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Using Participatory Workshops to Integrate State-and-Transition Models Created With Local Knowledge and Ecological Data

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Abstract

State-and-transition models (STMs) depict current understanding of vegetation dynamics and are being created for most ecological sites in the United States. Model creation is challenging due to inadequate long-term data, and most STMs rely on expert knowledge. There has been little systematic documentation of how different types of knowledge have been integrated in STMs, or what these distinct knowledge sources offer. We report on a series of participatory workshops where stakeholders helped to integrate STMs developed for the same region using local knowledge and ecological field data. With this exploratory project, we seek to understand what kinds of information local knowledge and ecological field data can provide to STMs, assess workshops as a method of integrating knowledge and evaluate how different stakeholders perceive models created with different types of knowledge. Our analysis is based on meeting notes, comments on draft models, and workshop evaluation questionnaires. We conclude that local knowledge and ecological data can complement one another, providing different types of information at different spatial and temporal scales. Participants reported that the workshop increased their knowledge of STMs and vegetation dynamics, suggesting that engaging potential model users in developing STMs is an effective outreach and education approach. Agency representatives and ranchers expressed the value of both the local knowledge and data-driven models. Agency participants were likely to critique or add components based on monitoring data or prior research, and ranchers were more likely to add states and transitions based on personal experience. As STM development continues, it is critical that range professionals think systematically about what different forms of data might contribute to model development, how we can best integrate existing knowledge and data to create credible and useful models, and how to validate the resulting STMs.

Resumen

Los modelos de estados-y-transiciones (METs) describen el estado actual del conocimiento sobre la dinámica de la vegetación y están siendo elaborados para la mayoría de los sitios ecológicos de los Estados Unidos. La elaboración de estos modelos presenta desafíos debido a series históricas de datos inadecuadas, y la mayoría de los METs se basan en conocimiento experto. Ha habido escasa documentación sistemática sobre cómo diferentes tipos de conocimiento han sido incorporados en los METs, o sobre qué ofrece cada una de estas fuentes de conocimiento. Se informan los resultados de una serie de talleres participativos en los que las partes interesadas ayudaron a integrar METs desarrollados para una misma región utilizando conocimiento local y datos ecológicos de campo. Este proyecto exploratorio busca entender qué tipos de información pueden aportar a los METs, el conocimiento local y los datos ecológicos de campo, evaluar a los talleres como un método para integrar conocimientos, y evaluar la percepción de los modelos creados con diferentes tipos de conocimiento por parte de distintos participantes. Nuestro análisis se basa en notas tomadas durante reuniones, comentarios recibidos sobre borradores de modelos, y cuestionarios de evaluación de talleres. Concluimos que el conocimiento local y los datos ecológicos pueden complementarse mutuamente, proveyendo diferentes tipos de información a distintas escalas espacio-temporales. Los participantes manifestaron que el taller aumentó su conocimiento sobre los METs y la dinámica de la vegetación, hecho que sugiere que la participación de los usuarios potenciales de los modelos en el proceso de elaboración de los METs es un método efectivo de extensión y educación. Los representantes de las agencias del gobierno y los productores expresaron el valor tanto del conocimiento local como de los modelos basados en datos. Los participantes de las agencias gubernamentales fueron más propensos a realizar críticas o agregar componentes basados en monitoreo o investigación previa, los productores fueron más propensos a agregar estados y transiciones sobre la base de su experiencia personal. A medida que se continúe con la elaboración de METs, es sumamente importante que los profesionales de manejo de pastizales naturales piensen sistemáticamente acerca de los diferentes tipos de datos que podrían contribuir a la elaboración de los modelos, cuál es la mejor manera de integrar el conocimiento y los datos existentes para crear modelos creíbles y útiles, y cómo validar los METs resultantes.

Key Words: collaboration, coproduction of knowledge, expert knowledge, knowledge integration, participatory modeling, rangeland, stakeholder participation, traditional knowledge

INTRODUCTION

The Natural Resources Conservation Service (NRCS) and other land management agencies have adopted state and transition models (STMs) as a standard tool for depicting rangeland dynamics on distinct ecological sites within the United States.

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STMs originally were developed in response to critiques that arid rangeland dynamics do not always conform to the classic Clementsian model of succession (Westoby et al. 1989; Laycock 1991). STMs have been created using expert knowledge (McArthur et al. 1994) and ecological field data (Allen-Diaz and Bartolome 1998; Stringham et al. 2003); however, attempts to integrate these types of data systematically have been minimal. The NRCS is currently working to create STMs for most ecological sites in the United States, so this is a critical time to evaluate how best to develop these models. The challenge is to learn how to integrate management experience and scientific research to create models that are credible and useful to agency managers, landowners, and scientists. In this paper, we explore what kinds of information local knowledge and ecological field data can provide, assess one method for integrating ecological data and local knowledge, and evaluate how different stakeholders perceive models created with local knowledge or data.

Site-specific and long-term ecological data sets for creating STMs rarely are available (Allen-Diaz and Bartolome 1998), providing a strong rationale for using the knowledge of long-term land managers and ranchers in STM development (Ash et al. 1994; Bellamy and Lowes 1999). Although it has been suggested that model development requires, "the participation of as many relevant experts as possible" (Bellamy and Brown 1994), experts typically have been long-term agency employees rather than ranchers or other local residents. This project examines the integration of ecological data and knowledge held by ranchers, natural resource agency professionals, and local citizens.

Ecologists and social scientists use models to understand complex systems. Models focused on a single discipline can provide valuable insights, but they often treat external variables as static (Matthews 2006) and focus on what the model can tell about the system, rather than what the stakeholders in the system need to know (Prell et al. 2007). Participatory modeling can bring together diverse knowledge holders, build shared understanding about complex systems, and create useful models to understand the system of interest (van den Belt 2004). Research suggests that when on-the-ground managers are engaged in the process of model creation, the resulting tools are more credible and useful for managers (Prell et al. 2007). The process of modeling cumulative knowledge of a system can help individuals from different disciplines (Heemskerk et al. 2003) and different experiences (Fazey et al. 2006) communicate with one another, identify gaps in knowledge, and recognize conflicting or vague knowledge claims. Participatory modeling also can be a useful tool in adaptive management (Holling 1978), engaging stakeholders in the adaptive management process (Slocum et al. 1995), and helping them develop a joint understanding of the system of interest (Craig et al. 2002).

Workshops have been used to integrate different types of information and bring multiple stakeholders together to think through potential solutions for complex problems (Huntington 2002). Such workshops have been shown to facilitate knowledge sharing and social learning, build trust, and increase participant understanding of the subject matter (Patela et al. 2007; Dreelin and Rose 2008). We used participatory workshops to evaluate and integrate models developed independently using ecological data and local knowledge.

