Understanding Change: Integrating Rancher Knowledge Into State-and-Transition Models

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Abstract

Arid and semiarid rangelands often behave unpredictably in response to management actions and environmental stressors, making it difficult for ranchers to manage for long-term sustainability. State-and-transition models (STMs) depict current understanding of vegetation responses to management and environmental change in box-and-arrow diagrams. They are based on existing knowledge of the system and can be improved with long-term ecological monitoring data, histories, and experimentation. Rancher knowledge has been integrated in STMs; however, there has been little systematic analysis of how ranchers describe vegetation change, how their knowledge informs model components, and what opportunities and challenges exist for integrating local knowledge into STMs. Semistructured and field interviews demonstrated that rancher knowledge is valuable for providing detailed management histories and identifying management-defined states for STMs. Interviews with ranchers also provided an assessment of how ranchers perceive vegetation change, information about the causes of transitions, and indicators of change. Interviews placed vegetation change within a broader context of social and economic history, including regional changes in land use and management. Despite its potential utility, rancher knowledge is often heterogeneous and partial and can be difficult to elicit. Ranchers' feedback pointed to limitations in existing ecological site-based approaches to STM development, especially issues of spatial scale, resolution, and interactions among adjacent vegetation types. Incorporating local knowledge into STM development may also increase communication between researchers and ranchers, potentially yielding more management-relevant research and more structured ways to document and learn from the evolving experiential knowledge of ranchers.

Resumen

Los sistemas áridos y semiáridos frecuentemente responden de modo impredecible a las acciones de manejo y factores ambientales, hecho que hace difícil que un productor pueda llevar a cabo un manejo sustentable de largo plazo. Los modelos de estados y transiciones (METs) describen el conocimiento actual sobre las respuestas de la vegetación a factores ambientales y de manejo utilizando diagramas de cuadros y flechas. Dichos diagramas están basados sobre el conocimiento disponible del sistema y pueden ser mejorados con datos de monitoreo ecológico de largo plazo, observaciones históricas y experimentación. El conocimiento de los productores ha sido incorporado en los METs, sin embargo ha habido poco análisis sistemático del modo en que los productores describen cambios en la vegetación, como dicho conocimiento provee información acerca de los componentes del sistema, y cuáles son las oportunidades y desafíos asociadas con la integración de conocimiento local a los METs. Entrevistas de campo semi-estructuradas demostraron que el conocimiento de los productores es un elemento valioso en el suministro de información sobre historias detalladas de manejo e identificación de estados inducidos por prácticas de manejo en los METs. Entrevistas con productores también proveyeron una evaluación sobre el modo en que los mismos perciben cambios en la vegetación, información sobre las causas de las transiciones, e indicadores de cambio. Las entrevistas ubicaron a los cambios de vegetación dentro de un contexto más amplio de historia social y económica, incluyendo cambios regionales en el manejo y uso de la tierra. A pesar de su utilidad potencial, el conocimiento de los productores es frecuentemente heterogéneo, parcial y puede ser difícil de obtener. Las respuestas de los productores señalaron las limitaciones existentes en el desarrollo de ETMs a nivel de sitios ecológicos, específicamente en lo relacionado a la escala espacial, la resolución y la interacción entre tipos de vegetación adyacentes. La incorporación del conocimiento local al desarrollo de MET podría también aumentar la comunicación entre investigadores y productores, y potencialmente resultar en un mayor volumen de investigación que sea relevante al manejo y en modos estructurados de documentar y aprender del conocimiento dinámico que surge a partir de las experiencias de los productores.

Key Words: local knowledge, management, ranchers, semistructured interviews, state-and-transition model, vegetation change

INTRODUCTION

State-and-transition models (STMs) were developed as a response to observations of arid rangelands that do not always conform to the classic Clementsian model of succession (Westoby et al. 1979; Laycock 1991). In the classic model of

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succession, plant communities unimpeded by grazing or other disturbances progress toward a single stable state that represents the climax community, or historic natural community (Clements 1936). However, the removal of grazing does not always return a community to the prior state and can lead through a transition to a new stable state. Invasive species, not accounted for in Clementsian plant dynamics, have the potential to change nutrient cycling, disturbance regimes, and resilience (Muradian 2001). For some areas, the climax community is no longer possible without intensive inputs (Westoby et al. 1979; Allen-Diaz and Bartolome 1998), nor is the climax community always the goal of management. The STM is able to integrate these non-linear interactions (Westoby et al. 1989) while retaining the capacity to incorporate classic successional ideas (Rodriguez Iglesias and Kothmann 1997; Bestelmeyer et al. 2003). The result is a model that reflects current knowledge about vegetation dynamics and attempts to help managers understand the potential outcomes of management. The Natural Resources Conservation Service (NRCS) is currently creating STMs for each of the ecological sites in the United States.

To improve and verify these models, detailed knowledge of plant community dynamics, including potential states, thresholds, and transitions, is necessary (Allen-Diaz and Bartolome 1998; Jackson and Bartolome 2002), but site-specific and long-term data are rarely available (Allen-Diaz and Bartolome 1998). In the face of limited data, researchers have used other sources to piece together information regarding vegetation change. Models have been developed using a completely quantitative framework (Allen-Diaz and Bartolome 1998; Stringham 2003) and a qualitative analysis of quantitative data (Plant and Vayssieres 2000). Qualitative model building has relied on expert knowledge (McArthur et al. 1994), analysis of literature, workshops (Bellamy and Brown 1994; Forbis et al. 2006), and simulation modeling (Bestelmeyer et al. 2004). Some argue for the importance of integrating local knowledge, despite its qualitative and experiential nature (Ash et al. 1994; Bellamy and Lowes 1999), while others see long-term quantitative data as the most reliable basis for modeling (Allen-Diaz and Bartolome 1998; Stringham 2003). Both quantitative and qualitative data provide valuable information for model development; however, each has trade-offs that must be considered. Qualitative data often have more nuance and detail, particularly about past conditions and management histories, but also may include bias or be incomplete. Quantitative data are perceived as more objective, but accurate sampling plans require prior knowledge of the system, quantitative data collection limits the types of questions that can be asked, and the time series of quantitative field data needed to infer transitions is often lacking.

