MtnSEON and social–ecological systems science in complex mountain landscapes

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The Mountain Social Ecological Observatory Network (MtnSEON) is a US National Science Foundation-funded Research Coordination Network that focuses on social–ecological systems (SES) science approaches to understanding the vulnerability, resilience, and sustainability of complex mountain landscapes. Papers from members of several MtnSEON working groups are presented in this Special Issue, with topics ranging from applying an SES conceptual approach to social–ecological observatories to dealing with the human aspects of predator–livestock interactions in the American West. All of these articles portray varying degrees of integration of social and ecological sciences and methodologies in order to better address both complex and "wicked" problems inherent to many coupled natural and human systems. The diversity of approaches presented here reflect the different project histories, disciplines being integrated, fields of expertise, and nature of the environmental problems and issues being addressed.

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Complex mountain landscapes are characterized by steep biophysical gradients and socioeconomic transitions, including processes of in-migration, urbanization, and ex-urbanization. As integrated social–ecological systems (SES), these landscapes face unique challenges to their resilience and sustainability. The Mountain Social Ecological Observatory Network (MtnSEON), implemented under a US National Science Foundation (NSF) Research Coordination Network–Science, Engineering, and Education for Sustainability (RCN-SEES) award, was designed to focus on interdisciplinary topics that will advance sustainability science, engineering, and education through integrative approaches. Collectively, these approaches contribute to the challenges of attaining a sustainable energy future and adapting to environmental, social, and cultural changes associated with the growth and development of human populations in mountain–valley systems. The papers included here represent the efforts of several MtnSEON working groups (Figure 1) to address a basic, overarching question: how can we reduce the vulnerability of natural and human systems in complex mountain landscapes while at the same time improving their resilience and sustainability?

In a nutshell:

- The papers presented in this issue represent attempts at using social–ecological systems (SES) science approaches to address environmental issues in complex mountain landscapes
- Although it has been proposed that SES is a means of generating effective solutions to environmental problems, the "wicked" nature of these problems poses a substantial challenge to both research and management
- The efforts of several working groups of the Mountain Social Ecological Observatory Network are highlighted here, ranging from the creation of knowledge coordination networks to a conceptual model that recasts the range shifts of the bark beetle as a social–ecological phenomenon
- Developing and implementing interdisciplinary SES science presents many challenges to researchers and practitioners, but strategies for overcoming these hurdles are emerging from the research community

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The MtnSEON concept addresses the vulnerability of mountain systems – and the human communities they support – to climate change, environmental variability, and land-use change, as well as the effects of natural hazards, such as wildfires, floods, and insect and disease outbreaks. A better understanding of the impacts of such factors is essential for promoting sustainability, which we define here as viability, biodiversity, and human well-being. Biophysical models and environmental research alone do not necessarily inform management decisions that help to ensure long-term sustainability; SES approaches may therefore prove to be valuable tools for identifying and evaluating how various human and natural factors affect vulnerability because they integrate social science with traditional ecological research. MtnSEON has supported 12 working groups (Panel 1) that reflect the diversity of problems encountered in mountain environments. The primary goal of all MtnSEON working groups is to develop an SES-based approach to the specific issues being studied by their group.

The approach in MtnSEON to this RCN-SEES model builds on established relationships among representatives of numerous universities and interdisciplinary teams; engagement with local, tribal, state, and federal agencies; and engagement with specialists at institutions of higher education throughout the US and beyond. The intent is to engage research, learning, and policy action through the establishment of sustainable networks that apply SES research, models, and methods to gaining a better understanding of the effects of climate and land-use change on ecological and socioeconomic processes in mountain landscapes. This process has been implemented in the Intermountain West of the US, and we hope that this model will gradually be extended to other complex mountain landscapes nationally and internationally.