In this project, we examine how local and scientific knowledge each contribute to the development of an integrated model. Local knowledge can be defined as knowledge "integrally linked with the lives of people, always produced in dynamic interactions among humans and between humans and nature, and constantly changing" (Agrawal 1995). Local knowledge is dynamic, and helps managers adapt to changing conditions (Berkes et al. 2000; Olsson and Folke 2004). In this paper we use local knowledge to refer to the experiential knowledge of ranchers and other long-term local residents and land managers. Local knowledge holders verify and modify their own knowledge through ongoing experience and their social networks.

Scientific knowledge can be defined as "knowledge or a system of knowledge covering general truths or the operation of general laws especially as obtained and tested through scientific method" (Merriam-Webster 2010). Scientific knowledge can provide information about patterns of change and the mechanisms behind them, can take a longer time to collect and analyze, and is typically verified through repeated experimentation and observation across space and time, comparison of field data with simulation model predictions, and through the scientific peer-review process.

Previous studies have demonstrated the benefits of integrating different types of knowledge to better understand social–ecological systems. Fortmann and Ballard (2009) illustrated how partnership between salal harvesters and conventional scientists led to research that was more accurate and relevant for decision making. Knowledge coproduction also can provide insights about complex problems that are generated by processes operating at different spatial and temporal scales, as well as across scales (Cash et al. 2006). Integrating local and conventional scientific knowledge into STMs can help to bridge the gap among researchers, agency managers, and landowners by representing the total pool of knowledge, both scientific and local, regarding vegetation change over time.

METHODS: WORKSHOP PROCESS AND EVALUATION

Background and Objectives

These modeling workshops represent the culmination of 3 yr of work collecting two types of data: documentation of long-term ranchers' qualitative local knowledge and sampling of quantitative ecological field data. Our intention throughout this process was to integrate the resulting local knowledge and data-driven models (Knapp and Fernandez-Gimenez 2009). Throughout the project, researchers worked with the local community on a regular basis, through biannual community research meetings, interviews, fieldwork, and participant observation. The workshop was part of the research design, and had four objectives: 1) to obtain feedback about the credibility and usefulness of the local knowledge (LK) and data-driven (DD) models, 2) to create integrated LK-DD STMs for two ecological sites, 3) to increase participant knowledge about and understanding of STMs, and 4) to document and evaluate the participatory model evaluation and integration process.

Model Creation

Data for both models were collected primarily within the Elkhead watershed of northwestern Colorado. The LK model, a

Table 1. Overlap between states in the landscape-level local knowledge (LK) and the ecological-site specific data-driven (DD) state-and-transition models (STMs).

LK STM states	Claypan DD STM states	Mountain Loam DD STM states
Natural sagebrush steppe		
Native sagebrush steppe	Alkali sage shrubland with diverse understory[1]	Mountain big sage shrubland with diverse understory[1]
Degraded sagebrush steppe	Alkali sage/western wheatgrass[2]	Mountain big sage/western wheatgrass shrubland[2]
Improved sagebrush steppe		
Weedy sagebrush steppe		
Managed grassland	Native grassland[2]	
Thick sagebrush steppe		Dense mountain big sage shrubland[1]
Cultivated land	Cultivated lands[1]	Cultivated lands[1]
CRP	Planted grasslands[1]	Planted grasslands[1]
Weed monoculture		
	Alkali sage/bluegrass shrubland	
	Mountain big sage/three tip sagebrush shrubland	
	Eroding alkali sage shrubland	Eroding big mountain sage shrubland
		Snowberry shrubland

[1]Strong association.
[2]Moderate association.

general model of the sagebrush steppe, was developed through semistructured and field interviews with 32 ranchers and agency employees in or near the Elkhead Watershed (Knapp and Fernandez-Gimenez 2009). Five of the rancher participants in these workshops also participated in interviews to develop the LK models. The DD models for the Claypan and Mountain Loam ecological sites in MLRA 48A: *Southern Rocky Mountains* were based on ecological field data and multivariate model construction methods. Six of the rancher participants in these workshops allowed data collection on their ranches. A detailed account of the sampling and data analysis methods for the LK and DD models is beyond the scope of this manuscript, but can be found elsewhere (Fernandez-Gimenez et al. 2009; Knapp and Fernandez-Gimenez 2009).

Model Comparison

Many of the states in the LK model were similar to states in one (or both) of the DD models (Table 1). The LK model had four unique states and the DD models had five unique states. Discrepancies between defined states were due to management actions, management concerns, or preferred outcomes (LK model), or presence or abundance of specific species and dynamic soil characteristics (DD models). The LK and DD STMs included many of the same transition factors, but each also possessed factors not considered by the other modeling effort. The differences between the two model types point to the possibility for ecological data and local knowledge to complement one another (Table 2). The factors unique to the DD models included soil characteristics and presence of specific species, whereas the factors unique to the LK models included specific grazing management practices and other factors influencing transitions. The differences in transition factors were complementary, with each model providing additional information about transitions.

The Workshop Process

We invited ranchers, agency staff, local conservationists, and other long-term residents to attend one of two day-long workshops held on Friday, 21 August and Saturday, 22 August 2009. To recruit participants, we sent a letter, followed up with email and phone call reminders to 60 individuals who had participated in our project as interview subjects, landowners, or cooperators, or attended our community research meetings. Eight participants attended the first workshop day and nine the second day. Due to agency employees' preference to attend during the workweek, and ranchers' preference to attend on the weekend, most of the participants on Friday were agency staff (6/8) and most on Saturday were ranchers (7/9).

Each 7-h workshop was designed to provide many opportunities for feedback and discussion in both small and large groups. Small-group interaction has been suggested as an effective way to facilitate knowledge sharing in workshops (Patela et al. 2007). One member of the research team served as lead facilitator for the workshops, and three other members helped lead, observe, and take notes in small-group discussions. Each workshop began with an overview of ecological site and STM concepts and terminology. We then presented each model in turn, providing an overview of how it was created, and reviewing the model's components. After each presentation, there was a time for questions and answers about terminology, methodology, and process. Participants were divided into two breakout groups to discuss and comment on the model that was just presented. In each breakout session, we asked participants to reflect upon the model and their knowledge of the system, drawing their comments and corrections directly on a poster-sized printout of the model with colored markers. Specifically, we asked participants to evaluate the accuracy of the states, transitions, and thresholds depicted in the model, to provide details on the timeframe for and probability of each transition in the model, and the utility of the model as a whole. The breakout groups lasted 15–20 min, after which each group shared their discussion and feedback with the larger group. The breakout sessions elicited a broad range of comments, facilitated participation by all attendees, and helped ensure that no single individual's ideas dominated the discussion. This process was repeated three times for the LK model, the Claypan DD model, and the Mountain Loam DD model.