The level of integration of local knowledge is also debatable. While some argue for joint development by scientists and managers, with ongoing debate and hands-on workshops (Brown 1994; Bestelmeyer et al. 2003; Forbis et al. 2006), others see local knowledge as vital primarily for model validation (Bellamy and Brown 1994). Although some work has been done regarding performance testing of models (Bellamy and Brown 1994; Brown 1994), there are no studies that systematically look at the opportunities and challenges of developing STMs using local knowledge.

In this article, we adopt Agrawal's (1995) definition of local knowledge as knowledge "integrally linked with the lives of people, always produced in dynamic interactions among humans and between humans and nature, and constantly changing." Local knowledge increasingly is recognized as playing an important role in comanagement of natural resources (Fernandez-Gimenez et al. 2006; Plummer and Armitage 2007) and is thought to be an essential ingredient in institutions that manage for resilient social-ecological systems (Berkes et al. 2003; Walker and Salt 2006). Local knowledge studies have focused primarily on pastoralist communities in developing countries (Niamir 1995; Bollig and Schulte 1999; Fernandez-Gimenez 2000; Spencer 2004; Roba and Oba 2009), and only a handful of studies examine rancher knowledge in more developed countries (Belgrave et al. 1990; Garden et al. 2000; Gill 2005; Smidt and Brimer 2005). In the United States, formal research on ranchers' ecological knowledge has been minimal, and has focused primarily on rancher attitudes and perceptions (Saltiel and Irby 1998; Conley et al. 2007), decision making (Rowan et al. 1994), and adoption of new techniques (Didier and Brunson 2004).

STMs have been promoted as a tool to help land managers make good decisions in a changing environment (Westoby et al. 1989; Ash et al. 1994; Brown 1994); however, failure to integrate local knowledge may mean that new scientific concepts are not integrated into active land management practices. Paulson (1998) has suggested the need for an effective process of knowledge sharing in range management, and community involvement has been suggested as a way to increase acceptance and compliance with new policies by local communities (Johnston and Soulsby 2004). The resulting dialogue is useful for the education of both local producers and researchers (Kelly 2001). Although pastoralists have helped to develop indicators (Oba and Kaitira 2005), management plans (Kelly 2001; Arnold and Fernandez-Gimenez 2003), and STMs (Brown 1994; Bestelmeyer et al. 2003; Forbis et al. 2006), we are just beginning to explore the full potential for integration of rancher knowledge. Integrating local knowledge may help bridge the gap between researchers and ranchers by representing the total pool of knowledge, both scientific and local, regarding vegetation change over time. This attempt may also help clarify and highlight research needs of on-the-ground practitioners.

This article presents a case study completed in a watershed in northwestern Colorado, USA, using local knowledge to construct an STM for the sagebrush steppe community. Our objectives were to investigate 1) how ranchers describe vegetation change, 2) how rancher knowledge informs model components, and 3) the opportunities and challenges of integrating local knowledge into an STM. This study provides an example of how STMs can be constructed using rancher knowledge; however, it does not seek to assess the accuracy of the resulting model through data collection or experimentation.

Defining Terms

Westoby et al. (1989) asserted that there is no "single correct description" of vegetation change; instead, STMs are a way to describe what is known about vegetation change in plant communities depending on the objectives of the particular model. In this modeling exercise, we used local knowledge to describe changes in vegetation and perceived drivers of those changes. For each term, we define its common usage in the STM literature and the definitions used in this model to reflect ranchers' understanding of vegetation change.

A "state" is defined by Westoby et al. (1989) as "a relatively stable assemblage of plant species which is a product of the interaction between management and environmental factors." As Bellamy and Brown (1994) have suggested, the number of states partially depends on the objectives of management, as alternative states represent different levels of utility for management. For the purpose of this article, we define "state" as a relatively stable configuration of resources (plant/soil/water) that are differentiated by managers in terms of productivity and management potential. Within each state, there may be a set of communities and community pathways. Communities are consistently recognizable assemblages of plant species that may shift along pathways that are reversible with changes in climate and facilitating processes (Bestelmeyer et al. 2003). A change from one community to another does not necessarily affect the long-term productivity of the land, although changes may signify short-term differences in productivity.

A "transition" has been defined as a "suite of causes," including both management and ecological processes, that leads to a change in vegetation (Bellamy and Brown 1999) and that is reversible only with accelerating processes, that is, active management such as shrub removal or reseeding that requires significant inputs of energy, labor, and financial resources (Bestelmeyer et al. 2003). Recent STM literature has suggested that each transition also signifies a threshold, or a "change in the integrity of the site's primary ecological processes, resulting in a different potential set of plant communities" (Stringham et al. 2003; Briske et al. 2008). Earlier STM publications do not reflect this understanding; however, for the purposes of this study, primary transitions that move the vegetation away from the natural sagebrush community will signify thresholds. Thresholds in this article are defined as a boundary beyond which ecological processes are changed and cannot be regained within a management time frame without accelerating processes.

STUDY SITE

The Elkhead watershed straddles Routt and Moffat counties in northwestern Colorado and lies north of Highway 40 between the small cities of Steamboat Springs and Craig. It is approximately 60 700 ha in size and spans elevations from 1 800 to almost 3 000 m. Private land dominates the lower elevations, where sagebrush grassland is the primary vegetation type (75% of watershed), while the Routt National Forest encompasses the higher elevations and is composed of sagebrush grassland, aspen/tall forb, and conifer communities (25% of watershed). The Elkhead region is semiarid, with mean annual precipitation for Hayden at 43 cm and the majority of moisture coming during the winter as snow (High Plains Regional Climate Center 2008). The temperatures are moderate with yearly average high temperatures at 14.4°C and average lows at −2.7°C, although winters can be extreme (High Plains Regional Climate Center 2008).

The watershed encompasses 16 different ecological sites, with the primary sites being claypan, brushy loam, deep loam, mountain loam, and aspen woodland. Big sagebrush (*Artemesia tridentata* Nutt.) is common to all the primary ecological sites, with fringed sage (*Artemisia frigida* Willd.) common on claypan and mountain loam and alkali sagebrush (*Artemisia arbuscula* Nutt.) dominant on claypan. Western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Löve), needle-and-thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), and prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult.) are common grasses in the watershed. Common forbs include nodding onions (*Allium ascalonicum* L.), buckwheat (*Eriogonum alatum* Torr.), Indian paintbrush (*Castilleja* spp.), yarrow (*Achillea millefolium* L.), and arrow-leaf balsamroot (*Balsamorhiza sagittata* [Pursh] Nutt.).