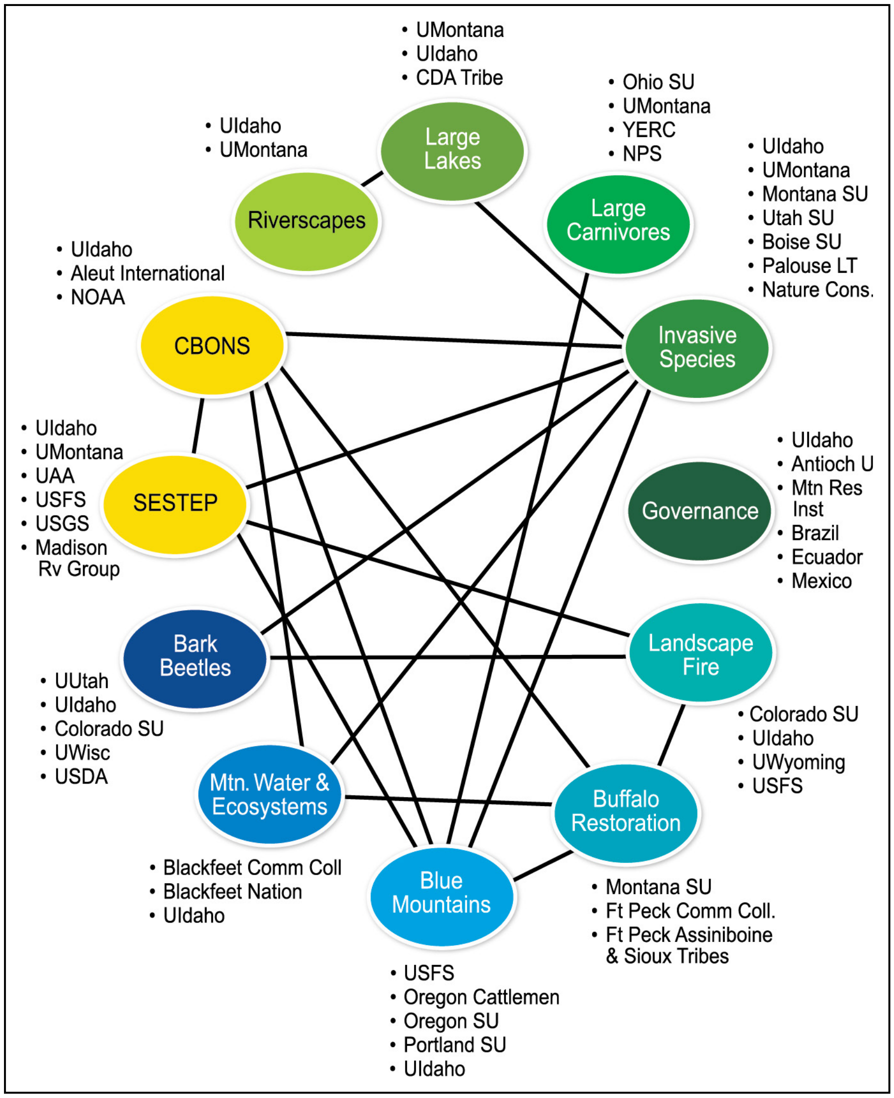

Figure 1. *The Mountain Social Ecological Observing Network (MtnSEON), showing constituent working groups (colored nodes), their institutional composition (bulleted text), and their connections (solid lines).*

Social–ecological systems

Social–ecological systems are integrated systems consisting of human and biophysical components connected through complex system feedbacks and dependencies (Berkes *et al.* 2003). The SES concept developed from a growing recognition of the inadequacy of traditional disciplinary approaches to identifying solutions for increasingly intricate environmental problems (eg climate change, biodiversity loss); rather, effective understanding of and the development of solutions to major contemporary environmental issues requires interdisciplinary, integrated approaches that provide deeper insight into the interactions between social and ecological systems (Folke 2006). An essential and defining component of SES is the merging of social and ecological perspectives to more fully understand the various factors within a system that influence ecosystem and human-system vulnerability and resilience (Gallopin 2006; Epstein *et al.* 2013).

