dynamics (e.g. fire, water and wildlife) and numerous and outspoken disputes between stakeholders and the Forest Service. For example, the SPLATs concept has been contested by environmental advocacy groups due to their lack of confidence in the strategy and in some cases in the US Forest Service’s capabilities. In this particular case study, collaborative adaptive management was seen by the Forest Service and the public stakeholders as the best method to manage the complex social-ecological forest system, and SNAMP began in 2005 in response to these dynamics.

SNAMP is organized around research interaction between SNAMP science teams that are focused on the impact of strategic fuel treatments on wildlife (namely, California Spotted Owl and the Pacific Fisher), water quality and quantity, forest health and fire prevention respectively. SNAMP also emphasizes collaboration among multiple stakeholders, government agency partners (such as the US Forest Service and other California State resource agencies), and the public, including local community members and representatives from environmentalist stakeholder groups. The Public Participation Team is in charge of nurturing such collaboration by reaching out to the public with SNAMP information (Lei, Iles, and Kelly 2014) and facilitating discussions among stakeholders in the SNAMP public meetings (Lei and Kelly 2014).

SNAMP public meetings

Public meetings, which are open to the public, serve as the primary engine for the collaborative adaptive management process in SNAMP because discussions influencing management of the Sierra Nevada forest take place among participants at these meetings: scientists share their latest research findings pertinent to the project, managers provide treatment updates, and public participants and environmental stakeholders give feedback on proposed management decisions to managers and scientists. Discussions at public meetings are facilitated by UC Cooperative Extension Specialists—PhD scientists with expertise in public participation and outreach—on the Public Participation Team. Through encouraging open dialogue, relationship building, and making information transparent to all parties, these public meetings aim to increase trust and learning among all participants in the project.

SNAMP hosts public meetings in a variety of formats and locations. The most common format is the theme-based integration team meetings hosted by one of the UC Science Teams. For example, when the Fisher team hosts an integration team meeting, the scientists on that team will update managers and public participants on their latest research findings, which can inform management decisions. In contrast, SNAMP annual meetings bring members of the science teams, agency partners and the public together to review overall project progress and set project goals for the following year. SNAMP field trips are also arranged to provide participants a more experiential understanding of forest management implementations, field experiments, or wildlife habitats. For the purpose of capacity building, workshops on how to use spatial mapping technologies or how to facilitate meetings for collaborative adaptive management are also held. These public meetings take place in different locations, generally near the northern and southern study sites, in order to reach out to a broader range of public participants, such as local residents and secondary school students. The range of meeting location, theme and format is designed to attract and accommodate as wide a variety of public stakeholders as possible.

SNAMP affiliation network

As a result of participating in these SNAMP public meetings, meaningful associations between people and public meetings are developed in a network around SNAMP. The SNAMP affiliation network analyzed in this paper consists of people who have attended at least one SNAMP-sponsored public meeting. Participants included people from two broad groups: Managers, or members of the Memorandum of Understanding Partners ("MOUP") agreement setting up the project (e.g. employees of the federal and state governmental agencies involved in forest management), and the Public (e.g. employees of numerous environmental advocacy groups, such as Sierra Club, Sierra Forest Legacy, Defenders of Wildlife, and etc., as well as the public). The requirement that members of the UC Science Teams must attend meetings removed their agency in affiliation network analysis even if they might be influential in the process, and thus they are not included in our analysis.

Methods

Dataset

Attendance information, along with attributes of participants (i.e. name, contact information, and affiliations) and public meetings (i.e. title, theme, time, and place), were collected through sign-in at every SNAMP public event between 2005 and 2013. However, since only one event was recorded in 2005 and 2006, respectively, the attendance information from these years was excluded from the analysis with negligible impact to the network structure. The sign-in sheets were then digitized, compiled and verified for completeness and accuracy by the SNAMP Public Participation team. An affiliation network was constructed from the attendance information spreadsheet, in which people and public meetings constituted two different modes of the network, and a tie between a person and an event in the network represented a person's attendance to an event. As mentioned earlier, a person would not directly connect to another person but only indirectly via an event in an affiliation network. The entire population of the affiliation network (588 participants) consisted of all the relevant SNAMP participants and public meetings in 2007-2013.

Data pre-processing

Data pre-processing was required before the dataset could be analyzed. First, duplicate and ambiguous entries of people and public meetings were eliminated. Second, people and public meetings were coded—replacing people's name with "P" and a numeral and public meetings' title with "E" and a numeral—in order to protect the privacy of individuals. Third, besides the collected attributes, additional attributes were added to the people and public meetings nodes to enhance data analysis and visualization. Individuals were characterized by their larger SNAMP categories (i.e. MOUP or Public) based on their affiliations, while public meetings were characterized by one of the research themes (i.e. Fisher, Owl, Spatial, Fire and Forest Health (FFEH), Water, Public Participation (PP)) or by integrating them.

Affiliation network analysis

The SNAMP affiliation network was first visualized by using the NetDraw tool in the UCINET program (Borgatti, Everett, and Freeman 2002), with different symbols (color and shape) to distinguish people and public meetings based on their attributes. The Spring Embedding algorithm (Hanneman and Riddle 2005) – placing points with smallest path lengths closest together in the graph through iterative fitting – was used to render the affiliation network, in which the positions of the people and public meetings nodes were determined according to the rate of attendance as well as how the nodes were connected to one another. Next, four two-mode centrality metrics (i.e. *degree*, *closeness*, *betweenness* and *eigenvector* centrality) (Borgatti and Everett 1997) were calculated in order to characterize the leadership structure and the norms of engagement in SNAMP. The top ten participants in each of the four types of centrality were tabulated; and, their yearly attendance rates (number of public meetings attended divided by the total number of public meetings in a particular year) were calculated and compiled in a table. Lastly, the attendance data was divided by years into seven two-mode sub-networks. In each of the sub-networks, people who attended at least one event formed its main component, while those who did not attend any public meetings were removed. The network cohesion metrics (i.e. *average degree*, *density*, and *centralization*) and the main component ratios (population in a main component over the entire population of the project) were calculated and charted over time for the seven main components.

Results

Results from affiliation network analysis, combined with different ways of counting people and public meetings, revealed the features of the SNAMP affiliation network, some characteristics of important network nodes, and the network's structural changes through time.

Overview of the SNAMP affiliation network

Between 2007 and 2013, the SNAMP project held 74 public meetings (44 took place near the northern study site, 28 near the southern study site, and 2 were webinars), with 588 unique participants and 1,599 total attendances (Table 4-1). Among the participants, 376 (64%) were in the "Public" group, and 212 (36%) belonged to the "MOUP" group. The 74 public meetings focused on Fire and Forest Health (16 meetings, 358 total attendance), Fisher (10 meetings, 353 total attendance), Owl (8 meetings, 107 attendance), Public Participation (6 meetings, 186 total attendance), Spatial (4 meetings, 78 total attendance), Water (6 meetings, 126 total attendance), and on integrated discussions that include all the themes as well as administrative issues with (14 meetings, 391 total attendance).

The SNAMP affiliation network diagram (Fig. 4-1) consisted of one component, in which every node was tied to at least one other node. The nodes and ties were denser in the center and sparser on the periphery. Nodes for public meetings near the northern site are on the left half of the diagram, those near the southern site are on the right half, and the two webinar nodes at the center. More people are located at the periphery, while more events are located near the center of the diagram; yet, a small number of people, in both green and orange, are found at the very center of the diagram.

Characteristics of important nodes in the network

The top ten SNAMP participants in *degree*, *closeness*, *betweenness* and *eigenvector* centrality, along with their affiliation categories (i.e. MOUP or Public), are listed in Table 4-2. In these four top ten lists, P1 through P5 occupied the first five positions in all four centralities. Beyond the top five positions, participants who were high in one centrality might not be high in the others, e.g. P6 ranked 6th in degree centrality but only 10th in closeness and betweenness centralities; P12, not even ranked among the top ten in degree centrality, appeared as 6th in closeness centrality and 7th in betweenness centrality. The eigenvector centrality rankings were generally similar to the closeness centrality except in the case of P12, which ranked 6th in closeness centrality but not among the top ten in eigenvector centrality. More participants (7) were in the Public category than the MOUP category (3) by degree centrality; however, participants from either category were represented evenly in the other three centralities.

The yearly attendance rates of the participants who appeared in the Top Ten table are shown in Table 4-3. Overall, these participants were consistent in their attendance to SNAMP public meetings, with a uniform decrease in attendance in 2013. However, four patterns of attendance to the SNAMP public meetings were observed: 1) *attending* c*onsistently*: some participants had been consistently, though at varying rates, attending SNAMP public meetings every year (e.g. P1-5, P10, and P12); 2) *joining late*: some joined the project a few years after the project began, but their attendance grew over time (e.g. P7-9, P13-4, and P21); 3) *stopping temporarily*: some participants stopped attending SNAMP public meetings for a period of time but rejoined the project (e.g. P12); and, 4) *exiting early:* participants stopped their attendance to SNAMP public meetings after a few years of participation (e.g. P6-7).

The important nodes for SNAMP public meetings in additional to people are shown in Table 4-4. Similar to the participants' top ten lists, most of the public meetings that had high degree centrality also showed up as one of the top ten meetings in the other centralities, e.g. E25, E32, E42, E50, E52, and E74 appeared in all four top ten centrality lists, albeit at different ranks. One notable event that occupied very different ranking positions in four different centralities was E74, which ranked 1st in closeness centrality and 2nd in eigenvector centrality but only 7th in both degree centrality and betweenness centrality. According to the themes of these public meetings, the most popular themes among the top ten public meetings were Fisher, Fire and Forest Health, and Integrated. Meetings about the Fisher take the top three spots in degree centrality, meaning that they are the most attended events, while Science Integration meetings take the three top spots in closeness centrality, which means that they reach the most people in the network. Three field trips (e.g. E28, E53, and E61) appeared in the betweenness centrality list, with E28 ranking 2nd in the list, which means that they bring together clusters of participants who would not normally co-attend other types of public meetings.

The SNAMP network through time

The longitudinal changes in the structure of the SNAMP affiliation network, measured by *average degree* (normalized and scaled), *density*, *centralization* and *main component ratio*, are shown in Figure 2. The average degree of the main components in the SNAMP network rose from 40.36 in 2007 to 53.93 in 2010, and then dropped to 33.58 in 2013. The network's density and centralization reached their local minima (0.11 and 0.13, respectively) in 2009, reached their peak values (0.21 and 0.28, respectively) in 2010, and then gradually declined to lower values (0.12 and 0.13, respectively) in 2013. In 2010, the average degree, density, and centralization reached their absolute maxima while the main component ratio its local minimum.