This area has been grazed since the late 1800s by both cattle and sheep. Much of the lower-elevation land in the watershed has been cultivated for wheat and has recently been put into the Conservation Reserve Program (CRP). The primary land use in the Elkhead watershed remains agriculture, although it is a decreasing contributor to the local economy. Many ranchers in the watershed balance traditional livestock-based earnings with sizable income from elk-hunting operations. This area has also seen a significant shift in landownership, with more amenity buyers moving into the area (Rowe et al. 2001; Johnston 2006). This has resulted in increased subdivision of ranches at the base of the watershed and parceling into ranchettes at the top of the watershed. Common vegetation management techniques include chemical and mechanical sagebrush control, spraying for noxious weeds, and seeding of irrigated meadows. Some of the ranchers in the watershed keep their herds year-round on their private land within the watershed, while others move their livestock onto US Forest Service allotments during the summer and graze lower-elevation lands outside the watershed during the winter.

We chose to focus the interviews within the Elkhead watershed because it has a mix of large and small landowners, has an active ranching community, is a manageable size, and is relatively unfragmented. Regional interviewing also made it easier to compare and compile knowledge claims, gain a representative sample of local knowledge, and model knowledge of similar sagebrush steppe communities.

METHODS

We identified potential participants through a search of county ownership records and included as potential interviewees all landowners in the watershed with more than 100 acres of deeded ground who had or were actively managing ranching operations. In addition, we asked current ranchers and community members to refer us to knowledgeable people within their community. This provided us with a list of former ranchers and ranchers in close proximity to the watershed and gave us insight into community assessment of local knowledge.

Participants were recruited using three techniques: letters, phone calls, and a community meeting. Once potential informants were identified, we contacted them with a letter introducing the research project and requesting their participation. Follow-up phone calls were made to set up interviews and answer any questions. After these initial contacts, we held a community meeting to introduce residents to the project and encourage their participation. Twelve community members attended this preliminary meeting. The meeting consisted of brief introductions, a description of the project, and an overview of STMs. The modeling project was presented as part of a larger research agenda looking at both ranchers' local knowledge and the environmental history of the watershed.

Seventy-eight potential informants were identified in the community based on county records and community recommendations. We completed semistructured interviews with 26 of these individuals and 11 field interviews with a subset of the same informants. Semistructured interviews occurred first, with follow-up field interviews to explore more tacit knowledge while touring ranchlands. We were able to interview a cross section of ranchers by ranch size, education level, and duration in the watershed and believe that the interviews are representative of the watershed as a whole. No one refused to be interviewed, and therefore the sample was drawn from the population of potential interviewees based on ranchers' availability to interview during researcher field visits. Although we had no preconceived number of interviews to conduct, we stopped interviewing when we felt that little or no new information was being collected with additional interviews (Neuman 2003).

We interviewed 10 women and 16 men, most of whom were in their mid-50s to early 60s. Sixteen were currently engaged in active management, while 10 had either retired or left the ranch. Most of the ranchers had grown up on a ranch (20), and many had been in ranching for more than two generations (14). Nine of the ranchers had gained their knowledge through experience only, while six had some formal education, and 11 had completed related undergraduate degrees. Three of those interviewed were primarily sheep ranchers, while the other 19 were primarily cattle ranchers, and four raised wheat and cattle. Of the ranchers interviewed, there were five small (640–1 000 acres), five medium (1 001–5 000 acres), and two large (5 001–10 000 acres) landowners and four who owned or leased over 10 000 acres. Thirty-one percent of the ranchers interviewed used public lands for grazing, while 15% of the ranchers interviewed owned or leased land both within and outside the boundaries of the watershed, and 11% owned ranches outside the watershed. In order to provide a wider context and insight, we also completed four interviews with agency staff members and one with a wheat farmer.

Interviews were conducted in five trips made over a 6-mo period. Semistructured interviews followed a predetermined interview schedule, ranged from 1 h to 3 h, and took place indoors. These interviews included questions on ranch characteristics, current management practices, and change over time. A subset of the original group were interviewed a second time in a field setting, and these interviews lasted from 2 h to 5 h. Questions for the field interviews were based on responses from the semistructured interviews and attempted to clarify and expand on previous answers while also leading to novel revelations sparked by the landscape itself.

All interviews were audio-recorded, transcribed, and coded using the qualitative data analysis software NVIVO. NVIVO is a database and analysis program that is capable of storing transcriptions of interviews and then manipulating them to understand themes of interest across interviews. Most ranchers were not familiar with the STM terminology, so the interview schedule included several questions regarding types of land, vegetation change, and potential agents of that change. First, we looked through the interviews for instances in which vegetation states, factors leading to transitions, thresholds, and indicators were mentioned. Interviews were coded for these different categories, and then coded passages were reviewed to assess whether each quotation was referring to the same category (state, transition, threshold, indicator). Interview questions were often intentionally open ended in order to capture and not direct rancher knowledge. Although this was a purposeful choice that led to a more open dialogue and assessment of rancher knowledge of vegetation change, it also made it challenging to categorize rancher quotations into a single group of states and transitions. After careful assessment of coded quotations, we compiled a working set of model components and relationships based on rancher knowledge (Fig. 1).

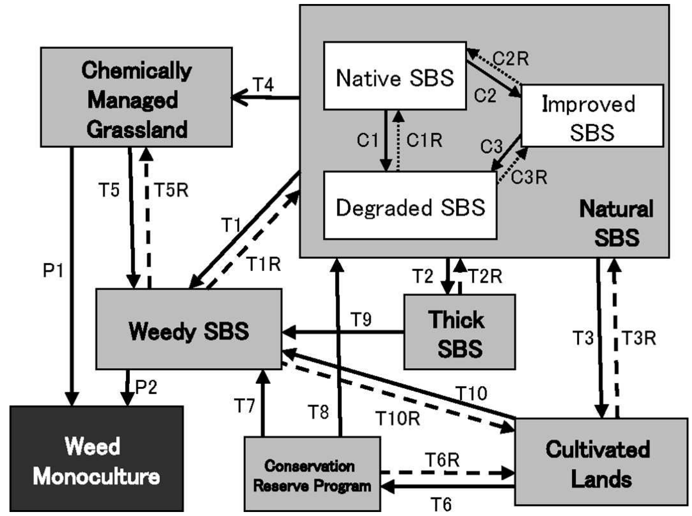

Figure 1. Generalized model of sagebrush steppe (SBS) for the Elkhead Watershed and surrounding region in northwestern Colorado, USA, showing states and transition. See Appendix for transition descriptions.