Table 2. Transition factors identified in one or both of the state-and-transition models (STMs) created with local knowledge (LK) or with ecological field data (DD).

	LK STM Only	DD STMs only	Factors shared by LK and DD STMs
Factors associated with transitions	Competition from natives	Accumulation of organic matter	Cultivation
	Competition by weeds	Loss of organic matter	Fire
	Drought	Presence of snowberry	Grazing (light, moderate, and heavy)
	Good precipitation	Recolonization by sagebrush	Mechanical brush control
	Grazing as a management tool	Removal of grazing	Planting grasses
	Lack of fire	Soil compaction	Presence of native seeds
	Lack of cultivation	Soil degradation	Presence of sagebrush
	Presence of weed seeds	Soil erosion	Spraying of sagebrush
	Spraying of weeds		
	Time		
	Wildlife grazing		

After lunch, the full group reconvened to work on the integration of the DD and LK models for the selected ecological site. To ensure sufficient time for an unhurried and high-quality discussion, we focused on creating an integrated model for only one ecological site each day (Mountain Loam on Friday and Claypan on Saturday). Participants created an integrated model using a large blank foam-core board (1.8 m × 1.5 m) sprayed with temporary adhesive that was placed in front of the semicircle of chairs where participants sat. A second foam board of the same size served as a "parking lot" for many smaller (7.6 cm × 15.2 cm) pieces of colored paper on which were printed the names of all of the states, communities, and transition factors from each of the models. Components from each model were differentiated by color so that participants could tell if they were integrating an element from the LK or DD models. There also were blank slips of paper where participants could add new states or transition factors that they felt were missing. Wide ribbons with arrows were used to connect states and communities, indicating transitions. When needed, the facilitator helped to guide the participants through the process, but in general she let the participants decide how to proceed with the integration process and added components to the model based on participant discussion. By the end of this exercise, participants in each workshop had constructed an integrated model that included components from both the LK and DD models.

When the model integration process was completed, the facilitator introduced an activity to assess agreement and disagreement regarding the model components and relationships. Each participant received four red and four green adhesive dots. Participants placed the dots on the model to represent states, transitions and thresholds with which they strongly agreed (green dots) and disagreed (red dots). This exercise provided a visual representation of the group's overall agreement and disagreement with the integrated models.

We provided time at the end of the workshop for participants to consolidate their notes, fill in the specific model evaluation forms, and answer the workshop evaluation questionnaire. We ended the workshop by collecting the completed evaluation forms and asking for any final comments about the process or the final integrated model. Some of the participants requested that a final draft of the integrated model be mailed to them in order to more thoroughly assess the model and provide additional comments. We mailed models to all participants, but only received a small number back with additional comments.

Workshop Data and Analysis

Our analysis approach is qualitative and inductive, as appropriate for an exploratory study (Bernard 2001). Qualitative analysis seeks to provide rich descriptions of the phenomenon of interest based on texts, such as interview transcripts, field notes, or responses to open-ended survey questions, and to identify emergent themes and patterns in the data (Miles and Huberman 1994; Bernard 2001). In qualitative research, sample size is generally of less concern than the depth and quality of responses or observations. For example, in focus-group research, the ideal focus group size is no more than 12 participants, in order to allow each individual ample opportunity for expression (Strauss 1998; Neuman 2002). Similarly, the small size of our workshops facilitated high-quality interactions among participants and active participation by all attendees, providing a set of texts in the form of discussion notes, written comments, and questionnaire responses, which permit qualitative analysis of these workshops. Workshops increasingly are used as a method for engaging stakeholder knowledge in the development of solutions to practical natural resource problems (Patela et al. 2007; Dreelin and Rose 2008; Binkley and Duncan 2009; Thompson et al. 2010), and several previous studies have reported on workshops as an opportunity to observe and analyze interactions among different types of knowledge holders or scientific disciplines (e.g., Huntington 2002; Heemskerk et al. 2003).

Our analysis was guided by our overall learning objectives, which included 1) understanding what types of insights and information local knowledge and ecological field data can bring to the development of STMs, 2) assessing workshops as a means of integrating different types of knowledge, and 3) evaluating participant perceptions of the credibility and utility of the LK and DD models, as well as the final integrated model. Data included detailed notes and reflections by the research team, models and participant comments from breakout discussions, feedback forms on each of the individual models, and workshop evaluation questionnaires. We received completed questionnaires from 12 of the 17 workshop participants.

Our data analysis comprised several iterative cycles of data reduction and synthesis, including synthesis of each team member's individual notes, collective discussions about the major themes within and across each team-member's notes, and coding and synthesis of notes, comments on feedback forms, and responses to the workshop evaluation questionnaire. Coding was organized by broad categories related to the overall objectives of the workshops, including the strengths and weaknesses of each model and participant perceptions of the models' accuracy and utility, and emergent themes identified from the workshop notes. The objective of our analysis is to provide a thorough description of the nature and range of participant viewpoints in order to better understand the potential and limitations of the workshop as a forum for knowledge integration in the creation of STMs. Where it was possible to quantify responses reliably from notes, feedback forms, or questionnaires, we provide frequencies of specific perceptions or statements. These tallies are reported by source with N indicating that the source was workshop notes and S indicating the survey questionnaire. Thus, "N 4/17" would indicate that 4 of 17 workshop participants expressed a particular view based on the workshop notes. When quantification was not possible, we use general terms such as "many" or "few" to characterize responses based on the collective assessment of each of the participating researcher observers.

RESULTS

Participant Comments on and Evaluation of Models

Both agency and rancher participants expressed agreement about the usefulness of the local knowledge model based on long-term experience in the region. Participants talked about how the LK model might be more representative of the landscape because it captures a wider range of temporal and spatial information than the DD models. When discussing the lack of long-term data, one agency participant remarked, "You need local knowledge, not just research, to identify the reference state." The LK model was able to integrate long-term dynamics, speak to the reversibility of specific states, and incorporate information about management histories and weather. The LK model also encompassed potential states (such as the *Weed Monoculture*) that are not on the landscape currently, but that reflected managers' concerns and might influence their management. The states were general and descriptive, and most participants agreed with the model. One agency participant stated, "This model is so general, it is hard to disagree with." Although most agreed with the primary components of the model, and liked its broad scale, several ranchers (N 2/8) and agency participants (N 4/6) saw the generality of the LK model as a weakness.