Discussion

Modeling social resilience with affiliation network analysis

The longitudinal changes of the SNAMP affiliation network cohesion, quantified by affiliation network cohesion metrics, followed the theoretical transitions expected in a typical resilience framework as introduced by Holling (1986): exploitation, conservation, creative destruction, and renewal. The SNAMP network expanded from 2007 to 2009, indicated by the increase in main component ratio and average degree as well as the decrease in density and centralization (Fig. 4-2). The gradual expansion of the SNAMP network from 2007 to 2009 mirrored the phase transition from the exploitive phase to the slow conservation phase of the adaptive cycle in the resilience framework, where a social-ecological system gradually accumulated resources. In the case of SNAMP, during this time, the network accumulated participants whose rates of attendance to public meetings in SNAMP were also increasing.

In 2010, the average degree, density and centralization of the network peaked, indicating an increase in participations from and connections among SNAMP participants. However, in the years after 2010, the cohesiveness of the network decreased as indicated by the decrease in the network's average degree, density, and centralization. I suggest that this decline in metrics records the network's entrance into the creative destructive phase of the adaptive cycle in the resilience framework. A system that could not adapt would eventually collapse, but an adaptive system would be able to reorganize and re-stabilize. Given that the SNAMP network did not completely collapse after 2010, which would have been signified by reduction of public meetings or a very significant drop in attendance in the following year, the system went through the reorganization phase, adapting to the unforeseen events, or surprises (e.g. Holling 1996), that took place after 2010.

Detecting surprises

By modeling adaptive cycles in the resilience framework according to the cohesion metrics in affiliation network analysis, "disturbances" or surprises in collaborative adaptive management processes could be detected quickly, and corrective action could be potentially discussed and taken by stakeholders in the project. According to Figure 2, the cohesiveness of the SNAMP network significantly declined by 2011, suggesting the occurrence of a disturbance. I surmise that the disturbance in SNAMP during that time was the heated discussion among all participants at the 2011 Annual Meeting surrounding a severe funding reduction. Participants debated over three scenarios in response to the funding reduction: 1) close out SNAMP by the end of 2012 (original end time would be the end of 2014), 2) close the Southern study site but continue the study at the Northern site with full funding, or 3) reduce budgets for all research teams (SNAMP 2011). While the funding crisis was eventually resolved by the Forest Service recommitting to much of the original budget, the budget uncertainties (Nelson 1995, 127) seemed to have led to the erosion of trust among some public participants and loss of interest in engaging with SNAMP. Tracking network cohesion over time is a way to detect disturbance in collaborative adaptive management, which in turn might help project coordinators to monitor, and even respond to, social surprises in order to increase the social resilience of a project.

Factors contributing to social resilience in collaborative adaptive management

In addition to detecting surprises, affiliation network analysis enable us to analyze how leadership, norms of engagement, and governance enhance the social resilience of management in the SNAMP network.

Leadership

Leaders in the SNAMP affiliation network were identified by examining their positions and ties in a network using a network diagram and four centrality metrics. A caveat of this analysis is that though affiliation analysis offers a way to frame hypotheses regarding leadership, it needs to be supplemented with further research methods, such as interviews, in order to explain the mechanics of leadership on the ground. The four centralities highlighted different types of leaders. In SNAMP, some participants could be influential due to their high attendance rate at public meetings (e.g. high degree centrality), which might result in having more knowledge about and larger presence in the project. Others might become influential because they attended a wider variety of public meetings (i.e. high closeness and eigenvector centrality), building connections with more diverse project participants. Still others might be critical in the project because they were positioned as information brokers (i.e. high betweenness centrality), linking two disconnected clusters of participants in the network. Several participants (e.g. P1-5) had high scores on all four centrality metrics while other participants scored high on one or two of the centrality metrics. As an example, participant P12 had relatively low degree centrality but ranked high in closeness and betweenness centrality. This individual retired from one of the MOUP organizations midway through the project; yet, he remained important to the project due to his strategic, post-retirement involvement in SNAMP.

Two salient characteristics of the core participants were their consistent attendance to public meetings throughout the seven-plus years of the project (Table 4-3) and their balanced representation from MOUP and Public (Table 4-2). This suggests that consistent participation with balanced representation among core participants could support social resilience for management despite unanticipated disturbances. This would extend our understanding of the role and characteristics of leadership in collaborative adaptive management. Leadership generally referred to key individuals who can shape change and provide directions and visions (Folke et al. 2005). However, if leadership was concentrated on a few individuals, it would negatively impact decision-making and learning, hampering collaboration (Tompkins and Adger 2004). According to this study, the type of leadership that could enhance resilience in management took the form of consistent involvement and interaction from among a core group of individuals with balanced representations from the Forest Service and the public. Rather than relying on a few visionary and charismatic individuals in resolving conflicts among stakeholders and advancing toward project goals (Allen and Gunderson 2011), the resilience of management, critical to the success of collaborative adaptive management, could be strengthened by fostering a core group of participants with balanced representations. This core group is presumed to have greater capacity to fulfill the many leadership roles and responsibilities, such as providing visions, facilitating collaboration and social learning (Davies and White 2012), enabling bridging or boundary organizations to have cross-level or cross-scale communications (Cash et al. 2006), and serving as knowledge brokers (Kallis, Kiparsky, and Norgaard 2009).

Norms of engagement

Norms of engagement, or operating principles, have also been credited as enhancing social resilience in management (Adger 2000; Folke et al. 2005). The SNAMP project has two operating principles that are relevant here. The first working premise is that I need stakeholder participation and feedback during each phase of Science Team research for our adaptive management program. The SNAMP framing document says: “We are committed to transparent decision-making and an ongoing analysis of the creation, adoption, and application of stakeholder and researcher information in the Forest Service adaptive management process” (Bales et al. 2007). This norm of transparent integration of social and ecological components of management was operationalized through public meetings and a website (Kelly et al. 2012) that facilitated dialogue and knowledge exchange among participants. Annual Meetings in 2008, 2011, and 2013 as well as the Public Participation meeting were among the most effective public meetings in bringing together a diverse group of participants (Table 4).

The second norm or working premise is an *integrated* approach to forest science and management. The science teams in SNAMP shared common goals, integrated across spatial scales, and shared spatial and modeling components. This commitment to integrated science and management provided opportunities for scale-crossing interactions, such as the fire scientists at the fire shed scale working with the water scientists at the watershed scale. Ernstson and his colleagues (2010) pointed out that scale-crossing in management could increase resilience in social-ecological systems. The integrated approach allowed participants who may be only interested in one research subject to hear and learn about how other ecological components were affected by forest treatments and other forest management policies, thus increasing their knowledge and interest in the overall project. For example, according to the degree centrality for public meetings, the most popular subject in SNAMP was the Pacific fisher. Without the integrated approach, participants who were interested in the fisher might not have the opportunity to learn about fire or water science, which was relevant to understanding fishers' habitats. Through these integrated public meetings, participants at different management scale had the opportunity to interact with and learn from one another, increasing trust among participants and, hence, enhancing social resilience for management.

Flexible governance

Flexibility in the governance was the third aspect of social capital that contributes to the social resilience of collaborative adaptive management. The flexibility of the SNAMP governance was reflected in two areas: first, in the ability of participants to join or leave the project at different points in time without causing interruption or collapse to the network; and second, the variety of meeting locations and formats. The clear separation between public meetings held in north and south (Fig. 4-1) indicated that meeting location was an important logistical factor in encouraging participation. Webinars were located at the center of the diagram, bringing together people who would normally attend public meetings near the northern or southern study site. In addition to the variety in meeting locations, SNAMP public meetings had different formats, such as field trips to see forest treatments as well as educational workshops on how to facilitate collaborative adaptive management. The field trips were effective in connecting people who would not normally attend the same public meetings as suggested by the public meetings' betweenness centrality (Table 4-4). The workshops, on the other hand, were effective in expanding the size of the network (Fig. 4-1) by attracting new participants who had not been to any SNAMP public meetings before.

Future use of affiliation network analysis

By evaluating the significance of people and public meetings in SNAMP based on their occurrences as well as their connections, affiliation network analysis revealed the aforementioned factors that could contribute to social resilience for collaborative adaptive management. Such analysis could not be achieved by simply counting the number of participants and public meetings in the attendance data. However, the use of affiliation network analysis could be improved in two ways in future research. First, node attributes could be devised and applied in the attendance data. For example, the organizational affiliations for participants could be broken down further into different government agencies or advocacy groups, instead of

MOUP and Public. This would allow a more in-depth examination on the connections among participating organizations. Second, this study explored a small subset of network metrics in the large affiliation network analysis toolbox. Other network analytical methods could shed more light on social resilience in collaborative adaptive management. For examples, the key player analysis (Borgatti 2006) measures the impact of important participants/events on the network, and the homophily metric (L. Newman and Dale 2007) enables evaluation of the effects of having similar people or events on management. Future research into the social resilience of collaborative adaptive management could employ these methods and metrics in innovative ways.

Conclusions

The collaborative adaptive management process incorporated concepts and strategies of adaptive management and collaborative management in order to tackle the social and ecological uncertainties that are inherent in managing within complex social-ecological systems. Many management uncertainties for public lands originate from conflicts among diverse environmental stakeholders who hold differing management values, goals, and strategies relating to natural resources. They also derive from unforeseen events in management, such as changes in funding allocations or changes in management personnel. In order to sustain collaborative adaptive management in the face of management uncertainties, methods that measure the resilience of a network might be useful in understanding what social factors contributed to social resilience.

This study applied affiliation network analysis to analyze the attendance data from a collaborative adaptive management project called the Sierra Nevada Adaptive Management Project (SNAMP). An affiliation network diagram was constructed to provide a qualitative view of the SNAMP social network, and to produce insights about participants at the core and periphery of the network as well as the impact of meeting locations on participation. More quantitative measurements of the network were obtained by calculating two-mode network cohesion measurements for the main components of the network over the duration of the project. The longitudinal cohesion measurements effectively modeled the resilience of our network as it experienced stages of the adaptive cycle from the resilience framework. These network metrics were a useful and responsive tool to quantify the dynamics of social resilience in a collaborative adaptive management project. When combined with centrality measurements for people and public meetings, these network metrics generated insights into how leadership, norms and flexible governance in a collaborative adaptive management project could increase social resilience for management. One practical insight from our work was that natural resource managers as well as key stakeholders in collaborative adaptive management should allocate resources, time and training to building and maintaining a core group of participants. In SNAMP, this core group was developed and maintained through the public meetings, in which the UC Science Teams facilitated open dialogues and mutual learning.

In conclusion, affiliation network analysis might provide a robust tool to evaluate the success of management efforts that focused on complex social-ecological systems. With this method, geographic and core-periphery patterns were revealed, the importance of individuals and particular public meetings were highlighted, and the dynamics of the network and its ability to withstand external perturbations were evaluated. In this case study, the SNAMP program showed aspects of social resiliency in the face of exogenous stressors. Important to the success of the SNAMP network were: 1) the ability of members of the management and public groups to become leaders; 2) the project norms of transparency and science integration; and 3) a flexible governance structure.

CHAPTER FOUR – FIGURES

Fig. 4-1. Visualization of the SNAMP social network constructed based on attendance data from public meetings in 2007-2013.