Science informed by SES concepts has the potential to fill the need for interdisciplinary, integrative approaches to environmental issues. MtnSEON promotes SES science as a powerful tool for evaluating uncertainty and vulnerability (Figure 2), to inform better policy and management decision making for increasing adaptation and resilience in human communities and the ecosystems in which they are embedded. Ideally, SES approaches more accurately reflect the chaotic real world in which human and ecological systems reciprocally affect one another in myriad ways (Folke 2006; Alessa *et al.* 2015). Science based on SES concepts differs from traditional disciplinary approaches in several ways, given that SES science is: (1) inherently interdisciplinary and integrative, incorporating the social sciences with biophysical, ecological, and other approaches; (2) problem-oriented and contextual; (3) a recursive process, in which the problem in question is continually refined; (4) respectful of and engages with local, place-based, and indigenous knowledge; (5) comparative, multi-temporal, and multiscalar; (6) dependent on partnerships between researchers and stakeholders; and (7) cognizant of the importance of the role of human values in defining and altering landscapes (Alessa *et al.* 2015).

There is no single way to engage in SES research or applications; rather, researchers have developed a wide variety of approaches, frameworks, and methods over the past 20 years, centered on many different concepts. These organizing concepts range from robustness and resilience to sociotechnical systems; vulnerability and uncertainty; and material, energy, and economic flows (Alessa *et al.* 2009; Binder *et al.* 2013). This diversity is reflected in the articles included

Panel 1. MtnSEON working groups, lead individuals, and institutions represented

Working group	Lead(s)	Institutions involved
Bark Beetles	Jesse Morris, University of Utah	University of Utah; University of Idaho; US Department of Agriculture; Colorado State University; US Forest Service; University of Wisconsin; Charles University, Czech Republic; and five other universities
Blue Mountains	Susan Charnley, US Forest Service; Mary Rowland, US Forest Service	US Forest Service; University of Idaho; Oregon State University; Portland State University; US Forest Service; Oregon Cattlemen's Association
Buffalo Restoration	Julia Haggerty, Montana State University	Montana State University; Fort Peck Assiniboine and Sioux Tribes; Fort Peck Community College
Fire Across the Landscape	Patrick Bourgeron, Colorado State University	University of Wyoming; University of Idaho; Colorado State University; US Forest Service
Governance	Sandra Pinel, Antioch University New England	University of Idaho; Antioch University New England; Mountain Research Institute, Switzerland; Universidad Autonoma Metropolitana, Mexico; Universidad Tecnica Particular de Loja, Ecuador; Universidad de Sao Paulo, Brazil
Invasive Species	Nicholas Norton, Palouse Land Trust	University of Idaho; University of Montana; Montana State University; Palouse Land Trust; US Forest Service; The Nature Conservancy; Utah State University; Boise State University
Large Carnivores	Jeremy Bruskotter, Ohio State University	Ohio State University; University of Montana; Yellowstone Ecological Research Center; National Park Service
Large Iconic Lakes	Shawn Devlin, Flathead Lake Biological Station, University of Montana	University of Montana; University of Idaho; Coeur d'Alene Tribe
Riverscapes	Brian Hand, Flathead Lake Biological Station, University of Montana	University of Montana; University of Idaho
Social Ecological Systems Training and Education Program (SESTEP)	Andrew Kliskey, Center for Resilient Communities, University of Idaho; David Griffith, Center for Resilient Communities, University of Idaho	University of Alaska Anchorage; University of Idaho; US Forest Service; University of Montana; National Park Service; US Geological Survey; Bureau of Land Management; US Global Change Research Program; Madison River Group
Student Led Initiative on Mountain and Water Ecosystems	Melissa Weatherwax, Blackfeet Community College	Blackfeet Community College; University of Idaho; Blackfeet Nation
Community-based Observing Networks and Systems (CBONS)	David Griffith, Center for Resilient Communities, University of Idaho	University of Idaho; University of Alaska, Anchorage; Aleut International Association; National Oceanic and Atmospheric Administration

in this issue, which encompass several different approaches tailored to specific locations and research questions.

Assimilating social and ecological perspectives presents numerous challenges to practitioners of SES science. Interdisciplinary work can be extremely difficult, due to the "combination of fragmentation [of disciplines], unorganized diversity, and dogma" (Bammer 2013). Institutional barriers, such as departmental structure, administrative management, and career or tenure-track requirements, can also increase the difficulty of effectively developing interdisciplinary teams and approaches, especially for long-term projects (Lyall 2013). Inconsistency in the design and application of SES approaches is another complicating factor (Alessa *et al.* 2015); in the absence of standardized approaches for addressing various kinds of SES problems, research teams are forced to rely on pre-existing examples and their own, often limited, experience to build novel SES experimental or synthesis designs from the ground up for every project.