Participants were concerned by the lack of specifics for the LK model. Several agency employees mentioned the lack of precision (N 3/6), because the LK model does not distinguish between dynamics on different soil types, or clearly specify the exact characteristics of each state (for example, percent cover of specific plant species or functional groups). Several agency employees (N 2/6) felt that the landscape scale of the model wasn't appropriate for providing a valid and specific description of rangeland dynamics. One agency employee stated, "The landscape scale that this model is based on is how folks see vegetation change—but the ecological site scale is more accurate." Ranchers (N 2/8) and agency participants (N 1/8) both expressed concern about the lack of detail about specific states, and felt that individuals would interpret these states differently based on their experience with actual places. These participants suggested that more detailed descriptions with indicator plant species for each state would be necessary to clarify states.

On both days, participants (N 6/17) commented about the values implied by the LK model, as conveyed by the terms "improved" and "degraded." As one agency employee stated, "How you rate the states is subjective. For example, the lack of understory in *Thick Sagebrush Steppe* is bad for grazing but good for sage grouse." One participant who identified herself as a citizen questioned, "STMs are very value-laden—how can we integrate the values and be explicit about their integration?" In the Saturday workshop, ranchers tended to define states by management practices and participants from both days (N ranchers 1/8, agency 4/6) expressed that the states from the LK model reflected management concerns more than ecological relationships. For example, ranchers and agency employees alike commented that the state *Weedy Sagebrush Steppe* (SBS) might mean different things to different people. As one rancher stated, "It is important to separate weeds from invasive species. Weeds are different and could be anything that the manager doesn't like." Agency employees (N 4/6) were also concerned that transition descriptions were too heavily focused on management, leading managers to assume that changing management alone might change vegetation. Several agency employees (N 2/6) were also concerned that model components might reflect what people believe and have seen rather than getting at the underlying causal processes.

Participants on both days felt that the DD models were credible and useful because they were based on actual vegetation and soil sampling of specific soil types. Participants appreciated the specificity of the descriptions of vegetation in the DD models and their ability to capture information regarding erosion. Participants respected the data underlying these models, but they also criticized them based on the limited number of sampling locations, how ecological sites were defined, and the lack of information regarding transitions. Ranchers (N 1/8) and agency participants (N 3/6) suggested states that the DD models did not possess and also questioned states represented in the DD models that seemed uncommon on the landscape. Although workshop participants were given summaries of soil and vegetation information for each state of the DD model, few read these descriptions during the workshop.

Several ranchers (N 2/8) questioned whether some of the states in the model were on slightly different soil types or topographic locations, and perhaps represented a different ecological site, rather than a different state within a given ecological site. During data collection, the ecological site was determined by matching soil descriptions collected at each site with NRCS soil descriptions from county soil surveys. The NRCS soil classification for Mountain Loam encompasses more variability than for Claypan, and participants questioned whether some of the states should be categorized in the same site. Participants (N 3/17) also were concerned about the ability of DD models to capture all the processes and drivers operating on a landscape either due to their limited spatial extent on the landscape (such as mechanical treatment) or limited recent occurrence on the landscape (such as fire). It also is important to note that although the model is based on ecological data, processes such as grazing often must be estimated, because not all landowners consistently track specific practices in particular areas (e.g., intensity, timing, frequency, and duration of grazing), and because these often vary from year to year. Factors such as climate also were difficult to integrate into the DD models because the data were collected over a short period of time, and high-resolution weather data (i.e., at the plot or ranch scale) were not available.

General Perceptions of STMs

In general, participants spoke highly about the value of STMs (S 10/12) as a way to: represent vegetation dynamics; integrate the knowledge of ranchers, agency employees and scientists; and serve as a tool for communication among stakeholder groups. One retired agency employee stated that STMs were, "more descriptive of the real world (than linear models) and at a usable level" and one rancher said he "wish(ed) we'd had them 30 years ago." Participants differed in the reasons why they felt the models were useful; whereas ranchers saw them as tools to understand their own landscapes better and learn to manage for opportunities and challenges, agency employees saw them as useful for communicating landscape dynamics and providing evidence for agency management decisions within a regulatory framework.

Two common concerns participants had about STMs in general are their focus on grazing and their lack of specificity regarding grazing. During the workshops, many of the participants (N 8/17) commented that the models focused too much on grazing, with little attention on other drivers of change or underlying ecological processes. Participants wanted to see more emphasis on weeds, recreation, oil and gas development, and climate change. One conservationist said, "This model is missing uses other than grazing—for example, the impacts of recreation. We have mostly talked about grazing and hunting. Recreation probably facilitates the transition to Weedy SBS." Ranchers (N 2/8) and conservationists (N 1/2) talked about how small-scale disturbances (winter hay-feeding areas, oil and gas drilling pads, or road corridors) affected the surrounding ecological site and the states present on the site. For both types of models, agency staff and ranchers wanted grazing pressure to be more thoroughly addressed and defined. They suggested the need to be more specific about grazing practices, including stocking rate, season of use, type of animal, and intensity. As one rancher stated, "The term *heavy grazing* is value-laden and overly simplistic. We need information about the class of livestock, stocking density, and seasons of use, etc … "

Both agency employees and ranchers expressed concern that STMs might not be useful for managers due to their focus on the ecological site as the unit of analysis, their inability to integrate cross-site dynamics, and their lack of critical information for making management decisions. For instance, although ecological sites might be a more credible and useful resolution to depict vegetation change, managers typically make decisions at a much broader spatial extent. As one rancher said, "Managing by ecological site requires a range rider (and) folks don't have those." There was also a concern that STMs didn't do a good job describing the interactions between states when they are located adjacent to one another on the landscape. One agency participant noted, "Spatial relationships between states matter, and those are not currently integrated into models." A quarter of the ranchers and half of the agency participants also wanted more detail about the timeframe for transitions and associated costs so that the models would be more useful for decision making. One rancher mentioned that the timescales for transitions on Mountain Loam would be different than for similar transitions on Claypan, and that should be addressed so that ranchers understand the time frames for transitions in different ecological sites. Several individuals also suggested that it would be useful to have a description of the advantages and disadvantages of particular states so that ranchers could more thoroughly think through possible implications of vegetation and soil dynamics.

A broader concern about STMs was that ranchers felt that it was difficult to translate the boxes, representing states, to actual places on the landscape. Ranchers in the workshop often stated that the models were difficult to understand (N 5/8); however, by the end of the workshop they felt that STMs would be useful for decision making on their ranch (S 6/6). Researchers noticed that ranchers engaged more readily with the models when they were asked to compare them with their own experiential knowledge. They suggested the need for field visits where someone knowledgeable about the STM could help identify states on their land. Ranchers also recommended developing a compact field model that they could refer to easily. As one said, "You have to be able to put it in your back pocket to use it."