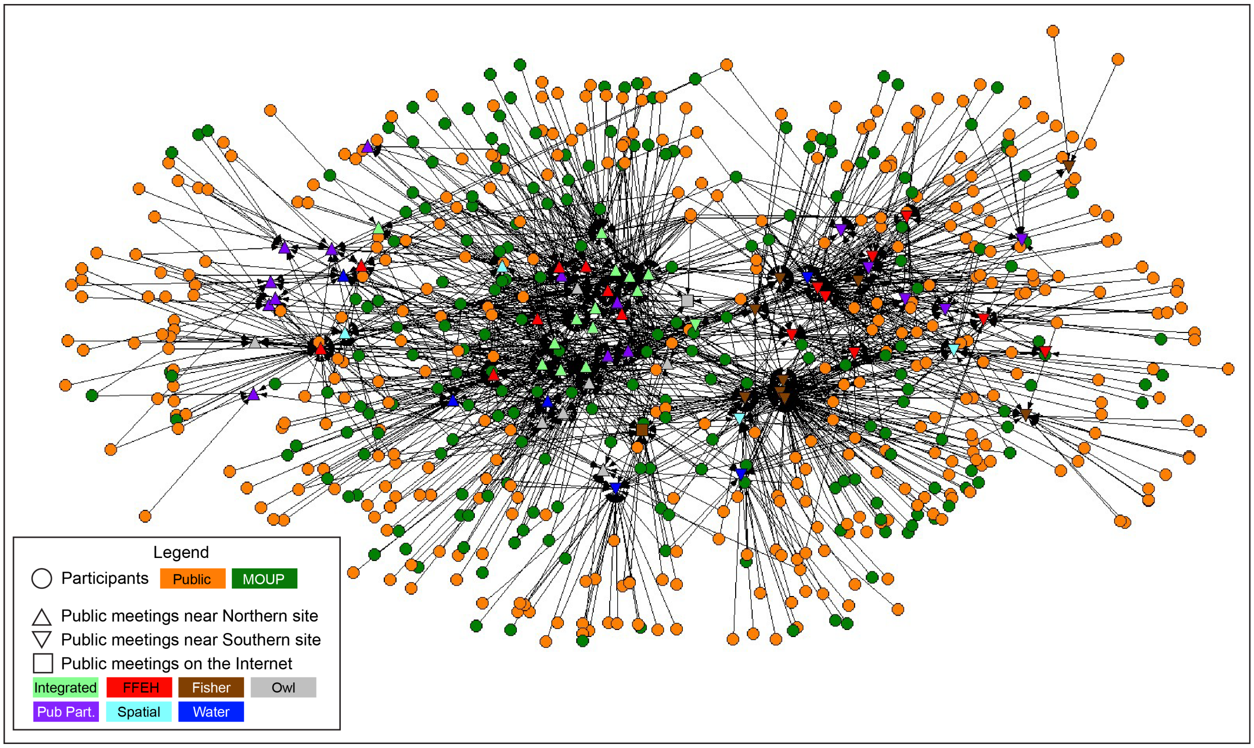
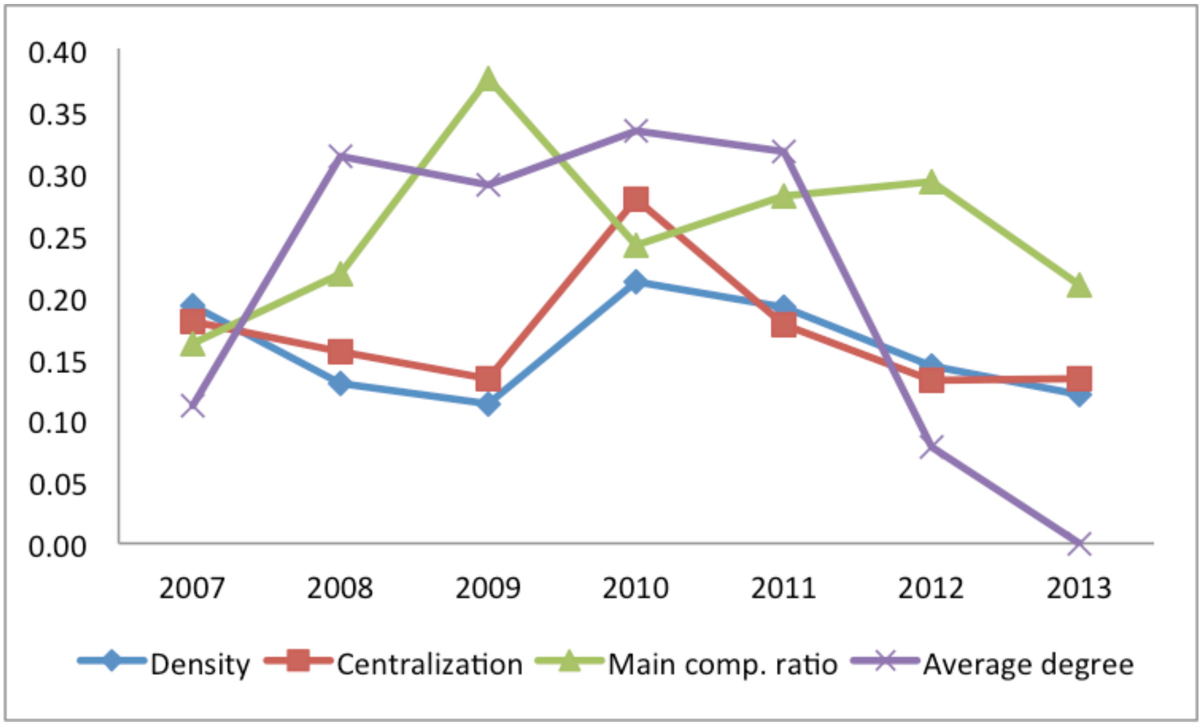


Fig. 4-2. Network cohesion metrics (i.e. density, centralization, main component ratio, and normalized and scaled average degree) of the main components of the SNAMP network in 2007-2013.



CHAPTER FOUR – TABLES

Table 4-1. Attendance at SNAMP public meetings through time.

Year	Number of public meetings	Attendance	Average attendance
2007	10	182	18.2
2008	15	246	16.4
2009	14	349	24.9
2010	6	180	30.0
2011	7	220	31.4
2012	10	246	24.6
2013	12	177	14.8
Total	74	1599	

Table 4-2. Top 10 participants ranked by different centrality measurements.

Ranking	Degree	Closeness	Betweenness	Eigenvector
1	P1 (Public)	P1 (Public)	P1 (Public)	P1 (Public)
2	P2 (MOUP)	P2 (MOUP)	P2 (MOUP)	P2 (MOUP)
3	P3 (MOUP)	P4 (Public)	P3 (MOUP)	P4 (Public)
4	P4 (Public)	P3 (MOUP)	P4 (Public)	P3 (MOUP)
5	P5 (Public)	P5 (Public)	P5 (Public)	P5 (Public)
6	P6 (Public)	P12 (MOUP)	P9 (Public)	P13 (MOUP)
7	P7 (MOUP)	P13 (MOUP)	P12 (MOUP)	P14 (Public)
8	P9 (Public)	P14 (Public)	P8 (Public)	P6 (Public)
9	P8 (Public)	P21 (MOUP)	P7 (MOUP)	P21 (MOUP)
10	P10 (Public)	P6 (Public)	P6 (Public)	P7 (MOUP)

Table 4-3. Attendance rates for participants showed up as top ten in one of the four centralities.

	2007	2008	2009	2010	2011	2012	2013
P1	0.70	0.60	0.50	0.50	0.43	0.50	0.17
P2	0.50	0.53	0.50	0.83	0.71	0.30	0.08
P3	0.20	0.40	0.29	0.33	0.43	0.40	0.25
P4	0.20	0.27	0.36	0.50	0.29	0.40	0.08
P5	0.10	0.20	0.29	0.17	0.57	0.60	0.08
P6	0.50	0.27	0.14	0.33	0.43	0.40	0.00
P7	0.00	0.20	0.36	0.17	0.43	0.60	0.00
P8	0.00	0.20	0.36	0.17	0.14	0.30	0.33
P9	0.00	0.27	0.14	0.17	0.14	0.40	0.42
P10	0.30	0.27	0.14	0.17	0.57	0.10	0.08
P12	0.30	0.20	0.21	0.00	0.29	0.10	0.17
P13	0.00	0.07	0.14	0.50	0.29	0.40	0.17
P14	0.00	0.00	0.14	0.33	0.43	0.50	0.08
P21	0.00	0.13	0.07	0.33	0.29	0.20	0.08

Table 4-4. Top 10 public meetings ranked by 4 different centrality measurements.

Ranking	Degree	Closeness	Betweenness	Eigenvector
1	E50 (Fisher)	E74 (Integrated)	E50 (Fisher)	E50 (Fisher)
2	E42 (Fisher)	E25 (Integrated)	E28 (FFEH)	E74 (Integrated)
3	E32 (Fisher)	E52 (Integrated)	E32 (Fisher)	E52 (Integrated)
4	E28 (FFEH)	E56 (PP)	E42 (Fisher)	E44 (Integrated)
5	E25 (Integrated)	E50 (Fisher)	E25 (Integrated)	E25 (Integrated)
6	E44 (Integrated)	E42 (Fisher)	E61 (FFEH)	E42 (Fisher)
7	E74 (Integrated)	E44 (Integrated)	E74 (Integrated)	E32 (Fisher)
8	E23 (Fisher)	E53 (Fisher)	E23 (Fisher)	E39 (Integrated)
9	E52 (Integrated)	E32 (Fisher)	E52 (Integrated)	E62 (Integrated)
10	E39 (Integrated)	E40 (FFEH)	E53 (Fisher)	E23 (Fisher)

E23 = Fisher IT meeting South (9/17/08)

E25 = 2008 Annual Meeting (11/5/08)

E28 = FFEH Field Trip SOUTH (5/28/09)

E32 = Fisher IT Meeting (7/15/09)

E39 = 2009 Annual Meeting (10/20/09)

E40 = FFEH IT Meeting (2/17/10)

E42 = Fisher IT Meeting (7/22/10)

E44 = 2010 Annual Meeting (10/21/10)

E50 = Fisher IT Meeting (7/19/11)

E52 = 2011 Annual Meeting (10/27/11)

E53 = Fisher field trip (5/1/12)

E56 = PP/SNAMP Update IT (6/22/12)

E61 = Cable logging - North (10/16/12)

E62 = 2012 Annual meeting (10/23/12)

E74 = 2013 Annual Meeting (10/29/13)

CHAPTER FIVE

Conclusions and directions for future research

Managing within complex social-ecological systems such as public forests at the landscape scale is fraught with challenges that come from uncertainties in ecological processes and disagreements arising from conflicting values and goals among multiparty environmental stakeholders. The traditional "command-and-control" resource management paradigm, with top-down agency control and a focus on a single resource, does not adequately respond to these two linked challenges. Consequently, natural resource managers are turning to collaborative adaptive management (CAM) to alleviate the natural and social uncertainties by increasing our understanding of the natural processes through policy experimentations and by overcoming social misunderstandings among diverse partners through social learning, dialogue facilitation, and enhanced social resilience. My dissertation concentrates on the second of these linked challenges in forest management: the social processes found in collaborative adaptive management. My research focuses on quantitatively measuring and analyzing the dynamics of social interaction among stakeholders -- the role of information, conversations and social connections -- in the CAM process in order to monitor the effectiveness of collaborative adaptive management in increasing social learning, facilitating dialogues, and enhancing social resilience.