A second community meeting was held to present the draft model to participants and collect feedback. Thirteen community members, including seven study participants, attended this meeting. Researchers presented methodology, findings, and the draft model at the beginning of the meeting. Participants were given copies of the model and encouraged to make suggestions and comments on their drafts, which were collected at the end of the meeting. The presentation was followed by time for discussion and suggestions from participants. They expressed broad acceptance of the model components and relationships as accurate and representative of their knowledge of the system. Although generally in agreement with the model as drafted, participants felt the model did not demonstrate interactions with other vegetation types, especially the interaction between upland sagebrush steppe vegetation and adjacent riparian areas. This critique addresses limitations with this model but also with the way that STMs are currently conceptualized and developed.

RESULTS

The model (Fig. 1) uses the STM framework to diagram how ranchers perceive vegetation change in the sagebrush steppe community within the Elkhead watershed. Representative quotations are included in the narrative as space permits. A complete compilation of supporting quotations can be found in the thesis that serves as the basis for this article (Knapp 2008). In this section, we will provide information regarding the scale of the analysis and each model component (states, transitions, and thresholds) identified within interviews.

Spatial Resolution and Scale of Model

STMs have traditionally used the ecological site as a unit of reference. An ecological site is defined as "a kind of land with a specific potential natural community, specific site characteristics, and responses to management" (Committee on Rangeland Classification 1994). As might be expected given their unfamiliarity with the concept, ranchers did not conceptualize or manage their land on the basis of ecological sites. When asked to describe the types of land they manage, ranchers classified their land into areas that had different uses for management (spring lambing areas, summer range, winter range), many of which corresponded roughly to vegetation types (oak brush, aspen/tall forb, sagebrush) but not specifically to ecological sites. They also saw the interaction and interconnection of these areas of use in a management and ecological context. When asked about their best-quality land, many ranchers said things like, "That is a hard question to answer because they are all good for something. Different times of the year mean that different elevations are better."

We developed a generalized model for the sagebrush steppe ecosystem as it occurs in the study watershed and surrounding areas because it more accurately reflected rancher knowledge. However, this model does not fully address the way ranchers perceive and make decisions regarding the landscapes they manage. As stated in the Methods section, several ranchers expressed concern about the inability of this model to show connections to other vegetation communities, especially aspen-forb, mountain shrub, and the riparian areas embedded within the upland vegetation types.

Recognized States

In interviews, ranchers defined seven primary states within the sagebrush steppe ecosystem by describing their common characteristics, use for management, relative functioning of ecological processes, and management and environmental factors that led to their existence. Their delineation of states was based primarily on utility for management and management actions rather than on ecological processes. States were relatively easy to identify from the interviews, as they were defined in relationship to other states and processes of change. The natural sagebrush steppe (SBS) was the only state for which more than one community was defined. Following is a list of the rancher-identified states and their associated communities, including, in parentheses, the number of ranchers that referenced each state.

"Natural" Sagebrush Steppe (12 Ranchers). This state includes three communities: *native sagebrush steppe*, *degraded sagebrush steppe*, and *improved sagebrush steppe*. These three plant communities were included within a single state because ranchers believed that these communities were able to regain natural vegetation composition and ecological processes within the time frame of management. The *native sagebrush steppe* (seven ranchers) was described through comparisons with more degraded sites and had high biodiversity, mixed age structure of sagebrush, ability to meet production and habitat goals, and absence of nonnative species. *Degraded sagebrush steppe* (11 ranchers) was differentiated as having nonnative forage species and scattered weed populations. It was also described as having less cover and more erosion than the previous community. Ranchers felt that this community was indicative of a change toward weedy SBS and suggested active management to prevent this transition. In the current STM vocabulary, this community could be considered an "at-risk" phase within the natural SBS state. However, ranchers also felt that the transition from degraded to native could occur fairly rapidly. As one rancher stated, "It wouldn't take long. If we didn't have any livestock for a few years, I think it would look like it had never been touched because I don't think that anything is really stressed out." The *improved sagebrush steppe* community (seven ranchers) was defined by active management of sagebrush, either by mechanical, spot chemical, or fire treatments. Ranchers identified the *improved SBS* as having less cover and lower density of sagebrush than in the *native SBS* community. Once regrowth began, ranchers stated that the age structure was more diverse. Ranchers also mentioned increased grass production and snowberry (*Symphoricarpus albus* S. F. Blake) establishment in the *improved SBS*. Most ranchers felt that this community was the most productive and desired community within the natural SBS state.

Weedy Sagebrush Steppe (Nine Ranchers). Ranchers defined this state as less productive with lower forage value than the previous state. Weeds, such as leafy spurge (*Euphorbia esula* L.), and invasive grasses, including cheatgrass (*Bromus tectorum* L.), were cited as an increased problem that required constant management attention. Ranchers also described the weedy SBS state as having less diversity and loss of specific native species.

Thick Sagebrush Monoculture (Five Ranchers). Ranchers described this state as a thick monoculture of even-aged sagebrush with less diversity, limited grass and forb cover, and low productivity.

Chemically Managed Grassland (Seven Ranchers). Ranchers defined this state by management practices, namely, broad aerial spraying of sagebrush. Unlike the *improved SBS* community in the natural SBS state, this state has experienced a large transformation in species composition in comparison with the smaller spot spraying in *improved SBS* communities. It was described as having higher grass production, nonnative seeded species, fewer forbs, and lower overall diversity.

Cultivated Lands (Eight Ranchers). Within this state, ranchers describe a range of lands with low (dryland hay) to high (wheat production) degrees of manipulation. These lands are managed not for natural vegetation but for the production of certain crops. The community meeting suggested that this category may be an oversimplification and that it may be necessary to split this into separate states.

Conservation Reserve Program (Five Ranchers). This state is a type of land defined by the NRCS that consists of lands that

Table 1. Factors contributing to transitions in the generalized sagebrush steppe state-and-transition model for the Elkhead Watershed in northwestern Colorado, USA. See Appendix for transition descriptions.