Model Integration

We found that the process of model integration had some common elements, and some differences, depending on the participants present. On both days, a few key participants helped to engage and motivate the group. These were people who knew the system well, and were willing to share their knowledge and think critically about how the system worked. This suggests that the dynamics within a workshop setting will provide better and more complete information than models integrated by a single individual.

The workshops also showed that communication and interaction styles might vary based on the educational and experiential background of participants and their occupational cultures. At the Friday workshop, agency participants were critical about the existence of states and the specific drivers of change, questioned both types of information (LK and DD), and were interested in discussing theoretical concepts behind STMs. Agency participants used a range of evidence to support their claims including monitoring data, published studies, and personal experience. At the Saturday workshop, ranchers relayed their knowledge in the form of stories about life experiences and were reluctant to question the information provided, wanting to add rather than change or remove information.

The Final Integrated Models

In this section, we discuss several of the decisions made during the integration process, in order to understand issues that

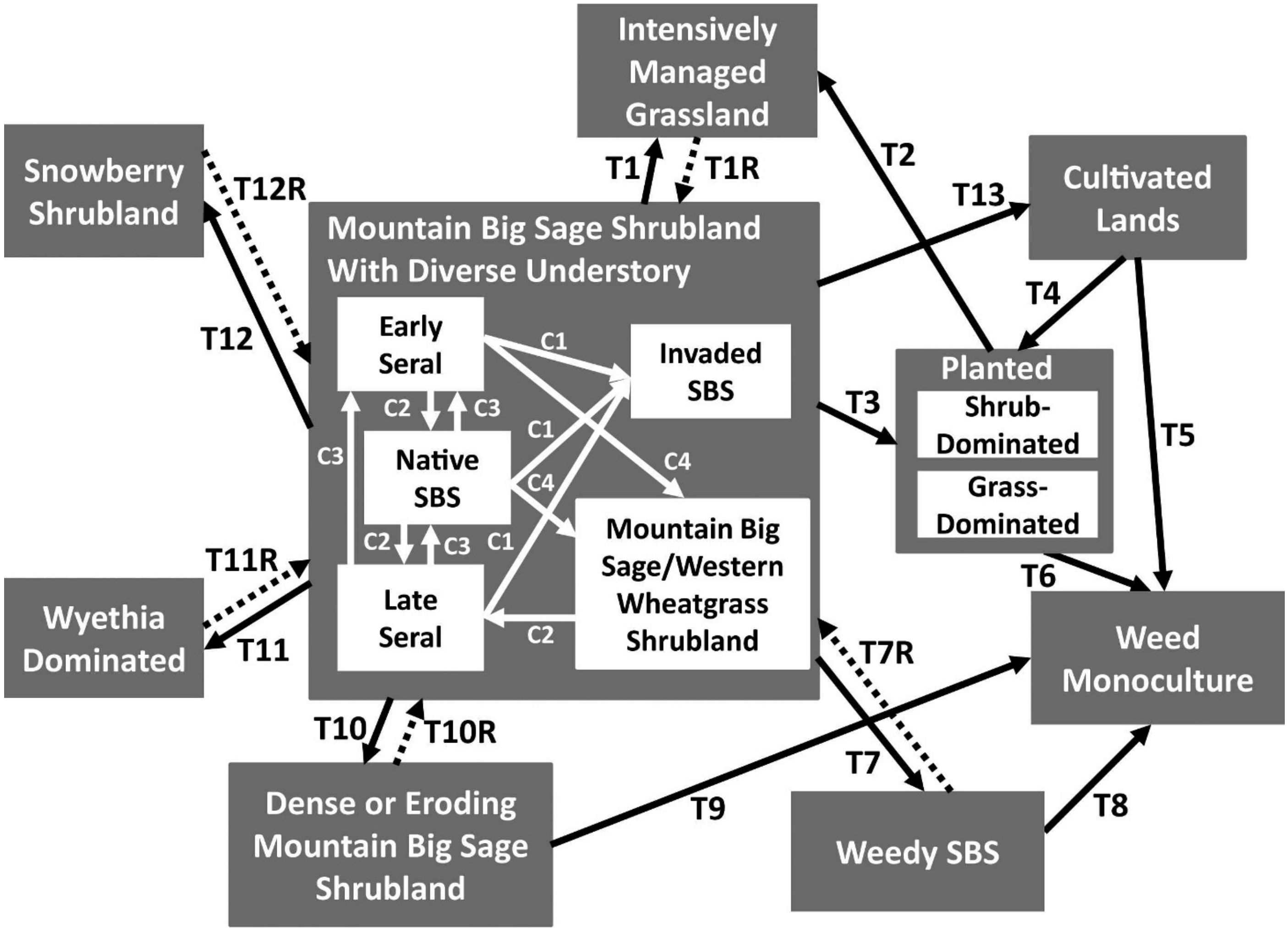

Figure 1. Integrated state-and-transition model for the Mountain Loam ecological site developed during the participatory workshop. This model combines information from two distinct models generated using local knowledge and ecological field data as well as feedback from workshop participants (ranchers, natural resource professionals, and other interested citizens).

facilitators of similar workshops might face. The final integrated models for the Mountain Loam (Fig. 1 and Table 3) and Claypan (Fig. 2 and Table 4) sites include components from both the LK and the DD models.

First, we found that workshop participants did not always agree with either DD or LK states. For the DD models, both agency and rancher participants were concerned that some states were not in the correct ecological site, represented a community rather than a state, or were not common enough in their experience to justify inclusion. For the LK model, both agency and rancher participants felt that some states had ambiguous definitions, were defined by management rather than species composition or ecological function, or did not currently exist on the landscape. The decision to remove states was motivated by personal experiences with the vegetation type, whereas decisions to change states to communities were motivated by the belief that transitions were common and easy to change within a management timeframe. These changes, especially to the DD models, caused the research team some concern, because the states were based on empirical field data. This suggests that it is important in a workshop setting to track all feedback regarding the model, but retain some mechanism to assess the validity of changes made during the workshop.

Second, for the Mountain Loam site, there also was some discussion about whether the reference state (*Mountain Big Sage Shrubland with Diverse Understory*) in the Mountain Loam model also should include seral stages. Several of the agency participants (N 3/6) strongly felt that seral stages should be included in the model despite the fact that such communities were not represented in either the DD or LK model. This suggests that there might be a desire from participants to integrate familiar successional concepts into STMs, regardless of whether they reflect vegetation dynamics in specific sites. Although STMs allow for integrating both linear and nonlinear pathways, model developers should be ready to critically evaluate whether such dynamics truly are operating at the specific site under consideration.