The research uses a case study – the Sierra Nevada Adaptive Management Project (SNAMP) – which was established according to the collaborative adaptive management framework. The primary goal of the project was to study the impact of forest fuel reduction treatment on a number of ecological elements, including forest health, wildlife, and water quantity/quality. SNAMP brings together primarily three categories of participants: managers, public environmental stakeholders, and university scientists, in which public environmental stakeholders and the managers hold conflicting environmental values and goals. To develop partnership and facilitate collaboration, SNAMP provides ongoing public meetings, facilitates discussions offline and online, as well as making science processes and information transparent to all participants. **I used a number of research methods, including content analysis, citation analysis, affiliation network analysis, and self-organizing maps, to analyze various datasets yielded from these social processes in SNAMP.** Several themes emerged from the mixed methods research, and below is a summary of all the key findings.

Summary of key findings

1. Information technologies enhance information flow and facilitate knowledge transfer.

In general, information technologies can dramatically increase the speed and the distance that information can travel, increasing the chance of reaching a wider audience. This finding is consistent with a number of studies in the *Journal of Extension* which have demonstrated that information communication technologies can reach wide audiences at a lower cost (Drill 2012; Dvorak J.S. 2012; Kocher, Lombardo, and Sweitzer 2013). However, the number of information channels and their combined usage become one of the factors that dictates how fast information can travel, how far information can reach, and how long information can persist. For example, SNAMP peer-reviewed publications had, on average, a time lapse of around seven months before their first citations, but they persisted much longer in scientific knowledge networks than a status update on a Facebook page. These information characteristics can affect future learning and collaboration. I also found that networks of information systems – not just networks of people – could help sustain collaborative learning by enabling certain SNAMP participants to transfer knowledge across multiple organizations. For example, this happened in SNAMP when academic journal articles were also published in the USDA Digital Collections, making it easier for US Forest Service managers to obtain science information produced in SNAMP.

2. *Facilitated discussions in public meetings improve collaboration.*

By using self-organizing maps to visualize and analyze the meeting notes from the SNAMP public meetings, four important features of the facilitated public discussions in the collaborative adaptive management process emerged. First, the discussion in the annual meetings remained largely focused on the project: on science, on administration and on the adaptive management process itself. Second, there was a natural evolution of discussion topics. Some topics ran their course earlier in the process – those focused on planning and logistics – and some remained a topic of interest with the public (e.g. wildlife, forest treatment, and LiDAR the remote sensing technology). Third, as expected, some of the more contentious and popular issues, such as wildlife in SNAMP, dominated the discussions through time. Finally, integrated discussion across topics did not seem to have taken place, largely due to the fact that SNAMP was not in the integration phase of the project at the time of this writing. Collectively, these results suggest that facilitated discussions in collaborative adaptive management can help focus discussion topics on the core research and administrative topics among the contentious participants in the project. These findings are important because they indicate that facilitated discussions can guide conversations, mitigate or prevent contentious and unfruitful debates, improve social learning, and build trust among participants.

3. *Affiliation network analysis models and monitors social resilience.*

When an affiliation network is constructed based on the attendance at public events in a collaborative adaptive management project, the social resilience of the network can be modeled and monitored by the affiliation network analysis metrics, such as network cohesion, network density and network centralization. By observing the longitudinal changes of these metrics, project coordinators could interpret the status of collaboration based on the resilience framework developed by Holling (1986). The resilience framework contains four phases—from *exploitation*, to *conservation*, to *creative destruction*, to *renewal*, and back to *exploitation*—across spatial, temporal, ecological, and social scales (Gunderson 2002; Holling 2001). This framework also provides the concept of *unexpected perturbation* in connection with the adaptive capacity of a system. In the case of SNAMP, the funding crisis in 2010 was the unexpected perturbation that dramatically reduced the cohesiveness of the network in SNAMP. By locating the collaboration progress in this framework, project coordinators can respond according to the rising or falling of collaborative cohesiveness in a timely manner. The way SNAMP responded to the funding crisis was to make the impacts of funding reduction on the project transparent to all participants at the 2010 Annual Meeting. Through discussing various scenarios with all participants, natural resource agencies and environmental stakeholders were galvanized to resolve the issue by seeking additional funding.

4. *Affiliation network analysis reveals the role of leadership.*

In addition to modeling social resilience in a collaborative adaptive management project, affiliation network analysis enables project coordinators to analyze how leadership, norms of engagement, and governance structure enhance the social resilience of management in the SNAMP network. Leaders in the affiliation network can be identified by their positions and ties in a network using a social network diagram as well as four different centrality measurements: *degree*, *betweenness*, *closeness*, and *eigenvector* centrality. Leadership is considered one of the most critical elements in making collaboration work because it provides project facilitation (Allen and Gunderson 2011). The affiliation network analysis of the SNAMP network suggests that leadership does not have to be one or a few individual charismatic leaders, but it can be composed of committed and consistent participants even with conflicting environmental values and goals. Such a "leadership" group can still push forward the overall project goals.

5. *Information tools enable "real-time" monitoring of social processes.*

The use of information tools to monitor social processes in collaborative adaptive management enable natural resource managers to conduct "real-time" analysis. The use and flow of digital information products could be monitored by citation analysis, web analytics and simple content analysis. Meeting notes from public meetings can be processed, visualized and analyzed by the self-organizing map soon after every public meeting. The affiliation network constructed from the linkages between people and meetings can also be carried out after each additional management event. The ongoing and "real-time" monitoring of social processes may enable natural resource managers to observe the "health condition" of multiparty collaboration, to detect problem areas in the processes, and to respond to issues in a timely manner before they corrode trust and good will among participants. One way that SNAMP has taken advantage of the "real-time" monitoring capability from information tools is in generating periodic reports to the US Forest Service as well as communicating project updates to project participants at public meetings.

6. *Triangulation of monitoring results provides internal verification.*

The monitoring tools in this dissertation can be applied simultaneously to different datasets including various information products (e.g. science briefs, newsletters, journal publications, and news articles), traffics on websites and web services, meeting notes, and attendance. A collaboration manager can triangulate the outcomes from each of these monitoring tools to verify validity of the results, as well as check for consistency among them. For example, the analysis of the SNAMP website traffic, the meeting notes, and the attendance data strongly suggest that the research about forest treatment's impact on wildlife draw the most attention from project participants. In the event of inconsistent results from different monitoring sources, managers can investigate the reasons for the differences, which may lead to a more nuanced understanding of the impact of different information tools. Overall, the ability to triangulate is important to ensure reliability of applying these research methods in monitoring the social processes in natural resource management.

Directions for future research

In this dissertation, I gained a rich understanding of the flow of information, the impact of facilitated conversations, and the dynamics of a social network in collaborative adaptive management by applying various research methods to monitor the social processes over the course of the SNAMP project. However, I recognize that this is only a sample of what can be accomplished by using quantitative research methods to monitor collaborative adaptive management in innovative ways. There are key areas that could be expanded for future research.

First, the information monitoring effort could follow the information trail further. By tracking the SNAMP digital information products, we can see that scientific information products have reached the management community and the public. However, the current study has not tracked how the US Forest Service has actually used SNAMP information, i.e. how the US Forest Service publications have cited the SNAMP publications and whether their publications have influenced management planning or decisions. Future research should track the US Forest Service publications that have cited SNAMP publications, not just online materials but offline usage as well. A detailed investigation would require interviews and surveys of natural resource managers on how they have used the information.

Second, I suggest that natural resource managers should invest in building social networks along with making information transparent and building information networks. Interesting and valuable information in online social network services, such as Facebook, may attract people who are interested in the subject. That is one way to build up a social network; however, another way is to directly reach out to potentially interested parties on online social networks. As the networks of people enlarge, information can reach more people, increasing the chances for building up public support for collaborative adaptive management. Therefore, it is worthwhile to strategically invest resources in building more robust and dynamic online social networks, e.g. adding contacts, inviting friends, sharing content, and finding similar projects.

Third, natural resource management can apply self-organizing maps to conduct stakeholder analysis. Stakeholder analysis has been employed to bring the right people to the management table so as to increase the chances of success in collaborative management (Reed et al. 2009). Research methods that have been used to identify appropriate stakeholders in collaborative management include focus groups, semi-structured interviews, social network analysis, and others (Reed et al. 2009). Self-organizing maps can be added to the battery of stakeholder analysis methods by identifying environmental stakeholders' concerns and values using the mission statements and documents that environmental stakeholders have published online. The process of applying the self-organizing maps to these public documents will be similar to that of processing the SNAMP public meeting notes. The process starts with collecting their publicly available mission statements and documents on their websites, processing these documents with the self-organizing maps algorithm, and then visualizing and interpreting their issues/values. After producing and comparing value maps for all relevant stakeholders, natural resource managers can identify common or conflicting issues/values and develop collaboration structures and strategies accordingly. This proposed method and process could be helpful for natural resource managers to form the right collaboration team.

Fourth, additional node attributes about people and meetings should be applied to affiliation network in order to enrich data analysis. For instance, the organizational affiliations for participants could be broken down further into different government agencies or advocacy groups, instead of staying at the most general categories of MOUP and public. Also, some participants could hold more influence than other people and additional attributes could reveal finer power dynamics among these participants. In short, adding more attributes to the network nodes would result in a more realistic representation of the actual affiliation network.

Finally, additional network analytical methods could be used to shed light on social resilience in collaborative adaptive management. For example, key player analysis (Borgatti 2006) measures the impact of important participants/events on the network, which may be another way to evaluate the importance of individual nodes in the network. Another social network metric called homophily (L. Newman and Dale 2007)—the tendency of individuals to associate with similar others—may be used to evaluate trust and credibility of the participants in the social network. Trust and credibility play a crucial role in building collaboration in management with contentious parties; therefore, it is worth pursuing additional tools and methods that can shine more light on these social aspects in future research.