Other factors that present challenges to integration include differences in methods, types of data, and jargon among the various disciplines that are often involved in SES research (Alessa *et al.* 2015): for example, qualitative and quantitative data are often seen as dichotomous and inherently incompatible. Alessa *et al.* (2015) proposed that qualitative and quantitative data would be more accurately viewed as a spectrum than as explicit opposites, and that each can inform the other in important and illuminating ways, but putting this into practice is often easier said than done. Working groups within MtnSEON have identified the lack of awareness and training in the incorporation of social-science methods and data as a major impediment to conducting SES science, and have addressed this deficiency in various ways in their work.

In many cases, the environmental issues that SES approaches are applied to, including several discussed in these articles, are "wicked" problems: that is, they are so intractable that people disagree on how to even define them, let alone how to solve them. Moreover, efforts to address the primary problem frequently lead to unanticipated secondary problems, creating conditions in which identification of an optimal solution becomes essentially impossible (Rittel and Webber 1973; Wilkinson 2012). In natural resource management, such issues arise for several reasons, including the following: no single organization or governance regime has sole responsibility, the different organizations involved are unable to agree on the problem due to divergent interests and goals, or each attempt to identify a solution changes the initial problem (Batie 2008; Chapin *et al.* 2008; Marshall 2013). Such wicked problems lead to "messy" SES (Alessa *et al.* 2009), which often consist of situations involving the simultaneous use of multiple resources by a range of users and jurisdictions, and the lack of a single, well-defined resource governance system (Ostrom 2007). It is the human dimensions and social dynamics of these SES issues that mark them as wicked problems regardless of whether they are also complex (Rittel and Webber 1973).

Figure 2. *Collaborative discussion during the MtnSEON Annual Meeting, September 2016, in Moscow, ID.*

Although the challenges presented in these articles are problematic, they are not insurmountable. As SES-based science gains in popularity, researchers are increasingly refining protocols and criteria for selecting effective approaches to particular questions and issues (Binder *et al.* 2013), combining seemingly incompatible methods, and devising a common language to facilitate integration (Alessa *et al.* 2015). These include the application of SES typologies (Alessa *et al.* 2009), which have been adapted specifically to complex mountain systems (Altaweel *et al.* 2015). Scholars in interdisciplinary and team science are also developing frameworks that would facilitate moving beyond the restrictions of disciplinary boundaries (Bammer 2013). The need for interdisciplinary research strategies that recognize the links between social and ecological systems is no longer in doubt; the task now is to continue to hone approaches and frameworks for SES research that will further develop its effectiveness and application.

Issue overview

The articles presented here are representative of MtnSEON Executive Team and working group efforts over the past several years, and were chosen based on their relevance to the topic of SES science in mountain landscapes. The 12 working groups of MtnSEON are diverse in both membership and goals, and this is reflected in the broad variety of topics and approaches discussed in this issue. The working groups, and the papers included here, bring an integrated social and ecological perspective to specific topics, ranging from riverscapes as integrated SES to finding a balance between endangered species protection and the interests of land-use stakeholders on federally owned lands. The various approaches include the creation of new community-based observing (CBO) methodologies, and the development of new conceptual models. Many of the papers present the same, basic motivation for using SES approaches to address specific problems: competing human values, attitudes, beliefs, and perceptions about how best to conduct environmental management. Examples of such conflicts include those between ranchers and forest managers over predator populations, between two agencies over the regulation of river flows and conservation of native salmonids, and between ecologists and economists over bark-beetle impacts on western forests.