Finally, participants chose to integrate weedy states into the model, although the DD model did not show weeds to be a significant component in plant community composition. In both models, the group chose to include a weedy sagebrush state, suggesting that weeds have important management

Table 3. Transition descriptions for the Mountain Loam ecological site (Fig. 1).

Transition	Description of factors leading to transition
T1	Mechanical brush control; chemical control of shrubs (aerial and manual); fire.
T1R	Application of herbicide to kill grass; moderate/heavy grazing; stop controlling brush.
T2	Mechanical brush control; chemical control of shrubs (aerial).
T3	Planting grasses; mechanical brush control. This state can transition from any other state via cultivation and/or planting grasses.
T4	Planting grasses; good precipitation.
T5	Abandonment; drought year; presence of weed seeds; lack of management (no weed control).
T6	Presence of weed seeds; drought year; lack of management.
T7	Presence of weed seeds; natural fire; brush control fire; wildlife/animal movements; no weed control; facilitated by recreation or land speculation.
T7R	Active treatment of weeds; good precipitation; lowered grazing pressure.
T8	Continuous abusive grazing; presence of weed seeds; drought.
T9	Fire (extreme?).
T10	Heavy grazing; lack of fire; time; terrain. Whether it becomes dense or eroding depends on slope.
T10R	Chemical control of shrubs (aerial and manual); presence of native seeds; managed grazing.
T11	Heavy sheep grazing (timing important); other heavy grazing; soil disturbance.
T11R	Grazed by sheep in early June.
T12	Fire; mechanical brush control; slope and aspect important.
T12R	Grazing as a management tool (long term and intensive).
Community Pathways	
C1	Drought; presence of weed seeds; repeated fires; repeated heavy grazing.
C2	Presence of native seeds; medium grazing; lack of fire; no grazing; good precipitation.
C3	Moderate fire (timing/intensity); mechanical brush control; chemical control of shrubs (aerial); dixie harrow; spike.
C4	Time; repeated heavy grazing.

implications even though they did not have high overall foliar cover in sampled plots. They also included the weed monoculture in each model, although participants agreed that it did not exist on the landscape currently. In the Mountain Loam model, they also included a weed monoculture based on a specific native but undesirable species (*Wyethia amplexicaulis* [Nutt.] Nutt.), suggesting that the species of weed might be associated with different processes and have different management implications. Although the DD approach overlooked small populations of weeds due to their low cover, the LK model and resulting integrated models demonstrated that the presence of weeds changes the way managers perceive and manage these sites.

Evaluation of Integrated Models and the Workshop Process

Participants agreed that the states (S 12/12) in the integrated models were mostly credible, with more disagreement surrounding the Mountain Loam than the Claypan model. Participants who created the integrated Mountain Loam model disagreed about the *Wyethia Dominated* State (a component added by participants), the existence of the *Snowberry Shrubland* State (DD component), and the *Weed Monoculture* State (LK component). Participants who created the integrated Claypan model expressed agreement about the states. In both models, there were concerns about overlap and redundancy between states. Despite these concerns, most participants were satisfied with the ability of the models to represent states on the landscape. One rancher reflected the agreement of most participants when he wrote, "I believe the models are accurate and the discussion today has increased my confidence in the states."

More participants expressed reservations about the transitions (S 9/12). Their concerns were about clarifying what is meant by grazing (N 8/17), and for ranchers, the lack of personal experience with transitions (N 3/8). Several agency employees suggested that there is substantial research and data that could support or crosscheck the transitions and that should be integrated into the models. When asked to comment on the time that each transition took, both agency and rancher participants expressed the difficulty of answering this question thoroughly (S 10/12). As one rancher stated, "transition time depends on a number of variables and each variable impacts the transition time." Participants understood the complexity of factors that could influence transition time, and this knowledge made it difficult for them to estimate transition times.

In the workshop evaluation questionnaire, participants wrote positive comments about the workshop process (S 11/12). Participants enjoyed integrating knowledge, felt the structure facilitated sharing and discussion of model elements, and enjoyed learning from one another. One rancher stated, "I enjoyed the input from the others in the room." Participants left feeling more comfortable with STMs and their understanding of the models. When asked how the workshop changed their perception or use of STMs, participants said they felt STMs were valuable for representing vegetation dynamics and useful as a management tool (S 10/12). Ranchers suggested that ranch visits to illustrate states with specific sites on their ranch would be useful.