In conclusion, a dominant recent trend in natural resource management in the last several decades has been the widespread adoption, at least in the US, of more collaborative modes of management. These have transformed natural resource management by employing the adaptive management process to explicitly acknowledge and incorporate ecological uncertainties, as well as by utilizing collaborative management techniques to mitigate conflicts and contentions among multiparty environmental stakeholders. An equally important trend has been the steady and increasing adoption of theories, methods and tools from the field of information science and technologies. Information technologies have allowed for massive overhaul in the ways in which information is distributed and gathered in resource management contexts. They have also provided the capacity to monitor social processes, such as information flow, conversations in management meetings, and connections among participants. This capacity is shown to be important for assessing the state of collaboration in this dissertation. Future research direction should evaluate whether and how project coordinators could detect and respond to obstacles and challenges based on such monitoring. Therefore, I recommend that future collaborative adaptive management should include the use of information technologies and plans for monitoring social processes. Building such monitoring capacity requires managers to plan and allocate resources at the beginning stage of the project. Given that monitoring social processes using information tools in collaborative adaptive management is relatively new to this research field, I also encourage researchers and practitioners to explore and experiment other information tools and methods for monitoring social processes in future natural resource management.

REFERENCES

Abel, Nick, David H. M. Cumming, and John M. Anderies. 2006. “Collapse and Reorganization in Social-Ecological Systems: Questions, Some Ideas, and Policy Implications.” *Ecology and Society* 11 (1). http://www.ecologyandsociety.org/vol11/iss1/art17/.

Ackoff, R. L. 1989. “From Data to Wisdom.” *Journal of Applied Systems Analysis* 16: 3–9.

Adger, W. Neil. 2000. “Social and Ecological Resilience: Are They Related?” *Progress in Human Geography* 24 (September): 347–64. doi:10.1191/030913200701540465.

Allan, Catherine, Allan Curtis, George Stankey, and Bruce Shindler. 2008. “Adaptive Management and Watersheds: A Social Science Perspective.” *Journal of the American Water Resources Association* 44: 166–74. doi:10.1111/j.1752-1688.2007.00145.x.

Allen, Craig R., Joseph J. Fontaine, Kevin L. Pope, and Ahjond S. Garmestani. 2011. “Adaptive Management for a Turbulent Future.” *Journal of Environmental Management* 92: 1339–45. doi:10.1016/j.jenvman.2010.11.019.

Allen, Craig R., and Lance H. Gunderson. 2011. “Pathology and Failure in the Design and Implementation of Adaptive Management.” *Journal of Environmental Management* 92: 1379–84. doi:10.1016/j.jenvman.2010.10.063.

Antelman, Kristin. 2004. “Do Open-Access Articles Have a Greater Research Impact?” *College & Research Libraries* 65 (September): 372–82.

Armitage, Derek, Chris Béné, Anthony T Charles, Derek Johnson, and Edward H Allison. 2012. “The Interplay of Well-Being and Resilience in Applying a Social-Ecological Perspective.” *Ecology and Society* 17 (4): 15.

Armitage, Derek, Melissa Marschke, and Ryan Plummer. 2008. “Adaptive Co-Management and the Paradox of Learning.” *Global Environmental Change* 18: 86–98. doi:10.1016/j.gloenvcha.2007.07.002.

Armitage, Derek, R. Plummer, F. Berkes, R.I. Arthur, A.T. Charles, I.J. Davidson-Hunt, A.P. Diduck, N.C. Doubleday, D.S. Johnson, and M. Marschke. 2009. “Adaptive Co-Management for Social-Ecological Complexity.” *Frontiers in Ecology and the Environment* 7 (2): 95–102. doi:10.1890/070089.

Bales, Roger, Reginald H. Barrett, John J. Battles, Martha H. Conklin, Lynn Huntsinger, N. Maggi Kelly, Qinghua Guo, et al. 2010. “University of California Science Team (UCST) Statement of Neutrality.” Sierra Nevada Adaptive Management Project. http://snamp.cnr.berkeley.edu/documents/335/.

Bales, Roger, Reginald H. Barrett, John J. Battles, Martha H. Conklin, Lynn Huntsinger, N. Maggi Kelly, Qinghua Guo, Ralph J. Gutiérrez, Kimberly A. Rodrigues, and Scott L. Stephens. 2007. “Revision of the SNAMP Workplan: Learning How to Apply Adaptive Management in the Sierra Nevada Forest Plan Amendment.” Sierra Nevada Adaptive Management Project. http://snamp.cnr.berkeley.edu/documents/91/.

Bar-Ilan, Judit. 2006. “An Ego-Centric Citation Analysis of the Works of Michael O. Rabin Based on Multiple Citation Indexes.” *Information Processing & Management* 42: 1553–66. doi:10.1016/j.ipm.2006.03.019.

Baskerville, G. 1985. “Adaptive Management Wood Availability and Habitat Availability.” *The Forestry Chronicle* 61 (2): 171–75. doi:10.5558/tfc61171-2.

Baskerville, G. 1988. “Management of Publicly Owned Forests.” *The Forestry Chronicle* 64 (3): 193–98. doi:10.5558/tfc64193-3.

Beierle, Thomas C., and David M. Konisky. 2000. "Values, Conflict, and Trust in Participatory Environmental Planning." *Journal of Policy Analysis and Management* 19 (4): 587–602. doi:10.1002/1520-6688(200023)19:4<587::AID-PAM4>3.0.CO;2-Q.

Bellinger, G., D. Castro, and A. Mills. 2004. "Data, Information, Knowledge, and Wisdom." http://courseweb.lis.illinois.edu/~katewill/spring2011-502/502%20and%20other%20readings/bellinger%20on%20ackoff%20data%20info%20know%20wisdom.pdf.

Bengston, David N., and David P. Fan. 1999. "Conflict Over Natural Resource Management: A Social Indicator Based on Analysis of Online News Media Text." *Society & Natural Resources: An International Journal* 12 (5): 493–500. doi:10.1080/089419299279560.

Berkes, Fikret. 2009. "Evolution of Co-Management: Role of Knowledge Generation, Bridging Organizations and Social Learning." *Journal of Environmental Management* 90: 1692–1702. doi:10.1016/j.jenvman.2008.12.001.

Berkes, Fikret, Carl Folke, and Johan Colding. 1998. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. Cambridge, U.K.; New York, NY, USA: Cambridge University Press.

Berkes, Fikret, and Helen Ross. 2012. "Community Resilience: Toward an Integrated Approach." *Society & Natural Resources* 26 (1): 5–20. doi:10.1080/08941920.2012.736605.

Bodin, Örjan, and Beatrice I. Crona. 2009. "The Role of Social Networks in Natural Resource Governance: What Relational Patterns Make a Difference?" *Global Environmental Change* 19: 366–74. doi:10.1016/j.gloenvcha.2009.05.002.

Bodin, Örjan, and Jon Norberg. 2005. "Information Network Topologies for Enhanced Local Adaptive Management." *Environmental Management* 36 (November): 772–73. doi:10.1007/s00267-005-6036-4.

Booher, David E., and Judith E. Innes. 2010. "Governance for Resilience: CALFED as a Complex Adaptive Network for Resource Management." *Ecology and Society* 15 (3). http://www.ecologyandsociety.org/vol15/iss3/art35/.

Borgatti, Stephen P. 2006. "Identifying Sets of Key Players in a Social Network." *Computational & Mathematical Organization Theory* 12 (1): 21–34. doi:10.1007/s10588-006-7084-x.

Borgatti, Stephen P., and Martin G. Everett. 1997. "Network Analysis of 2-Mode Data." *Social Networks* 19 (3): 243–69. doi:10.1016/S0378-8733(96)00301-2.

Borgatti, Stephen P., Martin G. Everett, and Linton C. Freeman. 2002. *UCINet for Windows: Software for Social Network Analysis*. Harvard, MA: Analytic Technologies.

Borgatti, Stephen P., Martin G. Everett, and Jeffrey C. Johnson. 2013. *Analyzing Social Networks*. The Sage Handbook. Thousand Oaks, California, USA: SAGE Publications Ltd.

Borgatti, Stephen P., and Daniel S. Halgin. 2011. "Analyzing Affiliation Networks." In *The Sage Handbook of Social Network Analysis*, edited by John Scott and Peter J. Carrington, 417–33. The Sage Handbook. Thousand Oaks, California, USA: SAGE Publications Ltd.

Bormann, Bernard T., Richard W. Haynes, and Jon R. Martin. 2007. "Adaptive Management of Forest Ecosystems: Did Some Rubber Hit the Road?" *BioScience* 57 (2): 186–91. doi:10.1641/B570213.

Boyd, D., S. Golder, and G. Lotan. 2010. "Tweet, Tweet, Retweet: Conversational Aspects of Retweeting on Twitter." In *2010 43rd Hawaii International Conference on System Sciences (HICSS)*, 1–10. doi:10.1109/HICSS.2010.412.

Brown, Gregory, Maggi Kelly, and Debra Whitall. 2013a. “Which ‘public’? Sampling Effects in Public Participation GIS (PPGIS) and Volunteered Geographic Information (VGI) Systems for Public Lands Management.” *Journal of Environmental Planning and Management* 57 (2): 1–25.

Brown, Gregory, N. Maggi Kelly, and Debra Whitall. 2013b. “Which ‘public’? Sampling Effects in Public Participation GIS (PPGIS) and Volunteered Geographic Information (VGI) Systems for Public Lands Management.” *Journal of Environmental Planning and Management* 57 (2): 190–214. doi:10.1080/09640568.2012.741045.

Brown, Katrina. 2013. “Global Environmental Change I: A Social Turn for Resilience?” *Progress in Human Geography*, August. doi:10.1177/0309132513498837.

Calkin, David E., Alan A. Ager, Matthew P. Thompson, Mark A. Finney, Danny C. Lee, Thomas M. Quigley, Charles W. McHugh, Karin L. Riley, and Julie M. Gilbertson-Day. 2011. *A Comparative Risk Assessment Framework for Wildland Fire Management: The 2010 Cohesive Strategy Science Report*. RMRS-GTR-262. General Technical Report. Fort Collins, CO, USA: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Carlsson, Lars, and Fikret Berkes. 2005. “Co-Management: Concepts and Methodological Implications.” *Journal of Environmental Management* 75: 65–76. doi:10.1016/j.jenvman.2004.11.008.

Carmines, Edward G., and Richard A. Zeller. 1979. *Reliability and Validity Assessment*. Beverly Hills, CA: SAGE.

Cash, David W., W. Neil Adger, Fikret Berkes, Po Garden, Louis Lebel, Per Olsson, Lowell Pritchard, and Oran Young. 2006. “Scale and Cross-Scale Dynamics: Governance and Information in a Multilevel World.” *Ecology and Society* 11 (2). http://www.ecologyandsociety.org/vol11/iss2/art8/.

Castells, Manuel. 1996. *The Rise of the Network Society*. Malden, Mass.: Blackwell Publishers.

Chakraborty, Jayajit, and M. Martin Bosman. 2005. “Measuring the Digital Divide in the United States: Race, Income, and Personal Computer Ownership.” *The Professional Geographer* 57: 395–410.

Chen, Hsinchun, Chris Schuffels, and Richard E. Orwig. 1996. “Internet Categorization and Search: A Self-Organizing Approach.” *Journal of Visual Communication and Image Representation* 7 (1): 88–102.