	Community transitions						State transitions																Potential transitions	
Factor	C1	C1R	C2	C2R	C3	C3R	T1	T1R	T2	T2R	T3	T3R	T4	T5	T5R	T6	T6R	T7	T8	T9	T10	T10R	P1	P2
Aerial spraying for brush treatment													X		X									
Fire, mechanical or mosaic brush treatment			X			X				X										X				
Competition from natives		X		X		X		X											X					
Competition from weeds	X				X		X							X				X		X	X			
Cultivation											X						X					X		
Lack of cultivation																X					X			
Drought	X				X		X							X										
Good precipitation		X						X		X														
Lack of fire									X															
Low to moderate grazing		X						X		X														
Grazing as a management tool		X						X		X														
Heavy grazing	X				X		X		X					X									X	X
Wildlife grazing	X				X		X		X					X									X	X
Presence of native seeds		X		X				X				X						X	X		X			
Presence of sagebrush seeds				X								X		X				X	X		X			
Presence of weed seeds	X				X		X							X				X		X	X		X	
Spraying weeds		X		X		X		X							X	X	X					X		
Seeding			X			X				X			X		X	X								
Time	X			X				X	X	X		X		X				X	X		X		X	X

were previously cultivated but have been actively seeded, primarily to perennial grasses. Ranchers described species that were often nonnative, although some remarked that native grass, forb, and shrub species have recently been added to the seeding mix.

Weed Monoculture (Four Ranchers). This potential state was suggested by several of the ranchers in the watershed, although none felt that it currently existed. It was defined as the extreme negative end of the spectrum of land health. Ranchers fear the possibility of this state because of the decrease in productivity and the domination of nonnative invasive species, specifically cheatgrass and leafy spurge.

Transitions

Transitions were defined by a factor (or factors) that led to a change in plant communities and ecosystem function. Factors listed by ranchers were management actions (10 factors), environmental disturbances and stressors (six factors), plant competition (two factors), and time (one factor). Factors were often common to several transitions but in varying degrees and in different combinations (Table 1). Because of the overlap of factors for various transitions, it was difficult to quantify the agreement about the likelihood of different transitions; therefore, transitions are not weighted within the model. Although there was mixed agreement on which set of factors led to changes, there was an overall awareness of the complexity of interacting factors, such as management, climate, and increased wildlife populations. The causal factors most commonly cited by ranchers in the Elkhead watershed were drought (18 ranchers) and increased wildlife populations (26 ranchers).

Several of the factors have similar perceived results but were described in different manners by the ranchers. For instance, low to moderate grazing was always found with grazing as a management tool, while heavy grazing was always found with wildlife grazing. Ranchers used low to moderate grazing to describe low-intensity grazing, while grazing as a management tool referred to grazing that was used to meet management objectives, such as control of woody or weedy species. Although similar in demonstrated impacts, the intent behind the management action is different. Similarly, heavy grazing was distinguished from wildlife grazing because of the ability of ranchers to control these factors. It is arguable whether these factors would truly have the same impacts, but on a landscape scale, ranchers identified them as having the same effects.

Ranchers defined a total of 10 transitions between states, four primary transitions that signaled the change from natural sagebrush steppe to another state, and six that connected these other states. Ranchers also defined six transitions that could reverse vegetation dynamics, all of which required accelerating processes to accomplish. Factors overlapped in many of the transitions, but in several cases transitions had identical or nearly identical sets of factors. The factors for C3 and T1 are identical, suggesting that ranchers see the degraded SBS state as a step toward the weedy SBS state. The factors for T5 and C1 are similar, with each including a single additional factor. There are also notable similarities between T7 and T10 and between T8 and C2R. These similarities suggest that ranchers perceive a set of similar and interacting factors that affect the entire landscape. A more nuanced discussion of the relative weight of different factors in each transition would be necessary in order to assess the differences between described transitions.

Thresholds

When ranchers were questioned about vegetation change over time, the initial response of many was that the vegetation was fairly stable or resilient. Although ranchers perceived minor to moderate year-to-year fluctuations and directional changes in vegetation, they reported that over the longer term (one or several generations), plant communities in the watershed demonstrated a remarkable capacity to withstand or recover from stress and disturbance and retain their characteristic species and processes. As one rancher stated, "It stays the same if you let it (don't overgraze it)." Others expressed amazement at the vegetation's ability to regain productivity after a disturbance or stress. A longtime ranching and farming family member said of the land that she was surprised that it "keeps producing and producing and staying fertile enough to produce. That is amazing to me." This initial response was often followed by examples of when productivity had been lost.

Ranchers revealed knowledge of thresholds by describing changed vegetation composition, productivity, and ecological processes. In this article, we define thresholds as a boundary recognized by managers beyond which it is difficult to regain the former productive potential of the land. Four primary thresholds were identified by ranchers' descriptions of changes in ecological processes and vegetative communities that were not easily reversible within a management time frame (Fig. 2). From the natural sagebrush community, the vegetation could cross a threshold into 1) weedy SBS, 2) thick SBS monoculture, 3) chemically managed grassland, or 4) cultivated lands. Each of these thresholds signified a change in the ecosystem that is hard to reverse without significant inputs of time, energy, and resources.

The threshold most managers were most concerned about was from degraded to weedy SBS. Interviews suggested that it is difficult to gauge when this threshold is crossed. Once crossed, however, ranchers were aware of the difficulty of returning to the prior state. As one rancher stated, "There is a lot of halogeton, cheatgrass and whitetop. It has taken that country and the guys use it too hard and don't let up." Many spoke of the additional work and inputs needed just in order to keep the system from slipping into a weed monoculture. As one remarked, "The spurge spreads so fast. This whole area is spurge if you don't spray each year." For several ranchers, fully eliminating weed populations was seen as improbable if not impossible. As one rancher stated, "If the weeds get too much then they will start taking pieces out." Reversing this transition is viewed as both time consuming and management intensive. As one rancher remarked, "The only place you see improvements is where someone is spending the money and making a concerted effort." Another speaks about the time it takes to reverse this transition by stating, "It takes a long time … years and years but it isn't hopeless."