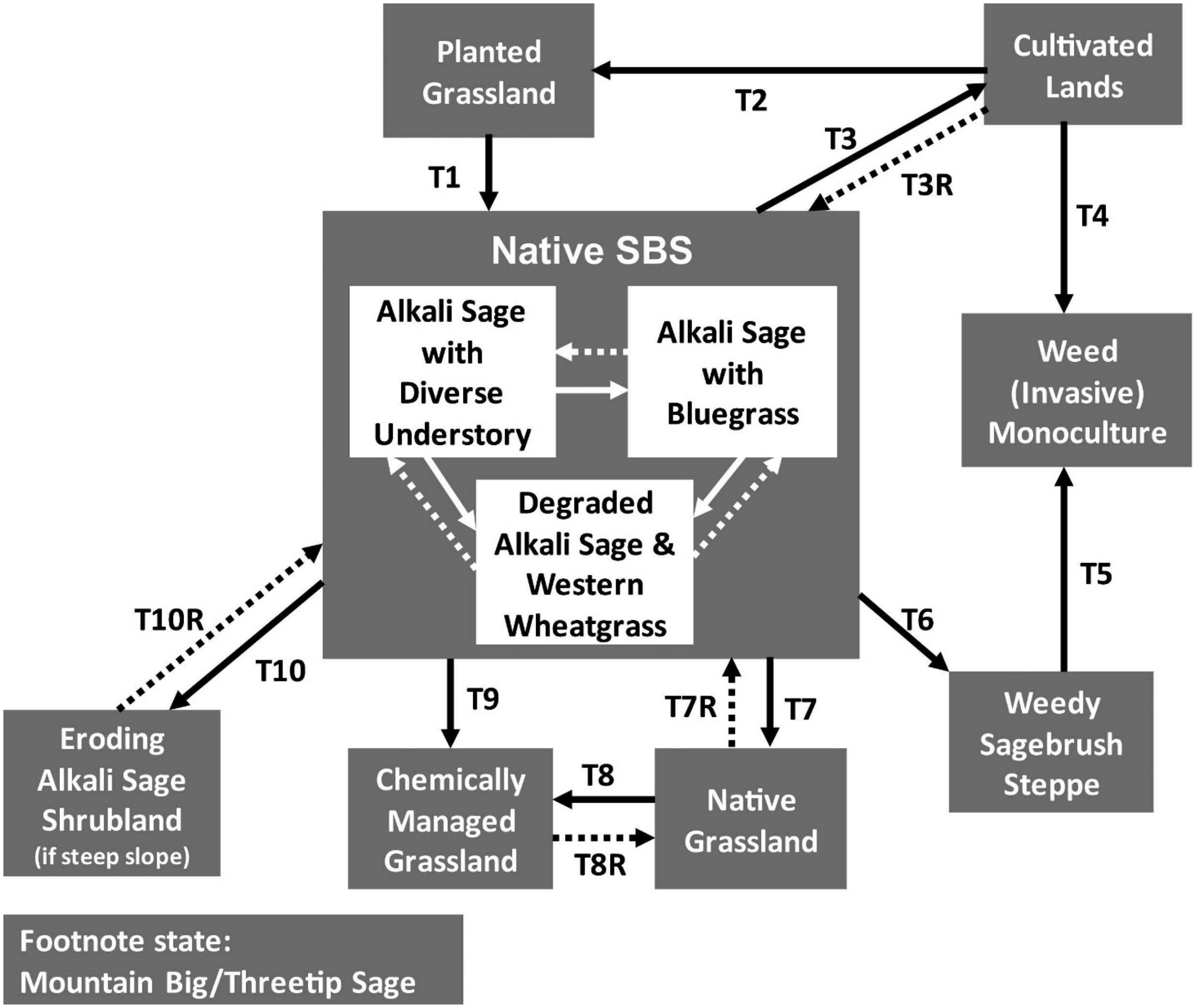

Figure 2. Integrated state-and-transition model for the Claypan ecological site developed during the participatory workshop. This model combines information from two distinct models generated using local knowledge and ecological field data as well as feedback from workshop participants (ranchers, natural resource professionals, and other interested citizens).

DISCUSSION

The Importance of Experiential Knowledge

Both ranchers and agency participants relied on their experiential knowledge in critiquing and discussing the models, although agency participants also used other information sources such as published research and long-term monitoring projects. This suggests that knowledge is often filtered through personal experience, and it is hard for participants to believe in a state or transition that they have not observed. The importance of first-hand experience in validating STMs is supported by the fact that participants agreed about most elements of the integrated model for the Claypan ecological site (which is less variable in soils and associated vegetation), whereas there was more controversy about the integrated model for the Mountain Loam ecological site (which encompassed more variability). This suggests that it might be easier to develop stakeholder agreement for STMs on clearly defined and relatively homogenous ecological sites, and it might be more difficult to reach agreement for less clearly distinguished and more heterogeneous ecological sites.

What Different Forms of Knowledge Can Provide

This process highlighted the similarities and differences between what scientific and local knowledge can bring to model development. As has been suggested (Fraser et al. 2006), these differences can complement one another and build more realistic and useful models. First, the LK and DD models did not present different vegetation dynamics as much as they represented different scales of perception and different termi-

Table 4. Transition descriptions for the Claypan ecological site (Fig. 2).

Transition	Description of factors leading to transition
T1	Spraying of weeds; lack of management; lack of cultivation; lack of fire; presence of sagebrush; lack of grazing; presence of native seeds; time (minimum 60–70 years).
T2	Spraying of weeds; seeding.
T3	Cultivation; spraying of weeds; time (less than other transitions).
T3R	Lack of cultivation; lack of fire; presence of sagebrush; lack of grazing; presence of native seeds; time (minimum 60–70 years).
T4	Drought; good precipitation (at the right time); soil disturbance. This transition was seen as more probable than T5.
T5	Presence of weed seeds; mechanical treatment of shrubs; heavy grazing; improper or incomplete reclamation. This transition was seen as less probable than T4.
T6	Presence of weed seeds; mechanical brush control; heavy grazing; improper or incomplete reclamation; soil disturbance.
T7	Natural fire; mechanical treatment of sagebrush; brush control (fire); heavy grazing; seeding.
T7R	Heavy grazing; presence of sagebrush seeds; lack of management.
T8	Chemical control of shrubs (aerial or manual).
T8R	Seeding.
T9	Chemical control of shrubs (aerial).
T10	Water erosion; flooding; heavy grazing; soil organic matter loss.
T10R	Good precipitation; seeding.

nology. The LK model reflects dynamics across a broad vegetation type (the sagebrush steppe of northwest Colorado), whereas the DD model is concerned with dynamics on specific ecological sites. The LK model reflects a temporal scale of personal and cultural experience on a landscape, and the DD model represents a temporal scale limited by the states that exist on the land currently. The LK model incorporated some information on transition times, but the DD model did not. These differences suggest that both qualitatively analyzed local knowledge and quantitatively analyzed ecological field data provide complementary information for model development.

Second, the DD and LK models suggest two different ways to define states: by species composition (DD model), or by representative species, utility for management, and past management actions (LK model). The DD models, by relying on species composition to define states and on management histories only to define transitions between them, demonstrated that management actions do not always have a direct effect on species composition. Managers categorize and understand resources through management actions; however, those actions might not alter underlying ecological processes, suggesting that in some cases management actions might have a more transient effect on vegetation dynamics than managers believe. Although integrating management goals and concerns is important to make models useful to managers, defining states based on management actions alone might fail to represent what is actually occurring on the landscape. It is important that models distinguish between management actions, the ecological processes they influence, and the associated change in plant composition.

A similar pattern is seen in the transition factors suggested by the LK and DD models (Table 2). The LK model is focused on different types of management actions, contextual factors such as weather and climate, and disturbances such as wildlife grazing and fire, while the factors included in DD models focus on processes such as erosion, soil compaction, and accumulation of organic matter. The LK model reflects a focus on management practices, whereas the DD models integrate information about ecological processes. In the STM literature, there has been an increased interest in integrating ecological processes into our understanding of transitions and thresholds (Stringham et al. 2003; Bestelmeyer 2006; Briske et al. 2008); however, many NRCS STM models still rely heavily on grazing management practices to explain transitions. As participants suggested, this approach overlooks other uses that affect vegetation (e.g., recreation, oil and gas development), neglects the influence climatic conditions and weather fluctuations, and assumes management effects on ecological processes without testing those assumptions. Workshop participants suggested that STMs would be more useful if they have applications beyond grazing management and distinguish between management actions that might contribute to transitions and ecological processes that underlie these transitions.