Chon, Tae-Soo. 2011. “Self-Organizing Maps Applied to Ecological Sciences.” *Ecological Informatics* 6 (1): 50–61. doi:10.1016/j.ecoinf.2010.11.002.

Chowdhury, Sudatta, Forbes Gibb, and Monica Landoni. 2011. “Uncertainty in Information Seeking and Retrieval: A Study in an Academic Environment.” *Information Processing & Management* 47: 157–75. doi:10.1016/j.ipm.2010.09.006.

Clifton, Brian. 2012. “Advanced Web Metrics with Google Analytics, Third Edition.”

Collins, Brandon M., Scott L. Stephens, Jason J. Moghaddas, and John J. Battles. 2010. “Challenges and Approaches in Planning Fuel Treatments across Fire-Excluded Forested Landscapes.” *Journal of Forestry* 108: 24–31.

Conklin, E. Jeffrey. 2006. *Dialogue Mapping: Building Shared Understanding of Wicked Problems*. Chichester, England; Hoboken, New Jersey, USA: Wiley.

Cundill, Georgina, and Christo Fabricius. 2009. “Monitoring in Adaptive Co-Management: Toward a Learning Based Approach.” *Journal of Environmental Management* 90: 3205–11. doi:10.1016/j.jenvman.2009.05.012.

Davies, Althea L., and Rehema M. White. 2012. “Collaboration in Natural Resource Governance: Reconciling Stakeholder Expectations in Deer Management in Scotland.” *Journal of Environmental Management* 112: 160–69. doi:10.1016/j.jenvman.2012.07.032.

Davis, Allison, Burleigh B Gardner, and Mary R Gardner. 1941. *Deep South*. Chicago, Illinois, USA: University of Chicago Press.

Dick, Gregory J, Anders F Andersson, Brett J Baker, Sheri L Simmons, Brian C Thomas, A Pepper Yelton, and Jillian F Banfield. 2009. “Community-Wide Analysis of Microbial Genome Sequence Signatures.” *Genome Biology* 10 (8): R85. doi:10.1186/gb-2009-10-8-r85.

Drill, Sabrina L. 2012. “Mobile Applications for Extension.” *Journal of Extension* 50 (5): 5TOT1.

Dvorak J.S., Franke-Dvorak T.C., Price R.R.,. 2012. “‘Apps’-An Innovative Way to Share Extension Knowledge.” *Journal of Extension* 50 (6).

Ernstson, Henrik, S. Barthel, E. Andersson, and S.T. Borgström. 2010. “Scale-Crossing Brokers and Network Governance of Urban Ecosystem Services: The Case of Stockholm.” *Ecology and Society* 15: 28.

Fabricius, Christo, and Georgina Cundill. 2014. “Learning in Adaptive Management: Insights from Published Practice.” *Ecology and Society* 19 (1). doi:10.5751/ES-06263-190129.

Federal Register. 2012. “National Forest System Land Management Planning; Final Rule and Record of Decision.” 36 (219.9): 21162–276.

Fernandez-Gimenez, Maria E., Heidi L. Ballard, and Victoria E. Sturtevant. 2008. “Adaptive Management and Social Learning in Collaborative and Community-Based Monitoring: A Study of Five Community-Based Forestry Organizations in the Western USA.” *Ecology and Society* 13 (2): 4.

Ferranto, Shasta, Lynn Huntsinger, Christy Getz, Maureen Lahiff, William Stewart, Gary Nakamura, and N. Maggi Kelly. 2013. “Management Without Borders? A Survey of Landowner Practices and Attitudes toward Cross-Boundary Cooperation.” *Society & Natural Resources* 26 (9): 1082–1100. doi:10.1080/08941920.2013.779343.

Finney, M. A. 2007. “A Computational Method for Optimising Fuel Treatment Locations.” *International Journal of Wildland Fire* 16 (6): 702–11.

Finney, Mark A. 2004. *Chapter 9: Landscape Fire Simulation and Fuel Treatment Optimization*. General Technical Report PNW-GTR-610. Methods for Integrated Modeling of Landscape Change: Interior Northwest Landscape Analysis System. Portland, OR: USDA Forest Service, Pacific Northwest Research Station.

Folke, Carl. 2006. “Resilience: The Emergence of a Perspective for Social–ecological Systems Analyses.” *Global Environmental Change* 16 (3): 253–67. doi:10.1016/j.gloenvcha.2006.04.002.

Folke, Carl. 2007. “Social–ecological Systems and Adaptive Governance of the Commons.” *Ecological Research* 22 (1): 14–15. doi:10.1007/s11284-006-0074-0.

Folke, Carl, Thomas Hahn, Per Olsson, and Jon Norberg. 2005. “Adaptive Governance of Social-Ecological Systems.” *Annual Review of Environment and Resources* 30: 441–73. doi:10.1146/annurev.energy.30.050504.144511.

Garfield, E. 1972. “Citation Analysis as a Tool in Journal Evaluation.” *Science* 178: 471–79.

Gillmor, Dan. 2004. *We the Media : Grassroots Journalism by the People, for the People*. Sebastopol, CA: O’Reilly. http://proquest.safaribooksonline.com/0596007337.

Goldstein, Bruce Evan. 2012. *Collaborative Resilience: Moving through Crisis to Opportunity*. Cambridge, Massachusetts, USA: MIT Press.

Greig, Lorne A., David R. Marmorek, Carol Murray, and Donald C. E. Robinson. 2013. “Insight into Enabling Adaptive Management.” *Ecology and Society* 18 (3). doi:10.5751/ES-05686-180324.

Gunderson, Lance H. 2000. “Ecological Resilience--In Theory and Application.” *Annual Review of Ecology and Systematics* 31 (January): 425–39. doi:10.2307/221739.

Gunderson, Lance H. 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, D.C., USA: Island Press.

Gunderson, Lance H, and Lowell Pritchard. 2002. *Resilience and the Behavior of Large-Scale Systems*. Scientific Committee on Problems of the Environment 60. Washington, D.C., USA: Island Press.

Gwartney, Patricia A., Lynne Fessenden, and Gayle Landt. 2002. “Measuring the Long-Term Impact of a Community Conflict Resolution Process: A Case Study Using Content Analysis of Public Documents.” *Negotiation Journal* 18 (1): 51–74. doi:10.1111/j.1571-9979.2002.tb00250.x.

Halbert, Cindy L. 1993. “How Adaptive Is Adaptive Management? Implementing Adaptive Management in Washington State and British Columbia.” *Reviews in Fisheries Science* 1 (January): 261–83. doi:10.1080/10641269309388545.

Hanneman, Robert A., and Mark Riddle. 2005. “Introduction to Social Network Methods.” http://faculty.ucr.edu/~hanneman/.

Hansen, Mark, Stuart Madnick, and Michael Siegel. 2003. “Data Integration Using Web Services.” In *Efficiency and Effectiveness of XML Tools and Techniques and Data Integration over the Web*, edited by Stéphane Bressan, MongLi Lee, AkmalB Chaudhri, JeffreyXu Yu, and Zoé Lacroix, 2590:165–82. Lecture Notes in Computer Science. Springer Berlin Heidelberg. http://dx.doi.org/10.1007/3-540-36556-7_15.

Hardy, Andrew P. 1982. “The Selection of Channels When Seeking Information: Cost/benefit vs Least-Effort.” *Information Processing & Management* 18: 289–93. doi:10.1016/0306-4573(82)90014-0.

Harnad, Stevan, and Tim Brody. 2004. “Comparing the Impact of Open Access (OA) vs. Non-OA Articles in the Same Journals.” *D-Lib Magazine* 10 (6). http://eprints.soton.ac.uk/260207/.

Helly, J. J., N. Maggi Kelly, D. Sutton, and T. Todd Elvins. 2001. “Collaborative Management of Natural Resources in San Diego Bay.” *Coastal Management* 29 (2): 117–32. doi:10.1080/089207501750069614.

Holling, C. S. 1973. “Resilience and Stability of Ecological Systems.” *Annual Review of Ecology and Systematics* 4 (January): 1–23. doi:10.2307/2096802.

Holling, C. S. 1978. *Adaptive Environmental Assessment and Management*. Chichester, New York, USA: John Wiley & Sons.

Holling, C. S. 1986. “The Resilience of Terrestrial Ecosystems: Local Surprise and Global Change.” In *Sustainable Development of the Biosphere*, edited by William C. Clark and R. E. Munn, 292–317. New York, New York, USA: Cambridge University Press.

Holling, C. S. 1996. “Surprise for Science, Resilience for Ecosystems, and Incentives for People.” *Ecological Applications* 6 (3): 733–35. doi:10.2307/2269475.

Holling, C. S. 2001. “Understanding the Complexity of Economic, Ecological, and Social Systems.” *Ecosystems* 4 (5): 390–405. doi:10.1007/s10021-001-0101-5.

Holling, C. S., and Gary K. Meffe. 1996. “Command and Control and the Pathology of Natural Resource Management.” *Conservation Biology* 10: 328–37. doi:10.1046/j.1523-1739.1996.10020328.x.

Honkela, T., V. Pulkki, and T. Kohonen. 1995. “Contextual Relations of Words in Grimm Tales Analyzed by Self-Organizing Map.” In , 2:3–7.

Hsu, Chin-Lung, and Judy Chuan-Chuan Lin. 2008. “Acceptance of Blog Usage: The Roles of Technology Acceptance, Social Influence and Knowledge Sharing Motivation.” *Information & Management* 45 (1): 65–74. doi:10.1016/j.im.2007.11.001.

Janssen, Marco A., Örjan Bodin, John M. Anderies, Thomas Elmqvist, Henrik Ernstson, Ryan R. J. McAllister, Per Olsson, and Paul Ryan. 2006. “Toward a Network Perspective of the Study of Resilience in Social-Ecological Systems.” *Ecology and Society* 11 (1). http://www.ecologyandsociety.org/vol11/iss1/art15/.

Kallis, Giorgos, Michael Kiparsky, and Richard Norgaard. 2009. “Collaborative Governance and Adaptive Management: Lessons from California’s CALFED Water Program.” *Environmental Science & Policy* 12: 631–43. doi:10.1016/j.envsci.2009.07.002.

Kaski, Samuel, Timo Honkela, Krista Lagus, and Teuvo Kohonen. 1998. “WEBSOM – Self-Organizing Maps of Document Collections.” *Neurocomputing* 21: 101–17. doi:10.1016/s0925-2312(98)00039-3.

Kaushik, Avinash. 2010. *Web Analytics 2.0 : The Art of Online Accountability & Science of Customer Centricity*. Indianapolis, IN: Wiley.

Kearns, Faith R., N. Maggi Kelly, and Karin A. Tuxen. 2003. “Everything Happens Somewhere: Using WebGIS as a Tool for Sustainable Natural Resource Management.” *Frontiers in Ecology and the Environment* 1: 541–48.

Keen, Meg, Valerie A. Brown, and Rob Dyball. 2005. “Social Learning: A New Approach to Environmental Management.” In *Social Learning in Environmental Management: Towards a Sustainable Future*, 3–21. London; Sterling, VA: Earthscan.