Charnley *et al.* (2018) is the least theoretical of the articles, and the one most concerned with the practical management and stakeholder-engagement aspects of SES science. The authors present the Blue Mountains Province of the Interior Pacific Northwest (Figure 3) as an SES in which managers, ranchers, environmentalists, and other stakeholders routinely clash over Endangered Species Act regulation. Their work illustrates the considerable degree of variance in perspectives about landscapes, salmonids, and wolves among wildlife regulators, ranchers, local communities, and courts; ranchers, for instance, often view management for conservation or restoration of

Figure 3. *Blue Mountains, OR, study site for the Blue Mountains Working Group of MtnSEON.*

endangered species as a threat to their livelihoods and lifestyles, whereas environmental groups and some wildlife managers tend to consistently prioritize protection of endangered species over local traditions and practices. Compounding the problem are a lack of interest by many ecologists and land managers in local knowledge about the landscape, and a distrust of "outsiders" by many local residents of the Blue Mountains region. An example of this is the threat of livestock depredation due to rebounding gray wolf (*Canis lupus*) populations: on the one hand, ranchers often perceive the threat of livestock predation to be greater than empirical evidence shows, whereas ecologists discount worries about future population dynamics altering the existing ecological balance and dismiss claims that estimates of livestock predation are incomplete. Federal land managers in turn must regularly mediate between the competing interests; in eastern Oregon, for example, conflicts between wolves and ranchers (ie predation of livestock) most often occur on federal lands. The authors suggest that an integrated SES approach to endangered species management is one way to bridge the gaps between ecologists and ranchers, researchers and managers, and federal and local interests.

Hand *et al.* (2018) focus on the social–ecological aspects of hydrological systems in the western US, concentrating on the conservation and restoration of salmonid species in the Columbia River Basin (CRB) as a case study. The authors describe the CRB riverscape as a series of nested, hierarchical SES affected by multiple competing "interests", encompassing habitat protection for wildlife, irrigation demands, and hydroelectric production among others. The CRB is heavily managed and has been subjected to some of the most extensive restoration efforts ever undertaken, but how these restoration endeavors – and their success or failure – are viewed varies according to perspective: some ecologists see these attempts as successful and others as failures, while dam operators often view them as complications and barriers to be overcome. The authors suggest that management of riverscapes in the Pacific Northwest is a classic wicked problem, and that the key to long-term, sustainable management of such systems will require the adoption of SES frameworks to bridge the divergent social, ecological, and economic viewpoints and interests. The value of social–ecological approaches in this case is the potential to create common ground between stakeholders, managers, and scientists by reframing the discussion in a way that does not focus solely on disciplinary expertise and expected outcomes.

Morris *et al.* (2018) broaden the conversation about well-known and documented ecological and economic phenomena by calling for and outlining a novel SES approach. The authors argue that bark-beetle outbreaks affect SES by altering ecosystem services, and that those outbreaks are in turn greatly influenced by the effects of climate change and other anthropogenic disturbances. The existing literature tends to present bark-beetle impacts from either an ecological or a socioeconomic viewpoint, but rarely are the two perspectives integrated; this paper frames feedbacks and dynamics of bark-beetle epidemics as inherently part of the same functional SES. Morris and colleagues argue that integrative, multi-scalar SES studies are necessary to enable managers and communities to make more effective decisions in the future. A key part of this analysis is that bark-beetle management programs are often strictly ecological in nature, thereby neglecting an important piece of an effective solution: to prepare communities that are likely to experience future bark-beetle outbreaks, best management practices should incorporate the experiences of communities that have been previously affected.

Bourgeron *et al.* (in press) discuss the issue of forecasting environmental change and outline the reasons why a new type of institutional observing system is needed. Their work highlights how forecasting long-term changes in environmental conditions is dependent on both ecological and social processes, and how a lack of long-term, interoperable datasets on integrated phenomena and a lack of transdisciplinary models of such processes are interfering with successful forecasting. As discussed elsewhere in this issue (Griffith *et al.* [in press], described below), integrated and matched datasets that cover both social and biophysical domains are extremely rare; the authors examine and classify current observing platforms and projects focused on social, biophysical, and integrated data collection, and then offer recommendations on how fully integrated social–ecological observatories (SEOs) can be developed and implemented. In order to do so, existing observing systems are described in terms of governance structure, scale of observations, and research strategy types, and include observatory models ranging from Long Term Research Networks to Integrated Observing Networks. In the final analysis, the authors suggest that the increasing complexity of environmental issues necessitates the development of new approaches and institutions to adequately deal with such issues, and that integrated SEOs are potential tools that may be of great utility in academic, government, and non-governmental organization efforts to address global environmental change. The paper further proposes a framework for creating such SEOs, outlines a pathway for development of these institutions, and concludes that the formalization and creation of SEOs will lead to the generation of integrated social–ecological datasets, which are currently lacking in many fields of research.