The second threshold of concern was a change from a natural SBS to a thick monoculture of sagebrush. As one rancher summarized, "The sagebrush is thicker and taller and there is less grass." The primary drivers of this change were thought to

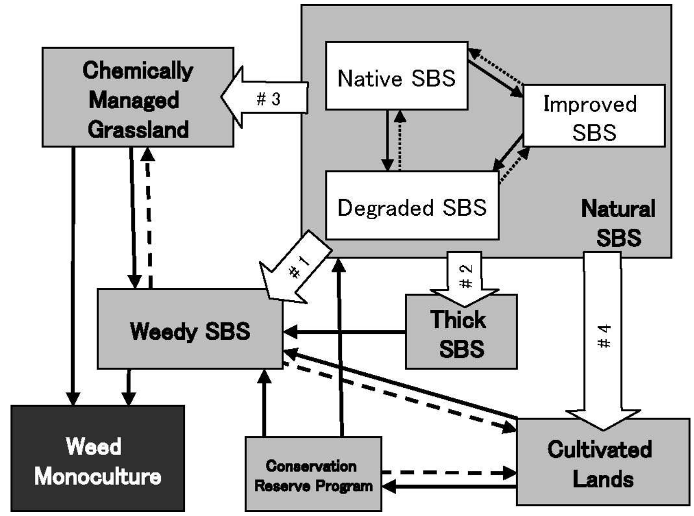

Figure 2. Generalized model of sagebrush steppe (SBS) showing the four major thresholds identified by ranchers.

be lack of fire (on a long-term scale) and management practices (on a short-term scale). One rancher stated, "[These ranges] saw 60 years worth of Smoky the Bear and the BLM fire suppression efforts … they are very unnatural in terms of the sagebrush biome because they are all an even-aged monoculture." Returning to a natural SBS state required management treatments to change sagebrush cover and often entailed a season or more of rest after treatment. As one rancher remarked, "The first year you should not graze it at all … the longer you could do it the better. [It is important to] let the grass get established." For many ranchers, this suggested rest period was challenging given limited land resources.

The third threshold was from natural SBS to chemically managed grassland. Instead of working hard to bring areas back to a preferred state, managers in this scenario had to work hard to keep this state productive and brush free. As one rancher explained, "We aerial sprayed about 500 acres from one big draw across and that was such an incredible, unbelievable thing. The grass is so gorgeous and the sage has not come back." Interviews suggested that weedy SBS was an intermediate state between chemically managed and natural SBS. Some ranchers caution against this management technique, stating, "I refused to aerial spray because the weeds will come back a whole lot sooner." Also, ranchers stated that multiple sprayings were able to reduce the native seed bank, thus limiting the potential of the system to return to a natural SBS. As one rancher remembered, "You lose diversity, and it takes a long time for it to come back. I could show you a place that we sprayed in the early 1950s and there is still not much diversity." One rancher hypothesized that sagebrush removal in this state altered ecosystem hydrological processes, suggesting that areas without sagebrush experienced later and more rapid snowmelt and therefore greater runoff and erosion potential and less infiltration compared to areas with intact sagebrush stands.

The final primary threshold was caused by plowing and seeding, which resulted in a cultivated landscape. The long-term plowing and planting resulted in weedy species, changed moisture-holding capacity, and a loss of native seed bank. Only long amounts of time, favorable weather conditions, seeding, and/or the presence of native seeds can bring this community back to a natural SBS community.

Indicators

Ranchers identified several indicators that they use to gauge the health of their land. They mentioned specific vegetation attributes that they look for across the landscape, such as canopy cover, presence of seed heads, and height of grasses. As one rancher stated, "You see heads of grass here and there and if you look at the sagebrush area and see bare ground then I think you are using it too heavy." Specific species also indicate the health of the rangeland. The loss of Yampa (*Perideridia gairdneri* [Hook. & Arn.] Mathias), wild onions (*A. ascalonicum* L.), and cow cabbage (*Veratrum* spp.) were identified as signs of overgrazing, while the return of mountain brome (*Bromus marginatus* Nees ex Steud.) signifies an improvement of rangeland condition. Sheep ranchers look at snowberry as a general indicator of rangeland health, while yearly growth of chicken-sage (*A. arbuscula* Nutt.) is a good indicator of moisture.

Ranchers also looked at overall diversity of species, presence of nonnative species, and presence of weedy species. One rancher commented on the importance of diversity by saying, "When I am deciding whether it is a healthy pasture or not I look to see that there is a lot of different stuff growing in it." Another rancher stated, "This dry land hay is the least healthy because it has one dominant species: smooth brome (*Bromus inermis* Leyss.)." Although diversity was highly regarded by many of the ranchers, there were places where diversity was traded for productive monocultures that could be relied on during the spring and fall when overall production was low. In addition, they showed understanding of indicators, such as erosion and lack of litter, which signaled unhealthy functioning of ecological processes. One rancher remarked, "[When] you don't have the vegetation on the ground and the litter to hold the water … then it just runs off and will not soak in. It just runs."

Ranchers also looked at broad-scale indicators such as overall production and available habitat for wildlife populations, including migrating birds, sage grouse, deer, and elk. As one rancher remarked about sage grouse abundance, "[They are] habitat dependent and the people who have taken care of the range, why they [sage grouse] are still there and where they haven't [taken care of the land] then they [sage grouse] aren't."

Integration of Ecological and Socioeconomic Information

Interviewed ranchers also demonstrated knowledge of the interconnections between socioeconomic and ecological systems and their ultimate impact on transitions between vegetation states. The past 20 yr have seen an increase in subdivision development at the lower end of the watershed and several ranchettes near the upper end of the watershed. Ranchers spoke about how these recent changes have affected land management practices and resulted in increased weed populations, contributing to the transition between natural and weedy SBS. One rancher recalled a discussion with a developer: "The guy said, point blank, I want to build houses and I don't care about the weeds and that mentality … the weeds will certainly reproduce and do very well, but there is that mentality among land developers that is scary beyond doubt." An agency manager in the region commented that a combination of development pressure from outside the watershed, a growing financial dependence on hunting revenues within the watershed, and new landowners' increased focus on wildlife have encouraged an increase in area elk populations within the watershed. Ranchers suggested that changes in wildlife populations and new owner management have contributed to the transition from natural to thick SBS. As one rancher described, "Weeds increased the most in the places where we have had the most elk traffic." In addition, ranchers mentioned how federal CRP funding and weakened local wheat markets have resulted in a transition from cultivated to CRP lands.