Kelly, N. Maggi, Shasta Ferranto, Shufei Lei, Ken-ichi Ueda, and Lynn Huntsinger. 2012. “Expanding the Table: The Web as a Tool for Participatory Adaptive Management in California Forests.” *Journal of Environmental Management* 109 (October): 1–11. doi:10.1016/j.jenvman.2012.04.035.

Knoot, Tricia G., and Mark Rickenbach. 2011. “Best Management Practices and Timber Harvesting: The Role of Social Networks in Shaping Landowner Decisions.” *Scandinavian Journal of Forest Research* 26 (April): 171–82. doi:10.1080/02827581.2010.545827.

Kocher, Susan, Anne Lombardo, and Rick Sweitzer. 2013. “Using Social Media to Involve the Public in Wildlife Research—the SNAMP Fisher Sock Collection Drive.” *Journal of Extension* 51 (1): 1IAW3.

Kohonen, Teuvo. 1998. “The Self-Organizing Map.” *Neurocomputing* 21: 1–6.

Kohonen, Teuvo. 2001. *Self-Organizing Maps*. 3rd ed. Berlin; New York: Springer.

Kohonen, Tuevo, S. Kaski, K. Lagus, J. Salojarvi, J. Honkela, V. Paatero, and A. Saarela. 2000. “Self Organization of a Massive Document Collection.” *IEEE Transactions on Neural Networks* 11: 574–85. doi:10.1109/72.846729.

Lawler, Joshua J, Timothy H Tear, Chris Pyke, M Rebecca Shaw, Patrick Gonzalez, Peter Kareiva, Lara Hansen, et al. 2010. “Resource Management in a Changing and Uncertain Climate.” *Frontiers in Ecology and the Environment* 8 (1): 35–43. doi:10.1890/070146.

Lazar, Jonathan. 2001. *User-Centered Web Development*. Jones & Bartlett Learning.

Lee, Kai N. 1993. *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Washington, D.C.: Island Press.

Lee, Kai N. 1999. "Appraising Adaptive Management." *Conservation Ecology* 3 (2): 3.

Lei, Shufei, Alastair Iles, and N. Maggi Kelly. 2014. "Characterizing the Networks of Digital Information That Support Collaborative Adaptive Forest Management in Sierra Nevada Forests." *Environmental Management* In Review.

Lei, Shufei, and N. Maggi Kelly. 2014. "Evaluating Adaptive Collaborative Management in Sierra Nevada Forests by Exploring Public Meeting Dialogues Using Self-Organizing Maps." *Society & Natural Resources* In Review.

Levin, Simon A. 1998. "Ecosystems and the Biosphere as Complex Adaptive Systems." *Ecosystems* 1 (5): 431–36. doi:10.1007/s100219900037.

Long, Jonathan, Carl Skinner, Malcolm North, Pat Winter, Bill Zielinski, Carolyn Hunsaker, Brandon M. Collins, et al. 2013. *Science Synthesis to Promote Resilience of Social-Ecological Systems in the Sierra Nevada and Southern Cascades*. Albany, CA, USA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Lu, Hsi-Peng, and Kuo-Lun Hsiao. 2007. "Understanding Intention to Continuously Share Information on Weblogs." *Internet Research* 17 (4): 345–61. doi:10.1108/10662240710828030.

MacRoberts, Michael H., and Barbara R. MacRoberts. 1989. "Problems of Citation Analysis: A Critical Review." *Journal of the American Society for Information Science* 40: 342–49. doi:10.1002/(sici)1097-4571(198909)40:5<342::aid-asi7>3.0.co;2-u.

Martin, Wade E., H. Wise Bender, and Deborah J. Shields. 2000. "Stakeholder Objectives for Public Lands: Rankings of Forest Management Alternatives." *Journal of Environmental Management* 58 (1): 21–32. doi:10.1006/jema.1999.0313.

Mayer, Rudolf, Taha Abdel Aziz, and Andreas Rauber. 2007. "Visualising Class Distribution on Self-Organising Maps." In *Artificial Neural Networks–ICANN 2007*, 359–68. Springer.

Mayer, Rudolf, and Andreas Rauber. 2011a. "On Wires and Cables: Content Analysis of WikiLeaks Using Self-Organising Maps." In *Advances in Self-Organizing Maps*, edited by Jorma Laaksonen and Timo Honkela, 6731:238–46. Lecture Notes in Computer Science. Springer Berlin Heidelberg.

Mayer, Rudolf, and Andreas Rauber. 2011b. *Java SOMToolbox* (version 0.7.5-3 svn4280). English. Institute of Software Technology and Interactive System: Vienna University of Technology. http://www.ifs.tuwien.ac.at/dm/somtoolbox/index.html.

McLain, R.J., and R.G. Lee. 1996. "Adaptive Management: Promises and Pitfalls." *Environmental Management* 20: 437–48.

Mclver, James D., Mark Brunson, Steve C. Bunting, Jeane Chambers, Nora Devoe, Paul Doescher, James Grace, et al. 2010. *The Sagebrush Steppe Treatment Evaluation Project (SageSTEP): A Test of State-and-Transition Theory*. RMRS-GTR-237. General Technical Report. Fort Collins, CO, USA: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Michaels, Sarah. 2009. "Matching Knowledge Brokering Strategies to Environmental Policy Problems and Settings." *Environmental Science & Policy* 12: 994–1011. doi:10.1016/j.envsci.2009.05.002.

Miller, Fiona, Henny Osbahr, Emily Boyd, Frank Thomalla, Sukaina Bharwani, Gina Ziervogel, Brian Walker, et al. 2010. "Resilience and Vulnerability: Complementary or Conflicting Concepts." *Ecology and Society* 15 (3): 11.

Mol, Arthur P. J. 2006. “Environmental Governance in the Information Age: The Emergence of Informational Governance.” *Environment and Planning C: Government and Policy* 24: 497–514.

Mol, Arthur P. J. 2008. *Environmental Reform in the Information Age : The Contours of Informational Governance*. Cambridge; New York: Cambridge University Press.

Moore, Clinton T., Eric V. Lonsdorf, Melinda G. Knutson, Harold P. Laskowski, and Socheata K. Lor. 2011. “Adaptive Management in the U.S. National Wildlife Refuge System: Science-Management Partnerships for Conservation Delivery.” *Journal of Environmental Management* 92: 1395–1402. doi:10.1016/j.jenvman.2010.10.065.

Moore, Michele-Lee, and Frances Westley. 2011. “Surmountable Chasms: Networks and Social Innovation for Resilient Systems.” *Ecology and Society* 16 (1). http://www.ecologyandsociety.org/vol16/iss1/art5/.

Murugesan, San. 2007. “Understanding Web 2.0.” *IT Professional* 9 (4): 34–41. doi:10.1109/MITP.2007.78.

Nelson, Donald R., W. Neil Adger, and Katrina Brown. 2007. “Adaptation to Environmental Change: Contributions of a Resilience Framework.” *Annual Review of Environment and Resources* 32 (1): 395–419. doi:10.1146/annurev.energy.32.051807.090348.

Nelson, Kristen C., Rachel F. Brummel, Nicholas Jordan, and Steven Manson. 2013. “Social Networks in Complex Human and Natural Systems: The Case of Rotational Grazing, Weak Ties, and Eastern US Dairy Landscapes.” *Agriculture and Human Values*, August, 1–15. doi:10.1007/s10460-013-9462-6.

Nelson, Robert H. 1995. *Public Lands and Private Rights: The Failure of Scientific Management*. Lanham, Maryland, USA: Rowman & Littlefield.

Neuendorf, Kimberly A. 2002. *The Content Analysis Guidebook*. Thousand Oaks, California: Sage Publications, Inc.

Newman, Lenore, and Ann Dale. 2007. “Homophily and Agency: Creating Effective Sustainable Development Networks.” *Environment, Development and Sustainability* 9 (1): 79–90. doi:10.1007/s10668-005-9004-5.

Newman, M. E. J. 2001. “Scientific Collaboration Networks. I. Network Construction and Fundamental Results.” *Physical Review E* 64 (016131): 8. doi:10.1103/PhysRevE.64.016131.

Nicholas, David, Paul Huntington, Tom Dobrowolski, Ian Rowlands, Hamid R. Jamali M., and Panayiota Polydoratou. 2005. “Revisiting ‘Obsolescence’ and Journal Article ‘Decay’ Through Usage Data: An Analysis of Digital Journal Use by Year of Publication.” *Information Processing & Management* 41 (6): 1441–61. doi:10.1016/j.ipm.2005.03.014.

Nkhata, Abraham B, Charles M Breen, and Wayne A Freimund. 2008. “Resilient Social Relationships and Collaboration in the Management of Social-Ecological Systems.” *Ecology and Society* 13 (1): 2.

Olsson, Per, Lance H. Gunderson, Steve R. Carpenter, Paul Ryan, Louis Lebel, Carl Folke, and C. S. Holling. 2006. “Shooting the Rapids: Navigating Transitions to Adaptive Governance of Social-Ecological Systems.” *Ecology and Society* 11 (1). http://www.ecologyandsociety.org/vol11/iss1/art18/.

O’Reilly, Tim. 2007. “What Is Web 2.0: Design Patterns and Business Models for the next Generation of Software.” *Communications & Strategies* First Quarter: 17.

Pampalk, Elias, Andreas Rauber, and Wolfdieter Merkl. 2002. "Using Smoothed Data Histograms for Cluster Visualization in Self-Organizing Maps." In , 871–76. Madrid, Spain: Springer.

Pandya, Rajul E. 2012. "A Framework for Engaging Diverse Communities in Citizen Science in the US." *Frontiers in Ecology and the Environment* 10 (August): 314–17. doi:10.1890/120007.

Pedersen, Brent, Faith Kearns, and N. Maggi Kelly. 2007. "Methods for Facilitating Web-Based Participatory Research Informatics." *Ecological Informatics* 2 (1): 33–42. doi:10.1016/j.ecoinf.2007.02.003.

Peltz, Chris. 2003. "Web Services Orchestration and Choreography." *Computer* 36 (10): 46–52. doi:10.1109/mc.2003.1236471.

Pinkerton, Evelyn W. 1994. "Local Fisheries Co-Management: A Review of International Experiences and Their Implications for Salmon Management in British Columbia." *Canadian Journal of Fisheries and Aquatic Sciences* 51 (10): 2363–78. doi:10.1139/f94-238.

Plummer, Ryan, and Derek Armitage. 2007. "A Resilience-Based Framework for Evaluating Adaptive Co-Management: Linking Ecology, Economics and Society in a Complex World." *Ecological Economics* 61 (1): 62–74. doi:10.1016/j.ecolecon.2006.09.025.