Griffith *et al.* (in press) describe CBO methodologies for generating linked social and ecological data based on the results of collaborations between agencies, indigenous communities, and academic researchers in the Arctic over the past several decades. The authors discuss community-based observing networks and systems (CBONS) and community observer forums, which rely on the collaborative production of scientific questions and observing protocols, and have been instrumental in placing biophysical and ecological data in social and cultural contexts. Examples of phenomena observed range from unusual wildlife sightings or behaviors, to sea-ice conditions, to mission-critical environmental data that facilitate search-and-rescue activities in extreme environments. Methodologies associated with CBO are well suited to the collection of data that can be used to inform empirical SES research, because they are able to produce scale-matched, interoperable social and ecological data; moreover, these techniques are currently being developed for use outside of Arctic regions with the support of MtnSEON and EyesNorth, a newly funded RCN that focuses on developing CBO science. New geographic domains and subjects for CBO include rangeland observing by both ranching and recreational communities in the American West, and the effects of ecological and cultural restoration efforts on tribal lands in the US Mountain West.

Synthesis

Each article summarized here encapsulates the process through which a MtnSEON working group sought or arrived at thinking in terms of SES, and the evolution of that thinking while engaged with projects embedded in interdisciplinary science contexts. In some cases, such as the Blue Mountains Working Group, efforts were founded on ecological approaches, with social-science approaches incorporated later, which most likely reflects the initial make-up of a team and their disciplinary comfort and familiarity with traditional physical and ecological science techniques. Alternatively, SES thinking may arise from the evolution of long-standing ecological research projects (such as the Starkey Project in the Blue Mountains) that were initiated prior to the conceptualization of SES science and are now attempting to incorporate it into ongoing projects. In other cases, research teams initially took more integrated approaches to coupled SES (eg the development frameworks for community observing by the CBONS Working Group).

The process of integrated SES science is not easy, because it requires negotiation about and establishment of terminology and methodology. There are few examples of studies contending with wicked problems by adopting fully integrated SES approaches from the outset (eg Kliskey *et al.* 2016), highlighting the importance and value of team-based integrative science guided by "synthetic thinking" (ie integrated systems thinking that accommodates synthesis). There is no single way to undertake interdisciplinary SES science, with the means often being as important as the ends.

Although the articles presented here exhibit a substantial degree of diversity in SES approaches and concepts, there are several important common themes. For one, each paper points out the critical need for integrating social and ecological sciences for advancing truly interdisciplinary SES; for another, the development of a holistic approach to identifying and mitigating environmental challenges, which takes into account local and social contexts, is also essential for advancing effective SES. Furthermore, several authors note the potential of SES in supporting long-term research and monitoring, and engaging with past, present, and future perspectives, as noted by Alessa *et al.* (2015) and Grier *et al.* (2017).

Another critical element identified by most of the authors is the need for engagement and collaboration with groups other than scientists. This can take many different forms, as demonstrated in the articles here, but what matters is that researchers aiming for useful SES science must develop ways to enhance communication and collaboration with stakeholders, managers, and policy makers. One essential component of such an effort is recognition of the value of local, place-based knowledge that developed experientially and contextually; a second aspect is the importance of tailored SES curricula and professional development, a need tackled by another MtnSEON working group that led to the design of the Social Ecological Systems Training and Education Program (SESTEP) and an innovative curriculum that addresses the challenges and issues addressed in this issue (Virapongse *et al.* 2016). Genuinely effective SES science should involve a reciprocal flow of knowledge among researchers, community members, and management and policy decision makers; in this way, SES may contribute to balancing and mitigating the different priorities and perspectives of affected stakeholders.

Ultimately, efforts in SES science should pave the way for new directions in research, management, and policy. The following papers provide specific examples of potential methodologies and settings in which SES science may be successfully utilized and implemented. Although SES should not be considered a panacea – traditional ecological and social-science research is still critical, and always will be – it does provide additional pathways to develop strategies for solving environmental governance challenges, and to increase the effectiveness of scientific approaches to complex environmental problems.

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