Self-Identified Limitations of Local Knowledge

Although ranchers offered original and valid insights into the workings of natural systems, they also recognized the limits of their own knowledge. Many expressed the difficulty of gauging vegetation change and said things like, "Vegetation changes, I guess you didn't notice them as much." Another stated, "I don't think we pay attention unless it is a great big thing, [but] it is a whole lot of little things that make a big change." Several also questioned whether ranching and ranchers have been around long enough to realize the potential outcomes of management. One stated, "We haven't lived here long enough to find out what this area can do." In addition, ranchers can be limited in their knowledge by what exists currently on the land. As one rancher remarked, "People around here just don't know what it could or should look like … how do they know if they are overgrazing because they think that if there is grass it is good."

Connection to Other Vegetation Types

The primary critique ranchers had of STMs was their inability to incorporate connections between adjacent land types, especially between upland and riparian communities. Ranchers must consider different vegetation types when planning for the season, intensity, and duration of grazing. As one rancher stated when asked about quality, "To me it is impossible to say [what is the best-quality land] because the higher land has one set of goals and the lower land has another." Grazing plans affect different vegetation types simultaneously because a decision to graze in one area often means rest for another part of the landscape. One rancher stated, "You don't want to stress that plant out completely but you also need to be thinking about what the mountain is doing and … you have to decide to stay a little longer on the winter range and rest the spring [range] a little bit and then the next year be on the mountain earlier." Ranchers with public lands often express frustration at not being fully able to manage for the needs of the different year-to-year variations in precipitation and wildlife populations on the different land areas and ownerships that make up their operations. As one rancher complained, "Regulators want to have neat little boxes where you can put a check on April 10–15 … those are the kind of things that create friction with agency guys when in fact we should be focused on the state of the resource." Ranchers see these relationships as critical to decision making, suggesting that the current scale of STMs limits the ability of STMs to be a useful tool for ranchers in their current form and perhaps suggesting the need for ranch-level decision-making tools that draw from STMs.

DISCUSSION

With the incorporation of STMs into the NRCS ecological site descriptions, it is likely that STMs will be a tool to help guide management on western rangelands for years to come. STMs offer an opportunity to represent current understanding and questions regarding vegetation change on rangelands (Forbis et al. 2006), investigate the processes driving those changes (Bestelmeyer et al. 2008), and suggest opportunities for proactive management (Westoby et al. 1989). They offer a tool that could help scientists, agency employees, and ranchers communicate their understanding of rangeland vegetation change with one another (Ash et al. 1994) and facilitate adaptive management (Forbis et al. 2006; Herrick 2006). In the following discussion, we briefly describe the potential benefits and challenges associated with integrating rancher knowledge into STMs.

Potential Benefits of Integrating Local Knowledge in STMs

Prior studies have suggested that rancher knowledge may be valuable to ground truth models (Bestelmeyer et al. 2004), inform adaptive management (Forbis et al. 2006; Herrick 2006), develop indicators (Briske et al. 2006), and fill in gaps in understanding of vegetation change over time (Ash et al. 1994). Interviews in the Elkhead watershed confirmed that ranchers are able to identify vegetation changes involving characteristic or novel species over time. Models developed with rancher knowledge may help ecologists cross-check scientific data with ranchers' experiential knowledge. Ranchers also provided detailed information about past management that contributes to understanding the factors leading to current vegetation composition. This information may help model developers refine ecological sampling approaches and fill in gaps where data on management history are missing. Ranchers conveyed the importance of management for the definition of states, suggesting that models may be more useful to managers if they reflect management-defined states.

Rancher knowledge of local disturbances and stressors provides information about past vegetation change on a scale that quantitative field sampling of plant community change may not. This may lead to the development of more nuanced models for use by ranchers and ecologists. Ranchers also demonstrated understanding of the interaction between management and natural ecological processes, which has been a concern in past model development (Rodriguez Iglesias and Kothmann 1997). There has been a growing interest in integrating ecological and economic information into STMs (Ash et al. 1994; Brown 1994; Gillson and Hoffman 2007), and interviews showed that ranchers may have practical insights to contribute because of their knowledge of these interactions. The literature expresses concern about the current scale of STMs (Bellamy and Brown 1994) and the importance of integrating cross-scale interactions (Ash et al. 1994; Bellamy and Brown 1994; Bestelmeyer et al. 2006). Ranchers have knowledge of the interaction between different scales that could be helpful for bridging these gaps in model development. By providing hands-on knowledge of interactions between management and natural processes, ecological and socioeconomic factors, and cross-scale interactions, models utilizing rancher knowledge may provide valuable information for both ranchers and ecologists.

Our findings suggest that spatial resolution and scale are two related issues that will be important to address as development of STMs moves forward. First, interviews suggested that the appropriate spatial resolution for ranchers is vegetation types (sagebrush steppe, aspen/forb, mountain shrub) rather than ecological sites. Second, the issue of scale relates to the fact that ranchers are continually balancing management among different vegetation types and wanted a model that expresses the ecological interactions and management trade-offs among different vegetation types within their management units. Because the ecological site is not the unit of analysis for most ranchers, it may be important to understand the limits of ecological site–based STMs as management tools for ranchers. More generalized models for similar ecological sites within a vegetation type may help address this challenge by providing managers with information at a relevant spatial resolution. Increased education and outreach to ranchers about ecological site–based STMs may help make ecological sites a more familiar concept. Representing the interactions among dynamics of contrasting but adjacent vegetation types within the management unit (e.g., riparian and upland sites) presents a greater challenge. This may require a spatially explicit approach or "meta-STM" that illustrates the relationships among adjacent ecological sites or vegetation types at the ranch or landscape scale. When considering the needs of managers, it may be necessary to see STMs as important building blocks for more integrated and landscape-scale decision-making tools.

Researchers have suggested that STMs may have utility not only as an end product to help decision making but also as a communication tool to help different groups of knowledge holders compare and contrast their perceptions of vegetation change over time (Ash et al. 1994; Bellamy and Lowes 1999; Bestelmeyer et al. 2004; Forbis et al. 2006). Integrating local knowledge into STMs has the potential to make assumptions, concerns, beliefs, and management intentions regarding a specific landscape more explicit (Lynam and Stafford-Smith 2004). This process may also reveal management-relevant questions that could be further explored through research or adaptive management, an approach where the principles of experimental design are applied to management to speed learning and increase the reliability of resulting information. In this project we were able to diagram how ranchers perceive vegetation change in the SBS. This may allow for better understanding, facilitate dialogue, and suggest research questions and hypotheses to be addressed in the future.