Plummer, Ryan, and John FitzGibbon. 2007. "Connecting Adaptive Co-Management, Social Learning and Social Capital through Theory and Practice." In *Adaptive Co-Management : Collaboration, Learning, and Multi-Level Governance*, edited by Fikret Berkes, Derek R. Armitage, and Nancy Doubleday, 55–78. Vancouver, Canada: UBC Press.

Portuese, Beth Gambino, Robert W Malmsheimer, Amanda Anderson, Donald Floyd, and Denise Keele. 2009. "Litigants' Characteristics and Outcomes in US Forest Service Land-Management Cases 1989 to 2005." *Journal of Forestry* 107 (1): 16–22.

Prell, Christina. 2012. *Social Network Analysis: History, Theory & Methodology*. Los Angeles, California, USA; London, UK: SAGE.

Rauber, A., D. Merkl, and M. Dittenbach. 2002. "The Growing Hierarchical Self-Organizing Map: Exploratory Analysis of High-Dimensional Data." *IEEE Transactions on Neural Networks* 13: 1331–41. doi:10.1109/tnn.2002.804221.

Reed, Mark S., Anil Graves, Norman Dandy, Helena Posthumus, Klaus Hubacek, Joe Morris, Christina Prell, Claire H. Quinn, and Lindsay C. Stringer. 2009. "Who's in and Why? A Typology of Stakeholder Analysis Methods for Natural Resource Management." *Journal of Environmental Management* 90: 1933–49. doi:10.1016/j.jenvman.2009.01.001.

Rittel, Horst W. J., and Melvin M. Webber. 1973. "Dilemmas in a General Theory of Planning." *Policy Sciences* 4 (June): 155–69. doi:10.1007/bf01405730.

Robins, David, and Jason Holmes. 2008. "Aesthetics and Credibility in Web Site Design." *Information Processing & Management* 44: 386–99. doi:10.1016/j.ipm.2007.02.003.

Rorissa, Abebe, and Xiaojun Yuan. 2012. "Visualizing and Mapping the Intellectual Structure of Information Retrieval." *Information Processing & Management* 48: 120–35. doi:10.1016/j.ipm.2011.03.004.

Rutherford, Matthew W., Paul F. Buller, and Patrick R. McMullen. 2003. "Human Resource Management Problems over the Life Cycle of Small to Medium-Sized Firms." *Human Resource Management* 42 (4): 321–35. doi:10.1002/hrm.10093.

Scarlett, Lynn. 2013. "Collaborative Adaptive Management: Challenges and Opportunities." *Ecology and Society* 18 (3). doi:10.5751/ES-05762-180326.

Schindler, Bruce, and Krinstin Aldred Cheek. 1999. "Integrating Citizens in Adaptive Management: A Propositional Analysis." *Ecology and Society* 3: 9.

Schusler, Tania M., Daniel J. Decker, and Max J. Pfeffer. 2003. "Social Learning for Collaborative Natural Resource Management." *Society & Natural Resources* 16 (April): 309–26. doi:10.1080/08941920390178874.

Scott, John. 1988. "Social Network Analysis." *Sociology* 22 (February): 109–27. doi:10.1177/0038038588022001007.

Shapiro, Carl, and Hal R Varian. 1999. *Information Rules: A Strategic Guide to the Network Economy*. Boston, Mass.: Harvard Business School Press.

Shenton, Andrew K., and Pat Dixon. 2004. "The Nature of Information Needs and Strategies for Their Investigation in Youngsters." *Library & Information Science Research* 26: 296–310. doi:10.1016/j.lisr.2004.01.006.

Shih, Cho-Wei, Ming-Yen Chen, Hui-Chuan Chu, and Yuh-Min Chen. 2012. "Enhancement of Information Seeking Using an Information Needs Radar Model." *Information Processing & Management* 48: 524–36. doi:10.1016/j.ipm.2011.08.010.

Shirky, Clay. 2009. *Here Comes Everybody*. Penguin Group USA.

Skupin, André. 2008. "Visualizing Human Movement in Attribute Space." In *Self-Organising Maps*, 121–35. John Wiley & Sons, Ltd.

Skupin, André. 2009. "Discrete and Continuous Conceptualizations of Science: Implications for Knowledge Domain Visualization." *Journal of Informetrics* 3: 233–45. doi:10.1016/j.joi.2009.03.002.

Small, Henry. 1999. "Visualizing Science by Citation Mapping." *Journal of the American Society for Information Science* 50: 799–813. doi:10.1002/(sici)1097-4571(1999)50:9<799::aid-asi9>3.0.co;2-g.

SNAMP. 2011. "SNAMP 2011 Annual Meeting Notes Description." *Sierra Nevada Adaptive Management Project*. http://snamp.cnr.berkeley.edu/documents/412/.

Stewart-Oaten, Allan, William W Murdoch, and Keith R Parker. 1986. "Environmental Impact Assessment: 'Pseudoreplication' in Time?." *Ecology* 67 (4): 929–40.

Susskind, Lawrence, Alejandro E. Camacho, and Todd Schenk. 2010. "Collaborative Planning and Adaptive Management in Glen Canyon: A Cautionary Tale." *Columbia Journal of Environmental Law* 35: 1–56.

Tear, Timothy H., Peter Kareiva, Paul L. Angermeier, Patrick Comer, Brian Czech, Randy Kautz, Laura Landon, et al. 2005. "How Much Is Enough? The Recurrent Problem of Setting Measurable Objectives in Conservation." *BioScience* 55 (10): 835–49. doi:10.1641/0006-3568(2005)055[0835:HMIETR]2.0.CO;2.

Timmerman, Jos G., Janneke J. Ottens, and Robert C. Ward. 2000. "The Information Cycle as a Framework for Defining Information Goals for Water-Quality Monitoring." *Environmental Management* 25 (3): 229–39. doi:10.1007/s002679910018.

Tompkins, Emma L., and W. Neil Adger. 2004. "Does Adaptive Management of Natural Resources Enhance Resilience to Climate Change?" *Ecology and Society* 9 (2): 10.

Tran, Liem T., C. Gregory Knight, Robert V. O'Neill, Elizabeth R. Smith, and Michael O'Connell. 2003. "Self-Organizing Maps for Integrated Environmental Assessment of the Mid-Atlantic Region." *Environmental Management* 31: 822–35. doi:10.1007/s00267-003-2917-6.

Ultsch, A. 1993. "Self-Organizing Neural Networks for Visualisation and Classification." In *Information and Classification*, edited by Prof Dr Otto Opitz, Dr Berthold Lausen, and

Prof Dr Rüdiger Klar, 307–13. Studies in Classification, Data Analysis and Knowledge Organization. Springer Berlin Heidelberg.

U.S. Forest Service. 2004. *Sierra Nevada Forest Plan Amendment: Final Supplemental Environmental Impact Statement*. U.S. Forest Service, Region 5, Vallejo, California, USA.

Van Wagtendonk, Jan W. 1996. "Use of a Deterministic Fire Growth Model to Test Fuel Treatments." In *Sierra Nevada Ecosystem Project, Vol. II. Final Report to Congress*, 1155–66. Davis, California, USA: Centers for Water and Wildland Resources, University of California, Davis.

Van Wilgen, B. W., and H. C. Biggs. 2011. "A Critical Assessment of Adaptive Ecosystem Management in a Large Savanna Protected Area in South Africa." *Biological Conservation* 144: 1179–87. doi:10.1016/j.biocon.2010.05.006.

Walker, Brian, Stephen Carpenter, John Anderies, Nick Abel, Graeme Cumming, Marco Janssen, Lois Lebel, Jon Norberg, Gary D Peterson, and Rusty Pritchard. 2002. "Resilience Management in Social-Ecological Systems: A Working Hypothesis for a Participatory Approach." *Conservation Ecology* 6 (1): 14.

Walker, Brian, Lance Gunderson, Ann Kinzig, Carl Folke, Steve Carpenter, and Lisen Schultz. 2006. "A Handful of Heuristics and Some Propositions for Understanding Resilience in Social-Ecological Systems." *Ecology and Society* 11 (1): 13.

Walters, Carl J. 1986. *Adaptive Management of Renewable Resources*. New York, New York, USA: Collier Macmillan.

Walters, Carl J. 1997. "Challenges in Adaptive Management of Riparian and Coastal Ecosystems." *Conservation Ecology* 1 (2): 1.

Walters, Carl J., and C. S. Holling. 1990. "Large-Scale Management Experiments and Learning by Doing." *Ecology* 71: 2060–68.

Walters, William H. 2007. "Google Scholar Coverage of a Multidisciplinary Field." *Information Processing & Management* 43: 1121–32. doi:10.1016/j.ipm.2006.08.006.

Wang, Xiaozhe, Ajith Abraham, and Kate A. Smith. 2005. "Intelligent Web Traffic Mining and Analysis." *Journal of Network and Computer Applications* 28: 147–65. doi:10.1016/j.jnca.2004.01.006.

Ward, Joe H. 1963. "Hierarchical Grouping to Optimize an Objective Function." *Journal of the American Statistical Association* 58 (301): 236–44. doi:10.1080/01621459.1963.10500845.

Wasko, Molly McLure, and Samer Faraj. 2005. "Why Should I Share? Examining Social Capital and Knowledge Contribution in Electronic Networks of Practice." *MIS Quarterly* 29 (1): 35–57.

Weber, Edward P., and Anne M. Khademian. 2008. "Wicked Problems, Knowledge Challenges, and Collaborative Capacity Builders in Network Settings." *Public Administration Review* 68: 334–49. doi:10.1111/j.1540-6210.2007.00866.x.

Williams, Byron K., and Eleanor D. Brown. 2014. "Adaptive Management: From More Talk to Real Action." *Environmental Management* 53 (2): 465–79. doi:10.1007/s00267-013-0205-7.

Wondolleck, Julia M. 1988. *Public Lands Conflict and Resolution: Managing National Forest Disputes*. New York: Plenum Press.

Wondolleck, Julia M., and Steven L. Yaffee. 2000. *Making Collaboration Work: Lessons from Innovation in Natural Resource Management*. Washington, D.C., USA: Island Press.

Xu, Zhi, and David N. Bengston. 1997. “Trends in National Forest Values among Forestry Professionals, Environmentalists, and the News Media, 1982–1993.” *Society & Natural Resources: An International Journal* 10 (1): 43–59. doi:10.1080/08941929709381008.

Yan, Jun, and Jean-Claude Thill. 2008. “Visual Exploration of Spatial Interaction Data with Self-Organizing Maps.” In *Self-Organising Maps*, 67–85. John Wiley & Sons, Ltd.

Yu, Tai-Kuei, Long-Chuan Lu, and Tsai-Feng Liu. 2010. “Exploring Factors That Influence Knowledge Sharing Behavior via Weblogs.” *Computers in Human Behavior* 26 (1): 32–41. doi:10.1016/j.chb.2009.08.002.

Zoellick, Bill, Sarah J. Nelson, and Molly Schauffler. 2012. “Participatory Science and Education: Bringing Both Views into Focus.” *Frontiers in Ecology and the Environment* 10 (August): 310–13. doi:10.1890/110277.