The Importance of the Coproduction of Knowledge

Roux has argued that sustainable management requires a new way of looking at knowledge—from thinking of it as a thing to be used to understanding it as a process to be shared (Roux et al. 2006). Developers of STMs have expressed concern that land managers might perceive STMs as too complex and therefore will fail to apply them to management (Fernandez-Gimenez and Knapp 2010). Although this might be the case if STMs are provided to landowners or managers with no interpretation or interaction, we found that the workshop process allowed managers to interact with models and test them against their own experience. As participants integrated their own knowledge into STMs, they began to appreciate their detail and complexity, and even expressed concerns about oversimplifications within the models. Including end users in knowledge production blurs the lines between "expert" and "recipient" and allows for the development of a more complete and applied understandings of systems (Kristjanson et al. 2009). STMs that are created through knowledge sharing and discussion can enhance communication between scientists and practitioners, becoming tools that help put knowledge into action (Cash et al. 2003). Although STMs presented without interaction or explanation might seem confusing to end users, the process of engaging users in STM creation can both improve models and help managers apply them to decision making.

Limitations of the Workshops and Resulting Integrated LK–DD STMs

The integrated models depended on the voluntary participation of community members. The first limitation of this approach is that the resulting models might be biased if nonparticipants consistently had different views and opinions than participants, or if the ranches in the watershed that were not sampled differed significantly in management histories or disturbance regimes from those sampled. Given our experience in the watershed, we believe that the participating ranchers provide a realistic sample of the watershed, based on ranch size, demographics, income, and management practices. A second weakness is that the integrated models lack transition probabilities and time frames, which are needed to make the models useful for decision making. Although we tried to elicit these probabilities in the workshops, participants found it difficult to settle on probabilities and time frames during the short time allotted to this activity. To address this weakness, our research team currently is working to elicit these probabilities using Bayesian belief networks (Cain 2001; Bashari et al. 2008).

A third potential weakness was that workshop participants tended to focus on the graphic depiction of the model rather than the descriptions of the component states and transitions. As a result, participants made assumptions about the meaning of some states. In future workshops, it might be important to emphasize the narrative descriptions of each state. Finally, the integrated models are the result of group participation, and suggestions from a single individual could change the model dramatically. In the future, it would be beneficial to have a systematic process for contributing, evaluating, and then integrating changes to the models. In both integrated models, there are some instances where states overlap. In a longer workshop these redundancies might have been identified and collapsed into a single state with internal communities.

Suggestions for Integrating Knowledge in STM Development

Integrating LK and DD models holds promise for providing a more credible and useful depiction of vegetation dynamics. There are several ways that this integration could be completed. The first method includes dual model development and integration, which is the method we chose to use in this project. This method allows for explicit comparison of the models created from local knowledge and ecological data, but it could lead to models with redundant components. We found that a day-long workshop was not long enough to fully integrate, discuss, and resolve questions regarding the models. The underlying dynamics represented by both models were similar, but the different terms used in each model gave the impression of contradiction. Finally, synergy between the two knowledge types was limited to this day-long workshop, and both participants and the model could benefit from more interaction during the model-building process.

Another method would create a model with one type of knowledge (either LK or DD) and use the second type of knowledge to validate the model. This method has been used in past efforts, with professional experience driving model development and published science or monitoring data used to verify the accuracy of components (Bestelmeyer et al. 2009). Alternatively, a model could be grounded in local knowledge and field data used to test and verify model components. The weakness with this approach is that some components might be "tacked on" or left out because they don't fit well within the original model structure.

The third method would be to conduct an integrated development process in which local ranchers, scientists, and agency employees come together to develop the base model, decide which relationships need further testing, design a sampling protocol, and review the resulting data to revise the model. This would allow long-term managers (both ranchers and agency employees) to provide detailed input on the conditions they have seen on the ecological site and the potential factors affecting transitions. This integrative and iterative process would allow participants the opportunity to interact with model creation in a more meaningful manner and understand how multiple stakeholders view a system, but it also requires more time and commitment on the part of all participants.

Suggestions for STM Development Workshops

Linking different forms of knowledge takes an investment in communication, translation, and mediation (Cash et al. 2003). Our workshops were successful in part because of preplanning and investment in effective facilitation. It is important that the agencies or organizations hosting modeling workshops design an effective process that includes providing a summary of background information, time for small group discussion, facilitated integration and evaluation of the final model, and multiple avenues for feedback. Our workshops also taught us the importance of allowing time for reflection, assessing the model for logical consistency, and integrating a process of validation for model elements. In addition to careful workshop planning, facilitation is critical to workshop success. In our workshop, the facilitator was not involved in the creation of either the DD or LK models. We suggest using an independent facilitator when possible to facilitate an open and unbiased process.

Our workshops included ranchers (8), agency employees (6), conservationists (2), and engaged citizens (1). In this watershed, grazing is the primary land use. Although participants brought up recreation and oil and gas development as other land uses that might influence vegetation dynamics, these uses were not pervasive on the ecological sites in this watershed. In other contexts, it might be important to engage additional stakeholders and consider other land uses in the development of STMs. In our workshops, heterogeneity within ecological sites was the main source of conflicting viewpoints about a model, and not differences of opinion about the impacts of different land uses. However, in different contexts it might be important to involve stakeholders with divergent views about the impact of different land uses on vegetation.

IMPLICATIONS

The results of the workshops reported on here suggest six key considerations for the development of STMs. First, models developed using local knowledge and ecological data can complement one another. DD models provided ecological site-specific interactions, detailed plant community descriptions, and states that are not defined by management actions, whereas the LK model provided valuable management and environmental contexts, place-specific and historic states, and dynamics at different scales and across scales. Second, these workshops demonstrate the importance of integrating some type of validation or review of model components. This process will help to minimize overlap between states and make sure that model components do not contradict one another or existing science. Third, STMs will be more useful if they include information about the level of verification for states and transitions. This is important both for assessing agreement in local knowledge of the system and for describing the amount of data and replication upon which DD models are based. Fourth, there is a tension in model development between creating simple and usable models for managers and detailed but complex models to represent ecological dynamics. Some workshop participants were initially intimidated by the terminology and structure of STMs; however, they readily engaged with the models when asked to share their own knowledge and integrate it in the modeling process. The STM outreach challenge might have less to do with complexity than with making the abstract tangible through hands-on workshops and field days where ranchers could connect state descriptions with actual landscapes. Fifth, we found that an inclusive process with a range of stakeholders worked well, but our watershed had relatively little land use conflict. Future workshop organizers should assess their contexts and invite participants who will represent different ways of knowing the land and different perspectives about land use in order to create credible and useful models. Finally, these modeling workshops provide just one example of how knowledge integration can occur. We hope that this discussion encourages others to explore different methods of integrating local knowledge and ecological data in STMs.

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