Challenges of Integrating Local Knowledge in STMs

Ranchers defined states primarily by management actions and objectives, even though they recognized associated plant communities and ecological processes. Prior research has shown that ranchers and pastoralists tend to have knowledge that is filtered through a management lens (Bollig and Schulte 1999; Knapp and Fernandez-Gimenez 2008). In addition, both scientists and ranchers are limited in their ability to perceive and understand all potential states if there are limited examples of a state on the landscape currently. Ranchers are among the first to admit that their knowledge is limited by their duration on the land and difficulty perceiving gradual changes. Despite these limitations, ranchers often have a longer observational period and larger spatial extent to their observations than researchers in a given landscape.

Although interviews may provide broad information about vegetation change, they may also be time consuming, challenging, and impractical. Interviewing requires a different skill set from ecological monitoring and may not fit into the time frame for model construction. It requires a time commitment from both ranchers and researchers that may be difficult to attain. The ranchers in this study were encouraged about the inclusion of their knowledge in models and expressed positive experiences about the research process; however, it is important that their time and knowledge are valued. This can be done by scheduling interviews around ranch work and making sure to include ranchers in the ongoing research process.

Interviews demonstrated that it may be difficult to elicit knowledge of vegetation change, especially when it relates to learning from past management mistakes. In order to verify the accuracy of STMs based on local knowledge, it would also be necessary to update and refine the models on the basis of data collection and experimentation. In the face of climate change, data-driven models and local knowledge alike may be insufficient for modeling changing dynamics. In this situation, ongoing experimentation and adaptive management accompanied by rigorous monitoring may be the best way to learn about rapidly changing systems.

Although this study was able to compile a rough model of vegetation change over time on the basis of local knowledge, there was relatively little consensus on model components. The most agreement was regarding the natural SBS state (12 ranchers) and degraded SBS state (11 ranchers), while the least consensus was around the potential weedy monoculture state (four ranchers). The lack of consensus could be due to the open-ended nature of interview questions that led to descriptions of vegetation that were difficult to compile into a single set of states. It could also be explained by the inherent variability of STMs regardless of the information source. Data-driven models also vary widely in how boundaries around states are determined. In part, this is because vegetation states are largely a human construct imposed on natural systems in which species respond individualistically to shifting environmental events, gradients, and management actions in space and time. It may also be due in part to the different "lenses" or worldviews, objectives, and model construction processes applied by different model authors. Future research by our team will examine in greater detail how these factors influence the designation of states, transitions, and thresholds in STMs and will include the perceptions of research scientists and agency managers as well as ranchers.

CONCLUSION

This study provides a concrete example of how rancher knowledge can be used to inform development of STMs. Local knowledge can strengthen STMs by integrating ranchers' detailed knowledge of management history, interconnections between vegetation states and regional socioeconomic trends, site-specific insights, and locally developed indicators of land health. Local knowledge is also able to provide critiques on the current scale and spatial resolution of STMs, and these critiques suggest how STMs may be integrated into tools that would be more helpful for managers. However, local knowledge must be understood and incorporated into model development with an awareness of its inherent limitations and heterogeneity. This example suggests that model development using multiple knowledge sources may facilitate communication among different knowledge holders, suggest research questions, and address issues of concern or conflict between different knowledge groups. This study identifies the opportunities and challenges of integrating rancher knowledge and highlights rancher concerns regarding current model development, including issues of spatial resolution and scale, interactions among vegetation types, and management-defined states.

IMPLICATIONS

This research suggests that if STMs are to be practical and useful for ranchers, models may need to be integrated into ranch-level decision-making tools that include management-defined states, reflect an appropriate spatial resolution for managers, and address rancher concerns about the interactions among adjacent vegetation communities, especially riparian areas. Rancher knowledge also can suggest indicators of approaching thresholds, lend insight into potential costs and benefits of different management techniques, and offer a more complete management history.

Our research team plans to conduct a second model review workshop in which ranchers and ecologists will jointly comment on the draft local knowledge STM presented here and help to integrate it with an STM based on ecological field data quantitatively analyzed. This next research step is important because it will provide an opportunity to compare and cross-check the models and discuss the differences and similarities between the local knowledge and ecological data-driven models.

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APPENDIX: TRANSITION DESCRIPTIONS

Community Transitions

C1 Competition by weeds, drought, heavy grazing, wildlife grazing, presence of weed seeds.

C1R Competition from natives, good precipitation, low to moderate grazing, grazing as a management tool, presence of native seeds, spraying of weeds, time.

C2 Brush control, seeding.

C2R Competition by natives, time, presence of native seeds and sagebrush, spraying weeds.

C3 Competition from weeds, drought, heavy grazing, wildlife grazing, presence of weed seeds.

C3R Competition by natives, brush control, spraying weeds, seeding.

State Transitions

T1 Competition by weeds, drought, heavy grazing, wildlife grazing, presence of weed seeds.

T1R Competition from natives, good precipitation, low to moderate grazing, grazing as a management tool, presence of native seeds, spraying of weeds, time.

T2 Lack of fire, heavy grazing, wildlife grazing, time.

T2R Brush control (fire, mechanical or mosaic spraying), good precipitation, low to moderate grazing, grazing as a management tool, seeding, time.

T3 Cultivation.

T3R Time, presence of native and sagebrush seeds.

T4 Aerial spraying for brush treatment, seeding.

T5 Competition by weeds, drought, heavy grazing, wildlife grazing, presence of sagebrush and weed seeds, time.

T5R Aerial spraying for brush treatment, seeding, spraying weeds.

T6 Lack of cultivation, seeding, spraying weeds.

T6R Cultivation, spraying of weeds.

T7 Competition by weeds, presence of native, sagebrush, and weed seeds, time.

T8 Competition from natives, presence of native and sagebrush seeds, time.

T9 Brush control (fire, mechanical, or mosaic spraying), competition by weed seeds, presence of weed seeds.

T10 Competition by weeds, lack of cultivation, presence of native, sagebrush, and weed seeds, time.

T10R Cultivation, spraying of weeds.

Potential Transitions

P1 Heavy grazing, wildlife grazing, presence of weed seeds, time.

P2 Heavy grazing, wildlife grazing, presence of weed seeds, time.